



## Counting without end: A cross-linguistic exploration of infinity beliefs in English and Hindi learners

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### ABSTRACT

Recent studies (Cheung et al., 2017; Chu et al., 2020; Sullivan et al., 2023) argue that children may infer the existence of infinite magnitudes through experience with number words, which provide a system of rules for generating ever-larger numbers. We tested this hypothesis by investigating the development of children's infinity beliefs in two languages – English and Hindi – whose counting systems differ with respect to the transparency of their rules. In a study with 240 four- to eight-year-old children, we found that children who learn to count in English ( $n = 120$ ) demonstrated both greater counting proficiency and better understanding of the successor relations between numbers relative to children who learn to count in Hindi ( $n = 120$ ). We also found that children's infinity beliefs were associated with their mastery of the verbal count list, but the proportion of children who endorsed the belief that numbers are infinite did not differ across languages. We conclude that transparency of the linguistic structure of a counting system may be important for understanding the rules governing counting, but in contrast to previous studies, suggest that the direct relationship between these rules and beliefs about the boundless nature of number words may be weak. The implications of these findings and avenues for future research are discussed.

Human experience of the world is finite, and yet by age 6 many children believe that numbers, space, and time are infinite (Sullivan et al., 2023; see also: Cheung et al., 2017; Chu et al., 2020; Evans, 1983; Hartnett & Gelman, 1998). To explain this phenomenon, recent studies have argued that children might infer the existence of infinite numbers through experience with number words, which provide a system of rules for generating ever-larger numbers (Cheung et al., 2017; Chu et al., 2020; Sullivan et al., 2023). For example, in a language like English, a finite set of unit labels ('one' through 'nine') and decade labels ('twenty' through 'ninety') can be combined to generate numbers between 'twenty-one' and 'ninety-nine', and even larger numbers when combined with labels like 'hundred', 'thousand', 'million', 'billion' etc. Although the labels they experience are in fact finite, children might nevertheless make an inductive inference based on their limited experience, and conclude that ever-larger number words (and thus numbers themselves), are always possible. However, while previous studies report that learning the rules of counting coincides developmentally with the emergence of elements of beliefs about infinity (Cheung et al., 2017; Chu et al., 2020; Evans, 1983; Hartnett & Gelman, 1998; Sullivan et al., 2023), these studies have been conducted exclusively in the US with children learning English. This is important, foremost because the transparency of this 1–9 additive rule described above differs across languages, and appears to be linked to how easily children learn counting rules (Miller et al., 1995; Miller & Stigler, 1987; Schneider et al., 2020; Song & Ginsburg, 1988; see Dowker

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et al., 2008). Also, cultural factors other than counting (e.g., parent interactions, religious beliefs, etc.) might inform US children’s inference that numbers are infinite. Here, we compared children learning to count in English in India to children learning to count in Hindi, a language with a more opaque counting structure, to test whether intuitions regarding infinity are delayed for children learning Hindi, as predicted by past accounts. Critically, by comparing performance across language groups but within a single cultural and social context, the present study allows for a clearer understanding of the role that counting structure plays in supporting beliefs about infinity.

In the US, children begin to recite the count list (e.g., ‘one, two, three...’) around 2½ years of age, but initially represent counting as a rote procedure: a meaningless list of words organized in a finite and unbreakable chain (Fuson, 1988). Children this age can often only recite numbers up to ‘five’ or ‘ten’, and lack meanings for these words, which they learn gradually over the next 2–3 years (Fuson et al., 1982; Fuson, 1988). Around the age of 2–2½ years, they learn the meaning of ‘one’, then acquire the meaning of ‘two’ several months later, then ‘three’, and sometimes ‘four’ a few months after that (Briars & Siegler, 1984; Frye et al., 1989; Fuson, 1988; Fuson et al., 1988; Sarnecka & Carey, 2008; Schaeffer et al., 1974; Secada et al., 1983; Siegler, 1991; Siegler & Robinson, 1982; Wynn, 1990; 1992). Such children are often called ‘subset-knowers’ because they know the meanings of only a subset of numbers in their count list. Eventually, around 3½–4 years of age, children appear to discover that counting can be used to label and construct larger sets, at which point they are called ‘cardinality principle knowers’ or just ‘CP-knowers’ (Fuson, 1988; Schaeffer et al., 1974; Wynn, 1990; 1992).

Given that most early counters’ knowledge of number words is limited to only a small set of highly memorized words – no different from letters of the alphabet (see Rips et al., 2008 for discussion), it is important to understand what might lead them to entertain the hypothesis that numbers are infinite. In particular, understanding the origin of infinity beliefs is important because it provides a window into when children’s knowledge of number words and counting transitions from being a finite and purely rote system to being a system that is governed by rules, and supports inductive inference. In keeping with this idea, Cheung et al. (2017) suggested that children’s hypothesis that numbers are infinite might originate from the structure of number words themselves (see also Barner, 2017; Hurford, 1987; Yang, 2016). Previous studies report that when asked to count as high as they can, although some children stop at random points in the count list – compatible with rote memorization – many stop at decade transitions like 29 and 39 (Chu et al., 2020; Fuson et al., 1982; Gould, 2017; Siegler & Robinson, 1982; Wright, 1994), suggesting that they have used an additive rule, combining words for 1–9 with decade labels like ‘twenty’ and ‘thirty’ to create larger numbers. According to Cheung et al., children might begin by memorizing items in their count list, but transition to using a system of rules for generating ever larger numbers when the number of items to which they are exposed is sufficiently large. Then, they might use these rules as the basis for an inference that ever-larger numbers can be generated, and that numbers must therefore never end. Thus, understanding how children acquire infinity beliefs might provide a window into how they acquire a generative system of number words.

As a preliminary test of the idea that children transition to using a system of rules for generating numbers, Schneider et al. (2020) examined children’s knowledge of counting rules across five languages: three with count lists in which the rules relatively transparent (Cantonese, Slovenian, and English) and two with relatively opaque count lists (Hindi and Gujarati). In a transparent system like Cantonese, the number 11 is expressed as 10–1, while twenty is expressed as 2–10, whereas in English, forms up to 20 are irregular and cannot be predicted from rules. In more opaque languages like Hindi and Gujarati, by contrast, novel number words and irregularities are frequent all the way up to 100 (Table 1; Berger, 1992; Bright, 1969), making it very challenging to extract the rules that govern these systems (Bright, 1969; Comrie, 2011). To test children’s understanding of the additive decade + unit rule, Schneider et al. used what they called the Next Number task, in which children were provided a number N and asked to say what number came next. They reasoned that children who have learned the rules of counting should be able to produce the next number, and found that performance on this task was lower in more opaque languages (Hindi, Gujarati), relative to more transparent languages (English, Cantonese, Slovenian).

Although the data from Schneider et al. provide evidence that knowledge of counting structure might be related to the transparency of rules within a counting system, they did not test how learning such structures impacted intuitions about infinity. Meanwhile, multiple previous studies have investigated when children’s beliefs about infinity first emerge, but relatively few provide strong tests of whether these beliefs might be related to mastery of counting, or the additive and multiplicative rules that govern the generation of number words (Evans, 1983; Falk, 2010; Hartnett & Gelman, 1998). For example, in one early study, Hartnett and Gelman (1998) probed the infinity beliefs of children in kindergarten, first grade, and second grade, by asking them a series of qualitative questions. One line of questioning probed knowledge of what they called the ‘successor principle’ by asking, ‘Can people always add to make a bigger number, or is there a number so big, we couldn’t make it any bigger?’. Following this, children were asked about whether numbers ever end: ‘If we count and count and count, will we ever get to the end of the numbers?’ They found that children were more likely to believe that it’s always possible to add to a number than to endorse the belief that numbers never end, suggesting that many children understand that counting is unbounded, but don’t understand the implication of this knowledge – i.e., that numbers must therefore be infinite. Also, although Hartnett and Gelman assessed how high children could count, and how readily they could do

**Table 1**  
Examples of number words in English and Hindi. Languages are arranged from most to least transparent. Bolded items are irregular/novel items in the count list.

Numeral	1	2	5	10	20	25	50	52	102
English	one	two	five	ten	twenty	twenty five	<b>fifty</b>	fifty two	one hundred two
Hindi	ek	do	pañch	das	bis	pachchis	<b>pachās</b>	bāvan	ek sau do

addition for large numbers (e.g., 'What would you get if you added 1–101?'), they did not directly analyze how these skills were related to knowledge of either the successor principle or the belief the numbers are endless.

In one more recent study, [Chu et al. \(2020\)](#) examined the link between English-speaking children's knowledge of the rules of counting and their infinity beliefs. To do so, like [Hartnett and Gelman \(1998\)](#) they conducted an infinity interview that tested children's beliefs that, (1) you can always add one to a number, and (2) numbers never end. They found that children's intuitions about infinity were linked to their knowledge of counting rules. However, while they showed that knowledge of the base-10 counting structure was correlated with children's infinity beliefs, their study only tested children in English, leaving open whether the transparency of a child's count list might impact not just their knowledge of counting rules, but also their infinity beliefs. Similar to Chu et al., a few studies have attempted to assess the relation between infinity beliefs and children's knowledge of counting (e.g., [Cheung et al., 2017](#); [Sullivan et al., 2023](#)), but these studies have also focused narrowly on children who count in English.

In the present study, we explored the hypothesis that children's beliefs about infinite number are linked to knowledge of counting structure by taking a novel, cross-linguistic, approach. Specifically, we investigated the origins of children's beliefs about infinity by comparing children learning a relatively transparent counting system (i.e., English) to children learning a relatively opaque counting system (i.e., Hindi) in the same cultural context of India. We examined these two groups because, as already noted, whereas the rules for generating number words are relatively transparent in the English number system (especially in the case of the additive rule, e.g., 'twenty-nine' is 'twenty' + 'nine'), the Hindi number system is much more opaque, and might therefore make it more difficult for children to extract rules (see [Table 1](#)). Given this, we reasoned that if learning the rules of counting is related to the emergence of infinity beliefs, then two results should be expected. First, familiarity with counting, and knowledge of rules that govern it should be related to beliefs about infinity within each language (i.e., within-subjects), similar to previous studies of rule knowledge ([Chu et al., 2020](#); [Schneider et al., 2020](#)). Second, assuming that counting abilities differ between groups – i.e., English-speaking children show higher counting proficiency than Hindi-speaking counterparts – then English-speaking children may also acquire beliefs about infinity earlier than Hindi-speaking children. This is because inferring the rules governing counting may be harder in Hindi relative to English. Critically, what should drive infinity beliefs across languages is children's knowledge of counting because some experience with number words may be critical to making generalized inferences about the structure of counting, regardless of the language being learned. Consequently, learning to count in Hindi or English is important to this study to the extent to which it leads to different counting abilities, and not due to global differences between the two languages.

As in previous research, we tested these questions by predicting infinity beliefs from two primary measures of counting knowledge: (1) Highest Count (i.e., the count a child reached before stopping or making an error); and (2) the Next Number task, in which children are prompted with one number and asked to generate the number that immediately follows it. The Highest Count task is a frequently used measure of children's counting skill (e.g., [Almoammer et al., 2013](#); [Barth, et al., 2009](#); [Chu et al., 2020](#); [Cheung et al., 2017](#); [Davidson et al., 2012](#); [Marušić et al., 2016](#); [Fuson et al., 1982](#); [Siegler & Robinson, 1982](#); [Wagner et al., 2019](#)). It provides a measure of children's exposure to number words. Moreover, the errors children make on the Highest Count task can be informative ([Chu et al., 2020](#); [Gould, 2017](#)). As we note above, English-speaking children often make errors at decade transitions (e.g., 29, 39, etc.), but can count past their errors if they are prompted with the decade label (e.g., [Chu et al., 2020](#); [Schneider et al., 2020](#)) and can often generate next numbers for much larger numbers beyond their initial highest counts ([Sullivan et al., 2025](#)), suggesting that they understand the rules governing counting. By contrast, children who make errors at other points in the count list (e.g., 23) are often unable to continue counting, suggesting that their list is likely memorized, and not generated by rules ([Chu et al., 2020](#); [Schneider et al., 2020](#); [Siegler & Robinson, 1982](#)).

Following previous studies, we combined this with the Next Number task, because Highest Count is a coarse measure of rule knowledge ([Schneider et al., 2020](#)), and may overestimate knowledge (e.g., children may have memorized the count list up to 100 before acquiring any knowledge of the logical relations between numbers) or may even underestimate it (e.g. when children understand the rules, but struggle to count past idiosyncratic irregularities in their number system). The Next Number task requires that children name the next number in the count list from arbitrary points, both within and beyond their initial highest counts. Therefore, only children who understand the productive rules governing counting should perform well on this task. Taken together, the two tasks allow us to distinguish memorized lists from those generated by rules.

In the present study, we asked if these two measures of counting – Highest Count and Next Number – were related to children's infinity beliefs, measured using an abbreviated version of the infinity interview used in previous research ([Evans, 1983](#); [Cheung et al., 2017](#); [Chu et al., 2020](#); [Hartnett & Gelman, 1998](#); [Sullivan et al., 2023](#)).

## Method

All methods and analyses were chosen based on a preliminary experiment ([Supplementary Materials](#)), and were pre-registered on the <https://osf.io/89cha/overview> [Open Science Framework](#).<sup>1</sup> Deviations from the pre-registered plan are stated in-text or in footnotes.

<sup>1</sup> Our preliminary experiment assessed infinity beliefs in 120 children (60 English speakers, 60 Hindi speakers) between 4;0 and 6;6 years of age using a similar design. We found a similar proportion of children who endorsed infinity beliefs in our sample, but did not have sufficient power to detect strong relationships between these beliefs and other measures of counting. See the Supplementary Materials for a detailed description of the methods and results.

## Participants

Participants were 240 children between 4;0 and 8;7 years of age recruited from schools in the Delhi National Capital Region (NCR) of India.<sup>2</sup> The sample included 120 English speakers ( $M = 70.20$ ;  $SD = 13.01$ ; range = 48–103 months) and 120 Hindi speakers ( $M = 76.65$ ;  $SD = 13.34$ ; range = 51–102 months). As pre-registered, the sample size for this study was determined based on a combination of factors, including data gathered from a preliminary experiment (see footnote 1), as well as the limited time available to test at field sites in India. An a priori power analysis indicated that a sample size of  $N = 70$  would be required to detect an effect size of  $d = .2$  with 80% power between the two language groups, and a sample size of  $N = 60$  would be required to detect an effect size of  $d = .2$  with 80% power within each language group.

Following Schneider et al. (2020), a child's inclusion in the English or Hindi dataset was determined based on parental report of the child's primary language, and the primary medium of instruction at the school they attended. This method was chosen because children in this region are typically exposed to two or three languages including English, Hindi, and regional languages or dialects spoken by their parents and extended families (see Mohanty, 2010, for discussion). However, based on discussions with teachers and school administrators who are familiar with local educational practices, and from our research group's previous experiences testing children in India, children generally only learn to count in the language they are formally instructed in at school, and rarely ever count in other languages during the preschool and early elementary school years.<sup>3</sup>

While the language of instruction differed across language groups, all children tested in this study completed the same standardized mathematics curriculum. This curriculum is prescribed by the National Council of Educational Research and Training (NCERT), and all participants were recruited from schools affiliated to the Central Board of Secondary Education (CBSE) – an organization of the Government of India. Formal schooling in the region typically begins between ages 4 and 5, wherein children are enrolled in preschool or kindergarten classrooms. The oldest children enrolled in our study were in the second grade, which is also compatible with early studies of infinity beliefs (e.g., Hartnett & Gelman, 1998). Crucially, the concept of infinity is not part of this curriculum for any included age group.

## Materials and procedure

Children were presented five tasks: (1) Give-a-Number, (2) Highest Count, (3) Next Number, (4) an Infinity Interview, and (5) a Picture Memory Task. Tasks 1–3 were presented in a pseudo-randomized order, and the Infinity Interview was presented either before or after these tasks, counterbalanced across participants. The Picture Memory Task was administered last as a control measure meant to account for non-linguistic, domain-general differences between English- and Hindi-speaking children.

### Give-a-Number

An abbreviated version of the Give-a-Number task (Wynn, 1992) was administered as a test of children's CP knowledge. A bowl of multiple objects of the same kind (plastic fish) was placed in front of the child. The experimenter said, 'Here are some fish and here is a plate. Can you put  $N$  fish on the plate?' If the child failed to give  $N$  fish, the experimenter prompted them to count to verify that they provided  $N$  (i.e., 'Is that  $N$ ? Can you count and make sure?'). Children were asked to give 6, 9, 7 and 5 objects in this order. If a child was only successful at constructing sets on three of the four trials, they were given another opportunity on the unsuccessful trial. Only the child's final response on each trial was recorded. Children who succeeded on all four trials were classified as CP-knowers, otherwise they were classified as subset-knowers. Both subset- and CP-knowers were included in analyses.

### Highest count

The experimenter introduced this task to the child by saying, 'In this game, I want you to count as high as you can.' If the child did not begin, they were prompted with, 'Let's start together — [one/ek]...' with rising intonation. If a child stopped upon reaching a decade label (e.g., 'ten', 'twenty', etc.), they were given two prompts: (1) 'keep going', and (2) 'count as high as you can'. No other feedback was provided to the child. The experimenter ended the task when the child made their first error or upon reaching 120, whichever came first.

### Next number

This task (Schneider et al., 2020) was used to test children's knowledge of the decade + unit rule. The experimenter introduced the task by saying, 'This game is called What Comes Next. In this game, I am going to say a number and you tell me what comes next.' For every number, the experimenter prompted the child saying ' $N$ . What comes next?' (e.g., '92. What comes next?'). Children were asked to name the next number from arbitrary points in the count list. The queried numbers were 1, 5, 23, 40, 62, 70, 37, 29, 86, and 59, in that

<sup>2</sup> Here, we preregistered a sample of 120 children between 4;0 and 7;11 years of age in each language. The final sample also includes 1 English speaker and 7 Hindi speakers between 8;0 and 8;11 years.

<sup>3</sup> As one reviewer notes, 'Hindi-instruction' and 'English-instruction' (or an equivalent term) would perhaps be a more appropriate descriptor for the two language groups, as it captures the primary criteria and strategy for recruiting children into the groups. That said, in past testing experiences in the region, our research group has found that children taught to count in English are generally unable to respond when asked to count in Hindi, as are some adults, who also feel unsure of their Hindi counting knowledge. This is also true for children taught to count in Hindi, who rarely count to high numbers in English. We use English-speaking and Hindi-speaking for this reason, and to maintain consistency with past work.

order (Table 2).

If a child gave a response that was less than the initial prompt, the experimenter prompted the child by reminding them that the game was called 'What comes *next*?' and gave them an opportunity to change their response. Children were only reminded once during the task. If a child failed to answer, their response was recorded as NA.

#### *Infinity Interview*

An abbreviated version of Chu et al.'s (2020) infinity battery was used. Children were asked four questions:

- i. What's the biggest number you can think about?
- ii. You said the biggest number you know / can think about is X. Can we add 1 to that number or is X the biggest number possible?
- iii. Could I keep adding one?
- iv. Do numbers ever end, or do numbers go on forever?

Consistent with previous research (Cheung et al., 2017; Chu et al., 2020; Sullivan et al., 2023), these questions were used to probe two types of beliefs: (1) endless beliefs (that there is no biggest number), and (2) successor beliefs (that you can always add one to a count). Children who judged that numbers are endless in response to item (iv) were classified as 'Endless Believers'. Those who judged that every number has a successor – i.e., if they answered both (ii) and (iii) consistently (i.e., that we can 'add 1' and 'keep adding 1' to a number) – were classified as 'Successor Believers'. Finally, those who had both beliefs were classified as 'Full Infinity Believers', whereas those who endorsed neither belief were classified as 'Non-Believers'.

#### *Picture memory task*

Adapted from the WPPSI-IV (Wechsler, 2012), this task assessed children's non-verbal working memory, and was used as a proxy measure for non-numerical cognitive skill. The stimuli and procedure were the same as Schneider et al. (2020). Children were presented with pictures of 1–5 items (e.g., hat, book, leaf) following a prompt, 'Look at this picture / these pictures.' After a 3 s (single target) or 5 s (multiple target) delay, children saw a set of pictures that contained the target picture(s) and some distractor items (e.g., chair, bell, block). Children were then asked to point and identify all the target items they had previously seen amongst the distractors ('Which picture(s) did I just show you?'). To avoid verbal rehearsal strategies, children were told that they should remain silent during the game, and should answer questions by pointing to the pictures ('Point to the picture(s) I just showed you'). Children completed three practice trials with feedback at the beginning of the game. If a child selected the correct objects on these practice trials, they were given positive feedback 'Good job!'. If they only selected one object, they were told to identify all the objects they saw ('Show me all the pictures I just showed you.'). If a child was incorrect, they were given corrective feedback ('I showed you these pictures, so you should choose these pictures.'). Test trials began with 2-item trials. The number of target items and distractor items increased as the task progressed, with targets ranging from 2 to 7 items and distractors ranging from 4 to 12 items per trial. A response was only considered correct if the child identified all target items. No feedback was provided at test. There were 32 possible test trials for children to complete, though the task was terminated after a child responded incorrectly on three consecutive trials. Children received 1 point for each correct response, and correct responses were summed to obtain a raw working memory score for each participant.

## Results

All analyses were conducted in R (version 4.3.3, R Core Team, 2023). Regression models with mixed effects were constructed using lme4 (Bates et al., 2015). To test for the significance of specific independent variables, we conducted likelihood ratio tests comparing models with and without particular effects of interest. Best fitting models were chosen based on reduced AIC value and a significant chi-squared statistic, and are reported below. All additional models and analyses are provided in [Supplementary Materials](#). We examined our results in three steps. First, we determined whether children's Highest Count differed based on the language in which they learned to count. Second, we asked whether children's successor knowledge (measured by Next Number) differed by Highest Count ability or language. Third, we analyzed whether children's Highest Count and Next Number performance predicted their belief that numbers are infinite within each language, and also when language was accounted for between-subjects.

#### *Give-a-Number*

We began by classifying children as CP-knowers and subset-knowers based on whether they could use counting to generate sets in the Give-a-Number task. Only 5/120 English-speaking children and 7/120 Hindi-speaking children were classified as subset-knowers based on their performance on the abbreviated Give-a-Number task, and the remainder were all CP-knowers, suggesting that nearly all children in the sample could use the counting procedure to construct large sets. Due to the limited number of subset-knowers in our sample, we did not include a term for knower-level in subsequent analyses.

#### *Highest count*

We constructed a linear model predicting children's highest count from language, while controlling for age and working memory [Highest Count ~ Age + Language + Working Memory], and found that English-speaking children ( $M = 82.40$ ;  $SD = 41.47$ ;  $Mdn = 104$ ;  $range = 3\text{--}120$ ) had greater Highest Counts ( $B = -65.76$ ,  $p < .001$ ) relative to Hindi-speaking children ( $M = 25.48$ ;  $SD = 15.02$ ;

**Table 2**

Queried number words in English and Hindi. Languages are arranged from most to least transparent. Bolded items are irregular/novel items in the count list, and therefore must be memorized.

Numeral										
	1	5	23	40	62	70	37	29	86	59
English	<b>one</b>	<b>five</b>	twenty three	<b>forty</b>	sixty two	<b>seventy</b>	thirty seven	twenty nine	eighty six	fifty nine
Hindi	<b>ek</b>	<b>pānch</b>	<b>teīs</b>	<b>cālis</b>	<b>bāsāth</b>	<b>sattar</b>	<b>saiṁtis</b>	<b>unatis</b>	<b>chiyāsī</b>	<b>unsāth</b>

$Mdn = 23$ ;  $range = 6-120$ ), suggesting that the relative transparency of rules in English might make it easier for children to learn to count than in Hindi (Fig. 1).

### Next number

We first analyzed the relation between counting tasks within-language. In both language groups, we constructed maximal logistic mixed effects models predicting Next Number performance (1/0) from age and Highest Count within each language, while controlling for trial magnitude (i.e., queried number word) and trial status (i.e., whether the model was inside or outside the child's highest count). These maximal models better fit the data relative to simpler models in both English ( $\chi^2(1) = 42.76$ ,  $p < .001$ ) and Hindi ( $\chi^2(1) = 12.74$ ,  $p < .001$ ). We found that age [English: ( $B = 0.52$ ,  $p < .001$ ); Hindi ( $B = 2.46$ ;  $p < .001$ )] and Highest Count [English: ( $B = 1.75$ ,  $p < .001$ ); Hindi ( $B = 0.86$ ;  $p = .01$ )] were both significant predictors of Next Number performance (Table 3).

We also found that English-speaking children were more accurate than their Hindi-speaking counterparts on the Next Number task overall (Fig. 2). To analyze these differences, we conducted cross-linguistic analyses, in which data from both language groups were analyzed in a single logistic mixed effects model. Participants' age ( $B = 0.95$ ,  $p < .001$ ), language ( $B = -1.39$ ,  $p < .001$ ), and Highest Count ( $B = 1.15$ ,  $p < .001$ ) were all significant predictors of Next Number accuracy.<sup>4</sup> Because language was a significant predictor of Next Number accuracy, we added a term for working memory to the model, to examine whether domain-general differences, other than language, might explain differences in performance between the two groups, and found that working memory was not a significant predictor of Next Number knowledge ( $B = 0.03$ ,  $n.s.$ ), and did not improve model fit ( $\chi^2(1) = 1.39n.s.$ ).

### Infinity beliefs

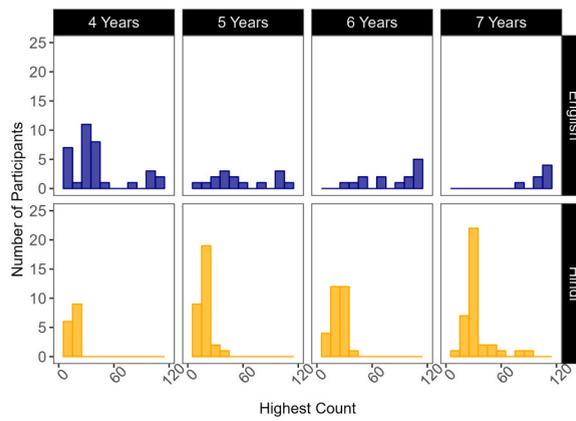
Based on their responses on the Infinity Interview, around half of all English-speaking children ( $n = 67$ ; 55.83%) and Hindi-speaking children ( $n = 61$ ; 50.83%) endorsed the belief that it's always possible to add 1 to any number. Nearly a third of English-speaking ( $n = 46$ ; 38.33%) and Hindi-speaking children ( $n = 41$ ; 34.16%) believed that numbers are endless. Finally, around a third of English-speaking children ( $n = 39$ ; 32.5%) and Hindi-speaking children ( $n = 38$ ; 31.66%) were classified as Full Infinity Believers (i.e., they provided responses consistent with both successor and endless beliefs). Using these data, we classified children into one of four categories as described in the Method: (1) Non-Believers, (2) Successor-Only Believers; (3) Endless-Only Believers; and (4) Full Infinity Believers (Table 4; Fig. 3). Preliminary analyses indicated that children's infinity beliefs did not differ based on when the Infinity Interview was administered (i.e., before or after the remaining test battery) within either language, nor between languages.

We next examined how infinity beliefs were related to Highest Count and Next Number knowledge within each language. Similar to the Next Number analyses, we first constructed three separate generalized linear model sets for individually predicting (1) Successor Beliefs (1/0), (2) Endless Beliefs (1/0), and (3) Full Infinity Beliefs (1/0) in English and Hindi from their Highest Count and Next Number performance (i.e., mean accuracy). We began with a maximal logistic mixed effects model [Infinity Believer  $\sim 1 + \text{Highest Count} + \text{Next Number} + \text{Age}$ ] and removed counting measures to determine the best fitting model in our within-language analyses. Among Hindi learners, only age predicted their successor beliefs ( $B = 0.49$ ,  $p = .004$ ), endless beliefs ( $B = 0.60$ ,  $p = .005$ ), and full infinity beliefs ( $B = 0.71$ ,  $p = .001$ ), and adding additional predictors for Highest Count and Next Number performance did not improve any models. By contrast, among English learners, only children's Highest Count emerged as a significant predictor of successor beliefs ( $B = 0.98$ ,  $p = .01$ ), endless beliefs ( $B = 0.75$ ,  $p = .01$ ), and full infinity beliefs ( $B = 0.86$ ,  $p = 0.009$ ), though in the case of successor beliefs, a maximal model that included a term for Next Number better fit the data relative to simpler models ( $\chi^2(1) = 4.53$ ,  $p = .03$ ), suggesting that children's Next Number knowledge might still inform their successor beliefs, even though it does not explain endless beliefs or overall full infinity beliefs (Supplementary Tables 2, 4, and 6).

Finally, as in our Next Number analysis, we analyzed differences in children's infinity beliefs across the two language groups. Our between-language analyses began with a maximal linear model [Infinity Believer (1/0)  $\sim 1 + \text{Age} * \text{Language} + \text{Language} * \text{Highest Count} + \text{Next Number}$ , family = 'binomial'], and we systematically removed counting measures to determine the best fitting model.<sup>5</sup> In three separate sets of models predicting each type of infinity belief, we first found that the language x Highest Count interaction was

<sup>4</sup> The maximal model we pre-registered included a language x highest count interaction term, which was not a significant predictor of performance ( $B = -0.15$ ,  $n.s.$ ), and including the interaction term did not improve model fit ( $\chi^2(1) = 0.08$ ,  $n.s.$ ) relative to the simpler model without this interaction term, reported here.

<sup>5</sup> We preregistered a three-way Age \* Language \* Highest Count interaction in our maximal model, but ultimately opted for a simpler model to avoid overfitting and allow for easier interpretation of the data.



**Fig. 1.** Distribution of English- and Hindi-speaking children’s highest counts. The y-axis represents the number of children in each age group, and the x-axis represents the highest count from 0 to 120 that a child reached before stopping or making an error. This and all subsequent figures were created using the ggplot2 R package (Wickham, 2016).

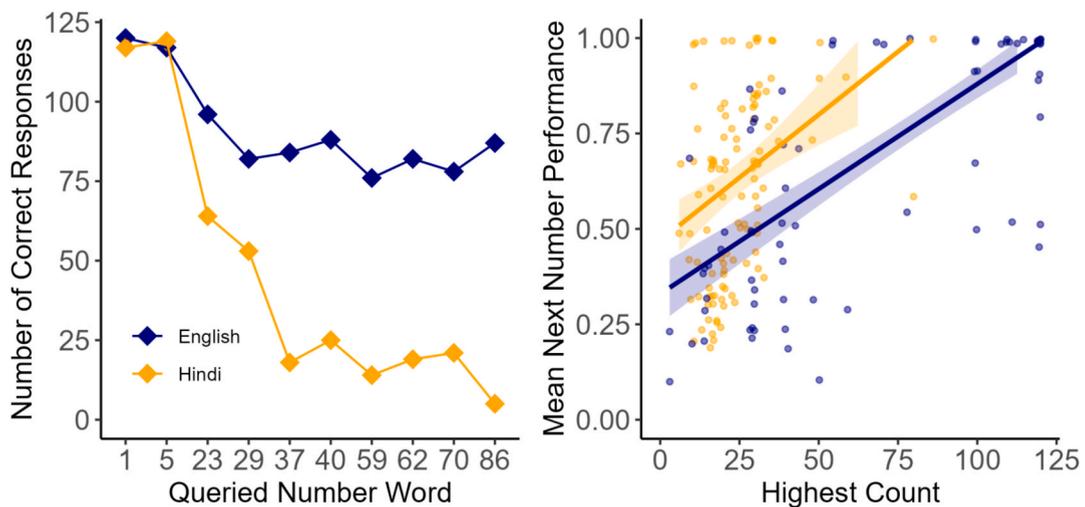
**Table 3**

Regression models predicting children’s accuracy on the Next Number task within each language.

Model	Coefficient Estimates (B)				Summary Statistics	
	Age	HC	TrialStatus	Magnitude	AIC	Log-lik
English						
Age + HC + Trial_Status + Magnitude	0.52***	1.75***	2.59***	−0.05***	768.4	−378.2
Hindi						
Age + HC + Trial_Status + Magnitude	2.46***	0.86**	1.07**	−0.03***	591.4	289.7

Abbreviations and Variable Names: HC = Highest Count; Magnitude = the number word queried on the Next Number trial; Trial Status = whether the queried number word in the Next Number task was within or outside the child’s highest count.

Reference Group – Trial Status: Outside. Significance codes: ‘\*\*\*’  $p < 0.001$ , ‘\*\*’  $p < 0.01$ , ‘\*’  $p < 0.05$ .



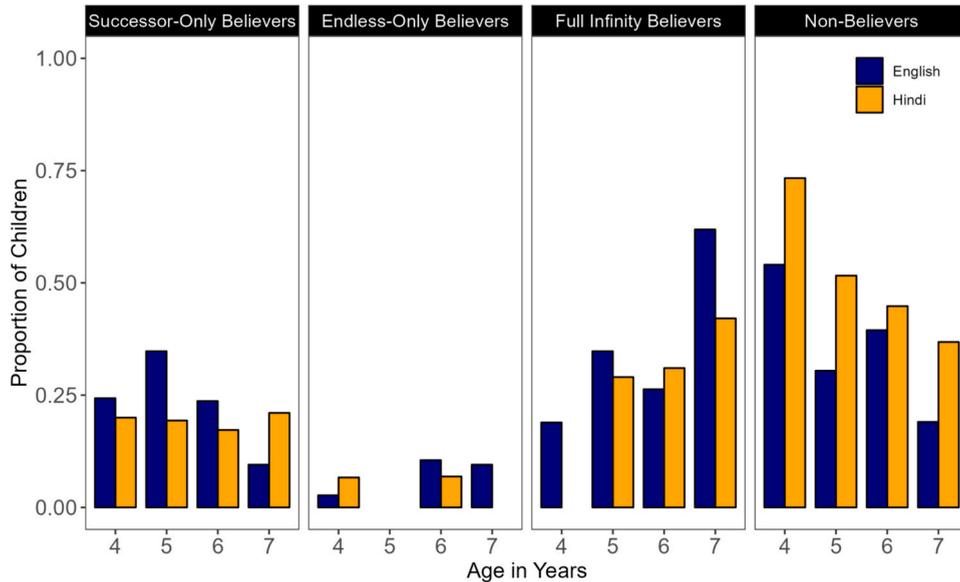
**Fig. 2.** Number of children (out of 120 per language group) who responded correctly to each number word queried on the on the Next Number task (left), and the relationship between children’s highest count and mean Next Number performance by language (right). Shaded areas represent 95% confidence intervals.

not a significant predictor of infinity beliefs [successor beliefs ( $B = -0.09, n.s.$ ); endless beliefs ( $B = -0.35, n.s.$ ); full infinity beliefs ( $B = -0.39, n.s.$ )]. In simpler models without the language x Highest Count interaction term, we found that Highest Count was a significant predictor of successor beliefs ( $B = 0.75, p = .01$ ), endless beliefs ( $B = 0.67, p = .01$ ), and full infinity beliefs ( $B = 0.77, p = .008$ ). However, in all three sets of analyses, neither age [successor beliefs ( $B = -0.14, n.s.$ ); endless beliefs ( $B = 0.32, n.s.$ ); full infinity beliefs ( $B = 0.13, n.s.$ )], nor language [successor beliefs ( $B = 0.50, n.s.$ ); endless beliefs ( $B = 0.60, n.s.$ ); full infinity beliefs ( $B = 0.88, n.s.$ )], nor

**Table 4**  
Frequency of overall infinity beliefs across languages.

Classification	English	Hindi
Non-Believers	46 (38.33%)	56 (46.66%)
Successor-Only Believers	28 (23.33%)	23 (19.16%)
Endless-Only Believers	7 (5.83%)	3 (2.50%)
Full Infinity Believers	39 (32.5%)	38 (31.66%)

Note: The proportion of children in each belief category by age is depicted in Fig. 3.



**Fig. 3.** Total proportion of children in each age group who endorse each infinity belief (i.e., when stacked, proportions in all four belief categories add up to 1). Colors denote English-speakers (blue) and Hindi-speakers (orange) The sample also included 1 English-speaking 8-year-old who was a full infinity believer, and 7 Hindi-speaking 8-year-olds (4 full infinity believers, 2 non-believers, and 1 successor only believer) who are not pictured in this figure. The overall number of children in each belief category are in Table 4. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the age x language interaction [successor beliefs ( $B = 0.59n.s.$ ); endless beliefs ( $B = 0.16, n.s.$ ); full infinity beliefs ( $B = 0.44, n.s.$ )] were significant predictors of infinity beliefs, suggesting that when accounting for children’s counting ability, no further differences in language or age were detectable across groups (Supplementary Tables 3, 5, and 7). Altogether, these data suggest that even though Highest Count was a significant predictor in English-only models but not Hindi-only models, the impact of Highest Count on Full Infinity beliefs did not actually differ across languages. As one reviewer notes, one possible explanation for why highest count was significant in the cross-linguistic and English-speaking only models, but not the Hindi-speaking models, is that the range of highest counts is restricted in the Hindi-speaking model. Whereas English-speaking children spanned the full range of possible counts (to 120), few Hindi-speaking children counted higher than 50. Overall, consistent with previous studies (Cheung et al., 2017; Chu et al., 2020), our data suggest that counting abilities predict the belief that it’s always possible to add 1 to a number, and that numbers never end.

**Discussion**

We investigated how children’s beliefs about numerical infinity are related to the mastery of counting. We found three main results. First, we found that English-speaking children could count much higher than children learning Hindi, replicating previously reported differences between these groups (Schneider et al., 2020). Second, also replicating past work, we found that English-speaking children were significantly more accurate than their Hindi-speaking counterparts on the Next Number task, which tests their knowledge of the successor relations between number words. Importantly, this difference persisted in models that accounted for working memory. Third, we found that in English, but not Hindi, Highest Count predicted the belief that every number has a successor, that numbers are endless, and also whether children held both of these beliefs simultaneously, and thus had ‘full’ infinity beliefs. However, in combined models Highest Count was again predictive of these outcomes, with no significant differences due to language. This suggests that although counting abilities are generally predictive of infinity beliefs, other sources of this knowledge may exist, and may influence the strength of correlations within language groups.

A focal point of our design was to assess the role of language structure on counting knowledge and mathematical intuitions within

the same culture. In most cross-cultural work on number, children learning different number systems also belong to different cultures, with different practices surrounding early numeracy. For example, although previous findings (Fuson and Kwon, 1992, Miller et al., 1995, Miller and Stigler, 1987, Miura et al., 1988, Miura and Okamoto, 1989; Song & Ginsburg, 1988) are consistent with the idea that cross-linguistic differences in children's counting knowledge are due to variations in count list transparency across languages, these results may also have emerged from differences in the levels of numerical training and mathematics exposure across cultural groups (Pan et al., 2006, Towse and Saxton, 1999/2022; see: Schneider et al., 2020 for discussion). Given this, we recruited all participants from a small geographic region in India, allowing us to conduct both within-language and within-culture, between-language analyses. This meant that our between-language comparison tested children from within the same culture, who were enrolled in the same education system, and therefore received comparable numerical training. We found that children's age and Highest Count were predictive of Next Number performance within each language, and that Highest Count also predicted Next Number performance between languages. This not only replicates previous work, but also provides strong evidence that linguistic rules, and not just cross-cultural or educational differences between language groups, explain differences in children's counting knowledge.

Moreover, our finding that Highest Count is related to children's intuitions about infinity (particularly in English) is compatible with results of previous studies that tested only English-speaking children (Chu et al., 2020; Cheung et al., 2017; Sullivan et al., 2023). For example, both Chu et al. (2020) and Cheung et al. (2017) found that children's Highest Count predicted their infinity beliefs when other factors were controlled, and concluded that experience counting to large numbers may contribute to children's inference that number words are boundless. Similar to Chu et al. (2020), we found that children's Next Number accuracy did not explain additional variance in their infinity beliefs, beyond their Highest Count (though Sullivan et al., 2023 reported that Next Number predicted the belief that it is always possible to add 1 a number). As noted above, a key finding of our study is that children's understanding of counting informs children's intuitions about infinity, even when domain-general factors like age and language are controlled.

At the same time, children learning English had much greater Highest Counts and Next Number knowledge relative to children learning Hindi, while children from the two groups had similar levels of infinity beliefs. The lack of differences in infinity beliefs between the two language groups was unexpected on the hypothesis that infinity beliefs should emerge later among children with weaker counting skills. At the outset, we reasoned that infinity beliefs may be lower among Hindi speakers, since they may not have as deep of an understanding of the structure of the count list as their English-speaking counterparts, owing to the opaque counting structure in Hindi. For reasons that aren't entirely clear, individual differences in Highest Count were globally predictive of infinity beliefs, but infinity beliefs in Hindi were not different from those in English despite lower highest counts. These findings suggest that cultural factors other than simple counting ability may play a role in children's developing infinity beliefs.

Consistent with this possibility, the proportion of children in our study who judged that numbers are finite and that not every number has a successor (i.e., infinity non-believers) was higher than in previous reports using similar methods within the US context, despite the fact that we tested older children.<sup>6</sup> Whereas studies of US children generally report that infinity beliefs emerge between 5 and 6 years of age (Cheung et al., 2017; Chu et al., 2020; Sullivan et al., 2023), in the present study many 6- to 8-year-old children lacked infinity beliefs in both languages. We know from teacher reports that the concept of infinite number is not explicitly taught to either language group between pre-kindergarten and second grade, which made up the sample of this study. This raises the possibility that infinity beliefs may be impacted by factors like socio-economic differences, parental math talk, other science training in the classroom, societal attitudes, or religious practices that emphasize the boundless nature of reality (e.g., Koponen et al., 2018; Lefevre et al., 2002; LeFevre et al., 2006; Manolitsis et al., 2013; Sarnecka et al., 2023; Silver & Libertus, 2022; Silver et al., 2023). Also, as noted by Sullivan et al. (2023), in some instances children's beliefs about infinite number may be informed by prior intuitions about infinite space, which may be easier to reason about in some contexts than number. In such scenarios, however, a correlation with counting abilities would not be expected.

Our data suggest that counting is an important, but perhaps not unique path to infinity beliefs. Our data also suggest that, across cultures and language groups, children's beliefs are likely acquired in a similar sequence. In particular, similar to previous studies, we found evidence that in both English and Hindi, children who believed that numbers are endless almost always judged that every number has a successor (Cheung et al., 2017; Evans, 1983; Sullivan et al., 2023). As with all previous work on the topic, we found that Endless-Only Believers were relatively rare (i.e., children who think numbers never end but that not all numbers have a successor). Also, like other studies, we found that Successor-Only Believers were more frequent (i.e., children who believed that every number has a successor, but not that numbers are therefore endless). This is important, because it suggests that children who claim that numbers are endless do not merely parrot statements they've heard from caregivers, but that their beliefs are integrated with their understanding of how numbers work – that in order to be endless, it must be the case that every number has a successor. Meanwhile, the high frequency of Successor-Only Believers, reported in studies since the 80s (Evans, 1983) suggests that certain beliefs, perhaps informed by experience with familiar numbers (that always do have successors), do not immediately supply children with knowledge of their logical entailments. While we currently have no account of how this reasoning unfolds in development, the current study suggests that the same pattern is found across languages and cultures, in addition to also being found across different dimensions of experience, like time and space (Sullivan et al., 2023).

In summary, we replicated past work that English-speaking children can count to higher numbers and showcase an understanding

<sup>6</sup> Non-believers in the Indian Sample [42.5% children aged 4;0 to 8;7 years (38.33% English-speaking children; 46.66% Hindi-speaking children)]; US samples reported similar rates of non-belief in 4–6-year-olds [Cheung et al., 2017 (37% among children aged 4;0–6;11 years); Chu et al., 2020 (48% among children aged 4;0–5;11 years); though see: Sullivan et al., 2023 who also included older children (9.2% among children aged 4;0–7;11-year-olds)].

of the successor relations between number words earlier in development than Hindi-speaking children, owing to the relative transparency of the morphological rules governing counting in English compared to Hindi. We also found that children's highest count is related to their intuition that you can keep adding one to a count, such that numbers are endless. However, children's infinity beliefs did not differ as a result of the language in which they learn to count, suggesting that other sources of knowledge beyond their experience with number words may shape children's intuition that number words are infinite.

### CRedit authorship contribution statement

**Urvi Maheshwari:** Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jessica Sullivan:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Conceptualization. **David Barner:** Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Funding acquisition, Conceptualization, Supervision.

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### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jecp.2026.106473>.

### Data availability

De-identified data are available on the <https://osf.io/89cha/overview> Open Science Framework.

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