Title
Zero in on This: Children are Exposed to Various Concepts of “Zero” Prior to Age Six

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Zero in on This:
Children are Exposed to Various Concepts of "Zero" Prior to Age Six

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Abstract

Math talk has implications for the development of numerical concepts. Research suggests that when caregivers talk about natural numbers (1, 2, 3…), it may enhance children's later math knowledge. Natural numbers have physical quantities that children can observe, yet abstract numerical concepts do not have such observable quantities. In this analysis, we examined how zero occurs in math talk. Using the CHILDES American English corpora (MacWhinney, 2000), we examined the frequency and nature of math talk about zero in naturalistic interactions between 2- to 6-year-olds and other speakers. Input from other speakers increased in frequency and complexity across development. Input with zero in symbolic sentential contexts (e.g., "one and zero make ten") and cardinal sentential contexts (e.g., "zero means nothing") increased with development. Children's production of zero did not change in frequency or context. These results have implications for the concepts about zero children may bring to formal education.

Keywords: math talk; corpus analysis; numerical cognition

Introduction

Children's early numerical development involves understanding fundamental concepts such as numerical magnitude (Gelman & Gallistel, 1986; Sarnecka & Carey, 2008). Importantly, understanding of these concepts is associated with math achievement in later elementary school and even into high school (Jordan et al., 2009).

Prior to formal education, how do young children acquire knowledge about number concepts? Children may acquire these skills through interactions with their parents—and in particular, through interactions that involve *math talk,* which is talk that refers to or invokes mathematical concepts, such as quantity (Levine et al., 2010) or shape (Pruden & Levine, 2017). For example, naturalistic observations of parent-child interactions revealed that the amount of parent talk about numbers between the ages of 14 and 30 months is associated with their child's numerical knowledge later at three years old (Levine et al., 2010).

How does context interact with knowledge about these concepts? Abstract number concepts (e.g., zero) have multiple meanings across various contexts (e.g., no more marbles in the marble jar vs. "it's below zero out" vs. zero as a placeholder; see Figure 1). Thus, zero may serve as a unique and valuable testbed for examining how math talk and context interact in the development of this concept.

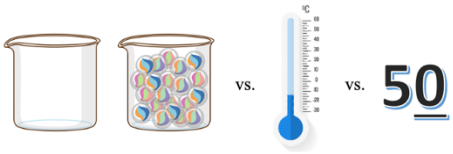

Figure 1: Different contexts in which zero is used.

Concepts of zero can be difficult for elementary school children to understand (Bialystok & Codd, 2000; Wellman & Miller, 1986; Wynn, 1998). Children's understanding of zero may involve misconceptions such as "zero is not a number" or vague ideas such as "zero is nothing" (Lappan & Wheeler, 1987). Wellman and Miller (1986) reported that children first learn to identify the symbol of zero without actually understanding what the symbol means. They also reported that it is not until kindergarten or first grade that children understand that zero is a number and correctly identify it as the smallest natural number (Wellman & Miller, 1986). However, to our knowledge, no research to date has examined concepts of zero prior to formal education.

From a language acquisition perspective, the word *zero* may be particularly difficult for children to learn. *Zero* refers to an abstract concept, and abstractions typically emerge later in children's vocabularies (Bergelson & Swingley, 2013; Vigliocco et al., 2018). Children learn the meanings of words by extracting statistical regularities in how often a word co-occurs with a referent (Smith & Yu, 2008) and how often it co-occurs in linguistic contexts (Vigliocco et al. 2014, 2018). This process may be complicated further in learning the word *zero* because parents could use multiple different terms to refer to the concept of zero. For example, a parent may refer to an empty plate and say, "Oh! You have nothing on your plate! Absolutely zero crackers left.", or they may say things like, "We need to put on your mittens, it's below zero outside." Thus, *zero* may have both an ambiguous referent and it may occur in many different linguistic contexts.

In naturalistic settings, children receive language input from a variety of sources (e.g., parents, siblings, and teachers)

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and children may use this input to learn the concept of zero. For example, maternal labeling of set sizes (i.e., "wow, four doggies!") predicts their child's understanding of numerical concepts such as cardinality (Gunderson & Levine, 2011) and first grade math achievement (Casey et al., 2018). Unlike other numerical words (i.e., *one, two,* etc.), however, *zero* does not have a perceptually obvious quantity in the environment that caregivers can readily label. That is, zero is defined by a lack or absence of quantity.

What kind of math talk do people provide for abstract quantities such as zero? Perhaps the earliest form of this input includes using non-numerical terms such as *nothing* or *none* to describe an absence or a null quantity. For example, when a child finishes their dinner, a parent may note that they have nothing left on their plate. Moreover, a child's first exposure to *zero* could be merely via overhearing someone recite a phone number or address. It's also possible that children hear *zero* in a numeric sense, such as the first number of a count sequence ("zero, one, two..."). Perhaps when people use *zero* in this numeric sense, children may begin to transform their concept of zero from a meaning of *nothing* to one of numerical value. It would be informative to disentangle these early concepts of zero for developmental and educational researchers alike.

The goal of the current study is to investigate the quantity and quality of math talk about zero experienced by two- to six-year-old children. To do so, we investigated how often math talk about zero originates from other speakers in a child's environment or from children themselves. We also conducted analyses of the sentential contexts in which *zero* occurs to examine the common meanings associated with math talk about zero. We hypothesize that (1) math talk using the word *zero* will increase with children's age, (2) math talk using the numerical word *zero* will originate more from other people than from children themselves, and (3) the contexts in which zero occurs will change over development.

We tested these hypotheses using transcripts from a repository of existing developmental corpora, the Child Language Data Exchange System (CHILDES; MacWhinney, 2000). We used the English-language transcripts of parents speaking with children between ages two and five. These data allow us to examine math talk input from caregivers as well as production of *zero* from children themselves. An advantage to using this database is that we can acquire a large sample of naturalistic parent-child conversations that span a variety of early environments.

Method

Participants

Data were drawn from the CHILDES database (MacWhinney, 2000). We conducted a search using the *childesr* package (Version 0.2.1; Braginsky et al., 2020) in R (Version 1.2.1335) to query North American English corpora for transcripts including the word *zero* from children between 24 and 72 months (M_{age} = 47.39, SD_{age} = 12.35). Our search yielded 185 utterances from 39 unique children (15 girls) across 92 different transcripts. The full sample included utterances from a variety of speakers including teachers, grandparents, siblings, and caregivers. We were primarily interested in how naturalistic language in the home may contribute to the development of numerical concepts. Thus, we also queried CHILDES for the sentential contexts surrounding mentions of *zero* to examine what kinds of information about zero is present in a child's early input and in their productions of *zero*. Specifically, we extracted the utterance immediately preceding and following each utterance that included zero, so we could consider whether zero was being used in a way that might be facilitative of later math learning.

Coding

To investigate the kinds of information that children hear accompanying instances of *zero* in their environment, each utterance of zero was categorized as belonging to one of five categories. Based on the surrounding sentential context, we categorized each utterance of zero as conveying either an interval, nominal, symbolic, cardinal, or vague meaning. An utterance was coded *interval* if zero was used in a numerical context such as a counting sequence, a time, or a temperature. An utterance was coded as *nominal* if it was used as a particular number (i.e., telephone number with zero). An utterance was coded as *symbolic* if it involved labeling the number zero in the environment. An utterance was categorized as a *cardinal* usage if the sentence described a quantity or value. Finally, if a zero utterance was nonsensical or had no other contextual clues present in the surrounding utterances, then it was coded as *vague*. Table 1 includes examples for each code.

Table 1: Each possible category "zero" was coded as with examples.

Category	Example
Interval	*Mother:* "Ten nine seven six five four three two one zero blast off"
Nominal	*Mother:* "What's your phone number NAME?"
	Child: "Three three three seven nine eight zero"
Symbolic	*Father*: "When you see five and zero together it's a fifty"
Cardinal	*Mother:* "So we have zero babies"
Vague	*Child*: "Zero" *Mother*: "Zero very good honey"

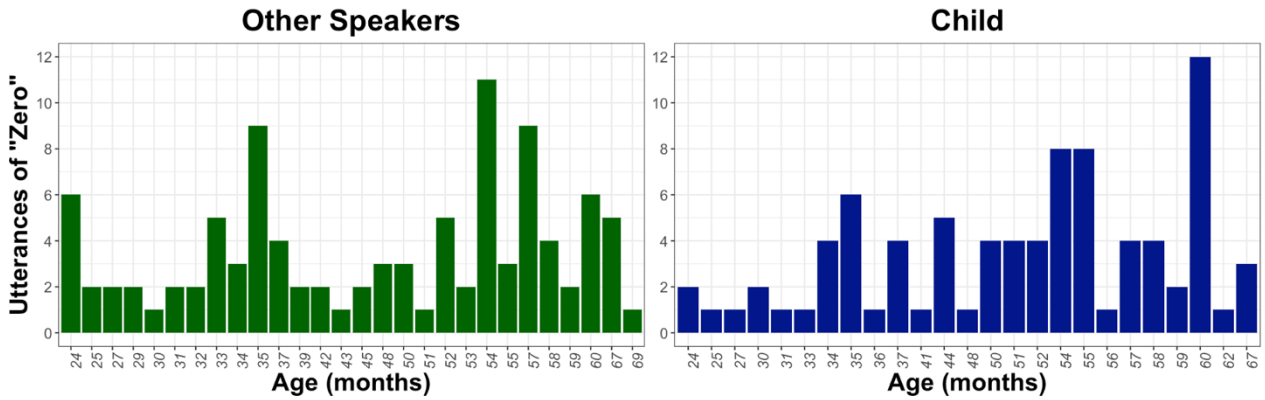

Figure 2: Utterances with zero from other speakers and the child across age. Some ages are missing because there was no data from that age.

Results

The dataset was comprised of utterances from a variety of speakers, including the target child, the child's parents, teachers, and siblings. Thus, the sample included language input about zero from several knowledgeable sources as well as children's own productions of zero. Each individual child contributed approximately 5 utterances of zero across all possible speakers ($M = 4.74$, $SD = 7.22$, $min = 1$, $max = 31$). Knowledgeable speakers contributed 63.5% of those utterances and children contributed 36.5%. See Figure 2 for the frequency of utterances for children at each age.

In the following sections, we analyzed the input that children hear from speakers who are knowledgeable about zero separately from children's own productions. Namely, we examined how utterances of zero change across age – in frequency and in the kinds of sentential contexts in which the utterance occurs.

Language Input with the Word *Zero*

First, we examined the language input that children received about zero. Per our first research question, we examined whether the frequency of input about zero changed as children became older. To test this, we fit a linear model with frequency of utterances as the dependent variable and age of the target child (in months) as the independent variable. Because some of the age bins included data from several individuals (i.e., some months included data from 3 children, while others only had data from 1 child), we included a count of children in each month as a covariate to control for age trends being driven by the number of children in each age group. Both age and count of children in each month were mean centered. Indeed, there was a significant main effect of age. As children became older, the frequency of *zero* utterances (from all sources) increased, $\beta = 0.06$, $F(1, 25) = 4.81$, $p = 0.038$.

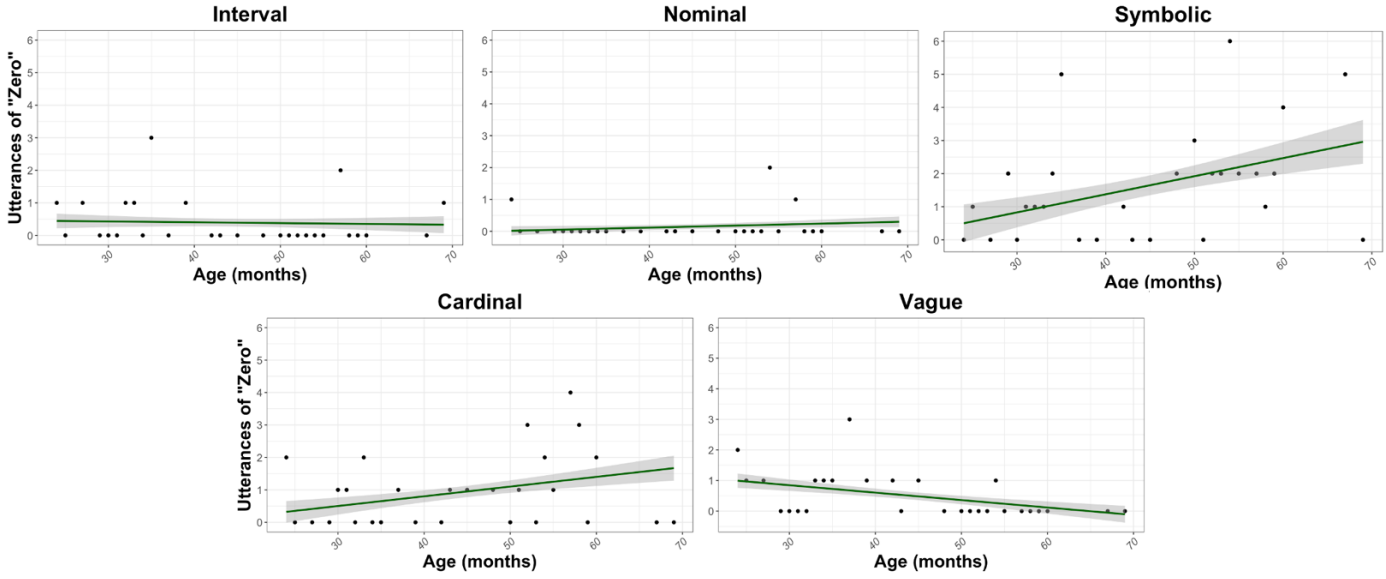

Figure 3: Change in utterances of zero for each sentential context across child age. Error bands reflect standard errors.

We next examined how frequently utterances of zero occurred in each of the context categories we coded, and whether those frequencies changed with the target child's age. To do so, we fit five separate linear models with utterances of zero from each category as the dependent variable and age (in months) as the independent variable. Again, we included the count of children in each month as a covariate.

Utterances of zero occurred in *interval* contexts 11% of the time (*min* = 0 utterances per month, *max* = 3 utterances per month), and this type of input did not change over child age ($p > 0.05$). Utterances of zero in the *nominal* context were even more infrequent, occurring only 4% of the time (*min* = 0 utterances per month, *max* = 2 utterances per month). This type of input also did not change with child age ($p > 0.05$). Utterances of zero in the *symbolic* context were most frequent, occurring 45% of the time (*min* = 0, *max* = 6). Interestingly, this type of input increased with child age, $\beta = 0.05$, $F(1, 25) = 5.28$, $p = 0.03$. Utterances of zero in the *cardinal* context were the next most frequent and occurred 26% of the time (*min* = 0, *max* = 4), and, again, this type of input increased with child age, $\beta = 0.03$, $F(1, 25) = 4.66$, $p = 0.041$. Last, *vague* utterances of zero occurred 14% of the time (*min* = 0, *max* = 3). In contrast to other contexts, this type of input decreased with child age, $\beta = -0.02$, $F(1, 25) = 6.12$, $p = 0.02$. See Figure 3 for the data for each context.

Child Productions of Zero

Next, we examined children's own production of *zero*. Per our first research question, we examined whether the frequency of producing *zero* changed as children grew. To test this, we fit a linear model with frequency of utterances as the dependent variable and age (in months) as the independent variable. Because some age bins included data from several children (i.e., some age bins had data from 5 children, whereas others had data from 1 child) we included the count of children in each month as a covariate to account for age effects being driven by the number of children contributing data. Both age and count of children in each month were mean centered. Contrary to our hypothesis, there was not a significant main effect of child age, $p > 0.05$. Thus, children's productions of *zero* did not change across this age span.

We conducted parallel analyses to those presented for the language input that children received regarding zero. That is, we examined how frequently utterances of zero occurred in each context (interval, nominal, symbolic, cardinal, and vague) and whether these frequencies changed across development. Thus, we fit five separate linear models with utterances of zero in each context as the dependent variable and age (months) as the independent variable. Again, we included the count of children in each month as a covariate.

Children produced utterances of zero in an *interval* context 7% of the time (*min* = 0 utterances per month, *max* = 4 utterances per month), and the frequency of utterances in this context did not change over time, $p > 0.05$. Utterances of zero in the *nominal* context were similarly infrequent, occurring 9% of the time (*min* = 0 utterances per month, *max* = 2 utterances per month). The frequency of child utterances in this context also did not change over time, $p > 0.05$. Utterances of zero in the *symbolic* context were most frequent and occurred 53% of the time (*min* = 0, *max* = 11). Unlike the input to children, children's own production of utterances in this context was stable across age, $p > 0.05$. Utterances of zero in the *cardinal* context were less frequent, occurring 11% of the time (*min* = 0, *max* = 2). Again, the frequency of child utterances in this context did not change over age, $p > 0.05$. Last, *vague* utterances of zero occurred more frequently at 20% of the time (*min* = 0, *max* = 2), but the frequency of this type of utterance also did not change over age, $p > 0.05$.

Summary

Overall, utterances of zero in naturalistic settings were frequent, even for very young children, and these utterances varied with children's age. Zero was used most frequently in a symbolic context (e.g., "When you see five and zero together it's a fifty.") Interestingly, the amount of *input* children heard about zero increased as children developed, and the kind of numerical information that adults provided also shifted with children's development (i.e., pointing to zero as a symbolic number vs. saying *zero* in a phone number). Utterances with zero from more knowledgeable speakers (i.e., parents, teachers, etc.) tended to occur in more sophisticated sentential contexts (i.e., symbolic and cardinal context) more frequently as children grew. However, children's age was not associated with the frequency of their own productions of zero in this sample.

Discussion

In this exploratory study, we examined language input to children and children's own productions to investigate the ways in which the word *zero* is used in naturalistic interactions. We specifically homed in on zero as an interesting early numerical concept because it has multiple meanings that can vary across sentential contexts (Vigliocco et al. 2013, 2018; Floyd & Goldberg, 2021). Moreover, early numerical concepts predict later math achievement (Jordan et al., 2009). Thus, the present study may highlight possible associations between early language input and understanding of abstract numerical concepts. Greater knowledge about the language input that children receive prior to formal schooling may provide insights for instruction about numerical concepts in the classroom. That is, instruction about zero could be informed by understanding the scope of possible meanings to which children are exposed in their early environment.

First, we hypothesized that instances of math talk about zero would increase as children grew. This hypothesis was partially supported. Across all sources of input (i.e., parents, siblings, etc.), the frequency of utterances with *zero* increased with child age. However, when examined separately, we found that children generally remained steady in the number of zero utterances they produced, whereas zero utterances in input from other speakers increased over time. One possible

explanation for these findings is that knowledgeable speakers begin to scaffold young children's understanding of *zero* by using the abstract word more frequently as children's language abilities develop (Huttenlocher et al, 2010). Older children have greater comprehension skills that may allow them to better accommodate abstract words such as *zero* (Gleitman et al., 2005).

Second, we hypothesized that utterances with zero would originate more from other speakers than from children themselves, regardless of age. Indeed, knowledgeable speakers accounted for more of the utterances with *zero*. This finding may be a result of the structure of the dataset, because language input was considered across many speakers rather than one source (i.e., the child). However, when considering young children's production of abstract words more broadly, it is possible that children struggle to self-produce the word *zero* because it is abstract and has several meanings (Mazzocco, 1997). Critically, the present findings suggest that young children hear many utterances of zero from a variety of speakers prior to formal education.

Third, we predicted that the types of sentential contexts in which *zero* occurred would shift with children's age. This held true only for other speakers' utterances. *Interval* and *nominal* utterances of zero remained steady over age, whereas *symbolic* and *cardinal* utterances of zero increased. Moreover, *vague* utterances of zero from other speakers decreased with age. It is possible that as children's language develops, other speakers begin using more advanced language about zero. For example, the symbolic meaning of zero requires a child to know that zero is a number in the number system; many children have difficulty recognizing this (Bialystok & Codd, 2000; Wellman & Miller, 1986; Wynn, 1998). Thus, one possible explanation for the data pattern is that knowledgeable speakers are sensitive to the abstract nature of zero, and they try to ground the meaning in a perceptually concrete symbol for older children who will soon enter formal instruction using this value. The cardinal sense of zero is perhaps an even more advanced concept, as it suggests that one meaning of zero is the empty set. The increase in language input in these categories might reveal why vague utterances of zero decrease. As children age, they are receiving more meaningful and complex utterances with zero, rather than vague ones.

Although we found changes in the kind of input about zero that children received, we were surprised that no shifts were observed in children's own utterances over the age span that we observed. It is possible that prior to formal education children do not need to use the word *zero* frequently in day-to-day activities. However, future research should examine whether utterances of zero in naturalistic settings increase after children begin formal education. Perhaps experience with counting and early arithmetic in school would lead to increases in the use of zero in more informal settings similar to those examined in the current investigation.

There are several limitations to the present study. First, there was a limited number of utterances of zero to examine, even in this large repository of corpora. In fact, there were significantly fewer tokens for zero compared to other natural numbers (i.e., 52,606, 14,700, and 185 for one, two, and zero respectively). Future studies should examine the extent to which natural numbers follow a similar trajectory of input to understand whether early difficulties with zero could be explained by varying patterns of input for different kinds of numbers. It would also be important to demonstrate that the patterns of math talk found in the CHILDES corpora can be replicated in other similar naturalistic language samples or environments. Second, we do not have demographic data to consider from these corpora. Age and utterances were the data available to us. Third, this study is purely an examination of relations among variables. This examination did not causally manipulate utterances of zero to see how it affected children's reasoning about zero or production of zero utterances. Future research should examine how utterances of zero influence reasoning about zero using methods that allow causal inference. Indeed, it is possible that developmental shifts in understanding of zero occur with formal education (e.g., zero as nothing vs. zero as the midpoint between positive and negative numbers when children learn integers; see Vest & Alibali, 2021). Last, while this data provided some repeated measures (i.e., some children had data across ages and some children provided utterances from several different speakers), there were too few data points to analyze the data using linear mixed effects models. Thus, we used linear models with a covariate accounting for the unequal contributions of *zero* utterances from various sources. Future research should gather more longitudinal data so that random effects for individual children can be accounted for. Importantly, future longitudinal studies could provide insight into how particular parent-child dyads construct meaning about zero across development.

The current investigation demonstrates that language in the years prior to formal schooling can provide useful insights into what ways zero is used. Although input involving the word *zero* is limited, the present findings suggest that there are important developmental shifts between the ages of two and six in the nature of math talk about zero. These results are in line with the burgeoning literature on changes in zero concepts and suggest a need for future empirical investigations regarding the origins and factors that shape the developmental trajectory of zero understanding.

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