Young Children's Number-Word Knowledge Predicts Their Performance on a Nonlinguistic Number Task

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Abstract

The present study investigated the link between number-word learning and changes in the child's attention and memory for implicit number information. 71 children (ages 2-2 to 4-9) were asked, without number words, to replicate sets of 1 to 4 objects. Children's performance on the set-replication task was correlated with cardinal number-word knowledge, independent of age, and also independent of target set size (e.g., 'three'-knowers did better than 'two'-knowers on all set sizes, not just on sets of 3). Analysis of the children's vocabulary scores suggests that the differences are not due to general language development. Findings suggest that number-word learning is closely tied to the development of nonlinguistic numerical cognition.

Keywords: cognitive development; number cognition; attention; memory; language and thought; knower-levels; numerals; early childhood; preschool; cardinality; number development; language acquisition

When we look at sets of 1 to 4 items, we can see how many there are, even without verbal counting. People track small numbers of objects through a process called parallel individuation (see Feigenson, Dehaene & Spelke, 2004 for review). This is done by mentally representing each object separately (i.e., representing three objects by forming three mental symbols), and does not rely on having a single symbol (e.g., the number 3) to represent the whole set's cardinality.

The parallel individuation system is already present in infancy, and has been demonstrated in several different research paradigms. For example, Wynn (1992a) showed babies a display in which 2 dolls went behind a screen, one at a time. Then the screen was lowered to reveal either 1 or 2 dolls behind it. Babies looked reliably longer (indicating surprise or curiosity) at the unexpected outcome of 1 doll than at the expected outcome of 2 dolls. Babies also succeeded with 2–1=1 (≠2). Similar results are found using up to 3 items, using habituation tasks (e.g., Starkey & Cooper, 1980; Feigenson, Carey & Spelke, 2002), as well as tasks where babies reach into a box to search for an object (e.g., Feigenson & Carey, 2003; 2005), or crawl toward the larger of two sets (e.g., Feigenson, Carey & Hauser, 2002). Thus, there is convergent evidence that human infants can attend to, remember, and perform some numerical (or at least numerically relevant) computations over small sets of individuals.

These tasks draw on attention and memory resources that are still developing, and infants do not perform perfectly. For example, in the crawling paradigm, infants failed (i.e., they chose the smaller reward) about 20% of the time (Feigenson, Carey & Hauser, 2002). This task seems trivially easy for older children and adults. The question is, what developmental changes make it easy? Presumably, one thing that develops is the child's ability to attend to and remember the number of objects in each set.

Another thing that develops is language—both language in general, and language about numbers in particular. Starting around 2 years of age, children learn the number-word list, usually in the context of counting (see Fuson, 1988 for review). Between about 2 and 4 years old, they gradually learn the cardinal meanings of the first few number words, one at a time and in order (e.g., Briars & Siegler, 1984; Condry & Spelke, 2008; Frye, Braisby, Lowe, Maroudas & Nicholls, 1989; Fuson, 1988; Le Corre et al., 2006; Sarnecka & Carey, 2008; Sarnecka & Gelman, 2004; Sarnecka, Kamenskaya, Yamana, Ogura & Yudovina, 2007; Sarnecka & Lee, in press; Slusser & Sarnecka, 2007, 2009; Wynn, 1990, 1992b). This requires more than just reciting the number words in order; it requires that children connect the number words to sets of the correct cardinality.

The term 'knower-level' is often used to refer to a child's progress on this front. The child starts out as a *pre-number-knower*, and then becomes a *"one"-knower* when she learns that "one" means 1. After the "one"-knower level comes the *"two"-knower*, *"three"-knower*, (and for some children *"four"-knower*) levels. After reaching the "three"- or "four"-knower level, the child achieves a conceptual breakthrough by figuring out the cardinal principle of counting (Gelman & Gallistel, 1978). The child is then a *cardinal-principal-knower* (often abbreviated *CP-knower*). Procedurally, the cardinal principle says that when you count a set of items, the last number word you say denotes the cardinality of the whole set. Conceptually, this principle means that the cardinal meaning of any number word is knowable from the word's position in the list (e.g., the seventh word in any count list, in any language, means 7.) Thus, CP-knowers (including adults) can use verbal counting to find the set size associated with any number word.

What is the relationship between number-word knowledge and numerical cognition? One study found that some minimal number-word knowledge is needed for children to make ordinal judgments (Brannon & Van de Walle, 2001). Other studies have found a connection between number-word knowledge and the ability to recognize numerical equivalence (Mix, Huttenlocher & Levine, 1996; Mix, 1999a, 1999b, 2008a, 2008b). The main goal of the present study is to see if number-word knowledge is also related to attention and memory for number information.

The present study examines the relations among several aspects of development: (1) the learning of cardinal meanings for individual number words; (2) the development of attention and memory for small-number information, as well as object-type and color information; and (3) the development of general vocabulary.

Method

Participants

Participants included 71 monolingual, English-speaking preschoolers with a mean age of 3 years, 7 months (range 2;2 to 4;9) Children were recruited at preschools in and around Irvine, California. Three additional children (ages 2;4, 2;5 and 4;0) began the study but quit after completing fewer than half the trials. These children's data were excluded.

Procedure

Give-N Task The purpose of this task was to determine what number-word meanings each child knew (i.e., to determine the child's knower-level.) A bowl of 15 identical rubber toys was used. The experimenter began the game by bringing out a stuffed animal (e.g., a lion), a plate, and a bowl of 15 small identical rubber toys (e.g., toy bananas). The experimenter said to the child, "In this game, you're going to give something to the lion, like this [experimenter pantomimes putting an item on the plate and sliding it over to the lion]. I'm going to tell you what to give him." Instructions were of the form, "Can you give the lion TWO bananas?"

All children were first asked for one item, then three items. Further requests depended on the child's earlier responses. When a child responded correctly to a request, the next request was for a higher number. When she responded incorrectly to a request, the next request was for a lower number. The requests continued until the child had at least two successes at a given N (unless the child had no successes, in which case she was classified as a pre-number-knower) and at least two failures at N+1 (unless the child had no failures, in which case she was classified as a cardinal-principle-knower).The highest numeral requested was "six."

A child was credited with knowing the meaning of a given number word if she had at least twice as many successes as failures for that number word. Failures included either giving the wrong number of items for a particular word "N", or giving N items when some other number was requested. Each child's knower-level corresponds to the highest number she reliably generated. (For example, children who succeeded at "one" and "two," but failed at "three" were called "two"-knowers.) Children who had at least twice as many successes as failures for trials of "five" and "six" were called cardinal-principle-knowers. (Because parallel-individuation-based 'subitizing' only works up to 3 or 4 items, children who succeed at set sizes 5 and 6 must do so by counting and correctly applying the cardinal principle.)

Set-Replication Task This task tested the child's attention to number and memory for number information, in a context where no number words were used.

The experimenter began the first block of trials (called 'copying' trials) by bringing out two different stuffed animals (e.g., a bunny and an anteater), two bowls with identical sets of 20 toys each, and two plates. An animal, a plate and a bowl of toys were placed in front of each person. The experimenter introduced the task as follows. "Now we're going to play a *copying* game. I will give something to the anteater, like this … (the researcher takes a single item from the bowl, puts it on his plate, and slides it over to his stuffed animal) … and you give something to the bunny. You copy me and make your plate *just like mine*." At this point, most children obliged by placing an item on their plate and sliding it over to their animal. If the child did not immediately do so, the experimenter encouraged her (e.g., "Go ahead. Now you give something to the bunny.") After the child had imitated the experimenter by giving an item to the animal, the test trials began.

In the test trials, the experimenter produced the target set and left it sitting on the table in full view while the child attempted to copy it. After the child produced her set and slid it over to the animal, the experimenter asked the follow-up question, "Is your plate just like mine?" Children who answered 'no' were asked to fix it (e.g. "Oh. Well, can you fix it so it's just like mine?") This happened on less than 1% of trials. At the end of each trial, the items were returned to the bowl.

The second block of trials (called 'remembering' trials) was like the first block except that only one stuffed animal, plate and bowl of toys were used. The experimenter introduced these trials by saying: "Now we're going to play a *remembering* game. I will give something to the bunny, like this (experimenter demonstrates) and you try to remember what I gave the bunny. OK? (Experimenter then returns the items to the bowl and puts the plate in front of the child.) OK, now it's your turn. You give the bunny something, and try to make yours *just like* mine was." After the child's response, the experimenter followed up, "Is your plate *just like* mine was?" In both blocks, children were not specifically instructed to count the items in the target set, but were allowed to continue if they started spontaneously.

Each child was given a total of 32 trials (16 'copying' trials followed by 16 'remembering' trials). Each of these blocks was divided into four sub-blocks of 4 trials each, presented in randomized order. Each of the 8 sub-blocks used a different set of stimuli, consisting of 20 small rubber toys. These sets were of four types: (a) homogenous (e.g., 20 green airplanes), (b) mixed color (e.g., 10 yellow buses and 10 blue buses); (c) mixed type (e.g., 10 orange boats and 10 orange fire engines); and (d) mixed color and type (e.g., 5 red cars, 5 blue cars, 5 red trucks and 5 blue trucks). Each sub-block included four trials: One trial each of set sizes 1, 2, 3 and 4, using an order from one of two pseudo-random lists. Items within each target set were homogenous, even when the bowl of items was not (e.g., from a set of 5 red cars, 5 blue cars, 5 red trucks and 5 blue trucks, the experimenter might place 3 red cars on the plate.)

Vocabulary Assessment After early testing showed a link between number-word knowledge and number replication (see *Results*, below), an assessment of general vocabulary was added. Vocabulary was assessed using the picture vocabulary subtest from the Woodcock Johnson-Revised (Woodcock & Johnson, 1985). 26 children completed this assessment.

Order of Tasks Half of the children completed Give-N first, then the Set-Replication task. The other half completed the first ('copying') block of Set-Replication trials first, then the Give-N task, then the second ('remembering') block of Set-Replication trials. The vocabulary assessment was always given at the end, after the second ('remembering') block of Set-Replication trials. Testing was typically spread over two test sessions, not more than two weeks apart. If Give-N was done in the first session and then more than one week elapsed before the second session, Give-N was repeated at the end. This happened 10 times; in all but two cases, the child's knower-level remained the same. In those two cases, the child's second Give-N score was one knower-level higher than the first score, and the later (higher) knower-level was used.

Results

Each child was assigned a knower-level, based on performance in the Give-N task. Of the 71 children who participated, there were 7 pre-number-knowers, 8 "one"-knowers, 15 "two"-knowers, 9 "three"-knowers, 7 "four"-knowers, and 25 cardinal-principle-knowers.

A 'number replication' score was calculated from the Set-Replication Task. For this score, the child's response was marked correct if she correctly replicated the number of items in the target set. A separate 'type/color replication' score was also calculated, which reflected the child's choice of the correct type and/or color of items, on trials where there was a choice between two types of object, two colors, or both. These measures were independent of each other; a trial could be scored 'correct' for number but 'incorrect' for type/color or vice-versa. The mean score for number replication was 63% correct (standard deviation 25%); the mean score for type/color replication was 49% correct (standard deviation 27%).

Initial analyses showed that children had higher number replication scores in the 'copying' trials than the 'remembering' block by a mean of 9% (standard deviation 19%), $T(65) = 3.64$, $p < .01$ in a paired-sample test (excluding 5 children that did not complete at least half of both types of trials). However, further analyses showed no effect in terms of relationship to other variables; in subsequent analyses, data from the 'copying' and 'remembering' trials were merged.

Participants' mean score from the Woodcock Johnson Picture Vocabulary Test was 22.69 (standard deviation 4.37). The Woodcock-Johnson norming data indicate that a score of 22 is typical for a child of 4 years, 7 months; our participants were somewhat younger than this (mean age 3 years, 7 months). Thus, language development in these participants was slightly accelerated, relative to the national norm.

Correlations

The measures to be compared were number replication, type/color replication, number-word knowledge, age and general vocabulary. Among these five measures, there were several independent correlations. We present these one by one.

Number Replication and Number-Word Knowledge Number replication performance was correlated with number-word knowledge when controlled for age ($r(69) = .64$, $p < .01$), type/color replication performance ($r(69) = .65$, $p < .01$) and vocabulary ($r(24) = .64$, $p < .01$). In other words, children who knew more number-word meanings did a better job of replicating the number of items in the target set (see Figure 1). This was true even though such small set sizes do not require verbal counting.

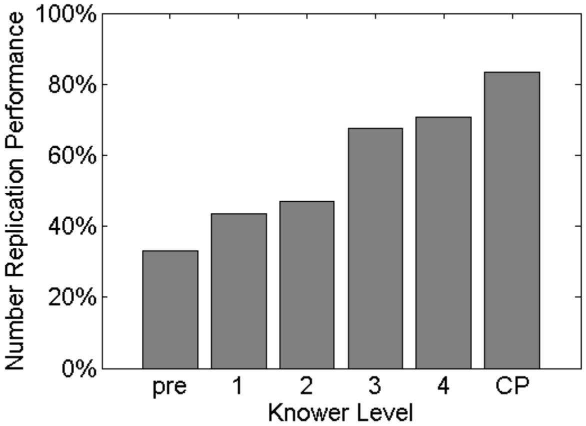

Figure 1: Knower-level and Number Replication Performance.

Children who knew more number-word meanings not only made fewer errors; they also made smaller errors. We found this by calculating a root mean square of children's errors (the number of items the child gave, minus the number in the target set, excluding correct answers). This measure was negatively correlated with knower-level, $r(69) = -.66$, $p < .01$.

At first pass, one might expect that number-word knowledge would predict better number replication performance only for the set sizes the child could name (i.e., "one"-knowers would perform well only on sets of 1; "two"-knowers would perform well on sets of 1 and 2, etc.). However, this was not the case. Number replication performance was actually correlated with knower-level at *each* target set size, from 1 to 4, $r(69) = .50, .62, .64, .66$, ps < .01. In addition, there was no interaction of knower-level with set size, $F(15,195) = 1.51$, $p = .10$. This means that, for example, "three"-knowers outperform "two"-knowers, not only on sets of 3, but also on sets of 1, 2 and 4 (see Figure 2).

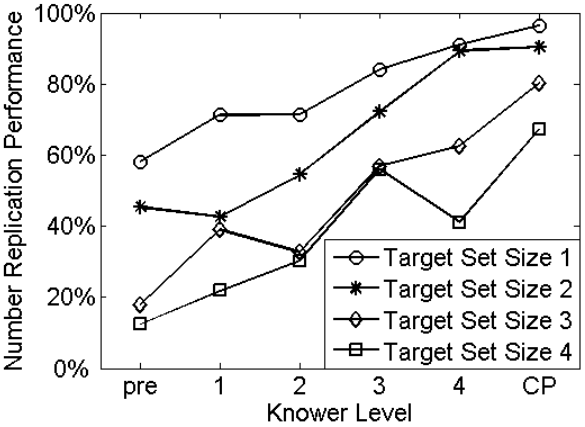

Figure 2: Knower-level and Number Replication Performance broken down by target set size.

Number Replication and Type/Color Replication Number replication performance was correlated with type/color replication performance, controlling for age and knower-level, $r(69) = .62, .52$, ps < .01. In other words, children who did a better job of replicating the number of items in the target set also did a better job of replicating the type and color of items in the target set.

Number Replication and Age Number replication performance was correlated with age, controlling for number-word knowledge and type/color replication performance, $r(69) = .27$, $p = .026$; $r(69) = .49$, $p < .01$. In other words, older children did a better job of replicating the number of items in the target set. This third correlation to number replication performance, however, was weaker than the first two, $Z(69) = 2.81, 2.61$, ps < .01.

Knower-level and Vocabulary Knower-level was related to vocabulary when controlled for each of the other variables of interest: age ($r(24) = .65$, $p < .01$), number replication performance ($r(24) = .39$, $p = .048$), and type/color replication performance ($r(24) = .57$, $p < .01$). In other words, children's knowledge of number-word meanings is related to overall vocabulary. However, vocabulary is not related to number replication performance when controlled for knower-level, $r(24) = .24$, $p = .23$. In other words, number replication is not related to vocabulary development in general, but to number-word knowledge in particular.

No significant correlations were found among the measures of age, number-word knowledge and/or type/color replication performance when number replication performance was controlled. This suggests that number replication performance links the other three variables together, with age being the weakest of the three influences.

Discussion

The present study examined the relationship between a child's understanding of cardinal number-word meanings and her attention/memory for number information in an implicit (non-number-word) numerical task. The implicit task asked children, without using number words, to replicate a set of 1, 2, 3 or 4 items, either while looking at the set or from memory. The study also measured the child's accuracy at replicating the type or color of objects in the target set, and (for some children) included a measure of the child's vocabulary.

Results indicate that a child's attention/memory for number information is closely related to her knowledge of cardinal-number-word meanings. In other words, children who know the meanings of more cardinal number words did a better job of replicating the number of objects in the target set.

Children who did well at replicating the number of items also did well at replicating the type and color of those items. Older children also performed better than younger children, although age was a much weaker predictor of performance than number-word knowledge or type/color replication performance. Children who knew more words in general (as measured by the vocabulary assessment) also tended to know more number-word meanings (as measured by the Give-N task). However, a child's vocabulary score did not predict her number replication performance when number-word knowledge was controlled. In contrast, number-word knowledge *did* predict number replication performance when vocabulary was controlled.

The most striking of these results is the correlation between cardinal number-word knowledge and number replication performance. At the same time as the child is learning the cardinal meaning of each number word, her attention and memory for implicit number information is improving. Somewhat surprisingly, we found that performance improved on *all* set sizes—not only the set sizes the child could name. Moreover, children who knew more number-word meanings tended to make smaller errors as well as fewer errors. When they did not replicate the number of items in the target set, they still gave a number that was closer to the correct number than children with less number-word knowledge.

We also found a correlation between number-word knowledge and vocabulary development: the children who knew more number words simply knew more words overall. But there was no effect of vocabulary score on number-replication performance when number-word knowledge was controlled. Thus, improvements in the child's attention and memory for numbers are specifically related to number-word knowledge, not to overall language development.

Age was a relatively weak predictor of performance. Older children did replicate set sizes better than younger children, but number-word knowledge mattered far more than age. And when it came to replicating the type and color of items in the set, age did not matter at all.

Perhaps the most interesting aspect of the present findings, from a theoretical point of view, was the *continuous* nature of improvement in number replication performance. Intuitively, we might expect children to perform better on the set sizes whose number-word labels they know. But we found that children improved at *all* set sizes, with *each* number-word they acquired. For example, a child who knows that "three" means 3 is not only better at replicating sets of 3 objects, but also at replicating sets of 1, 2 or 4 objects than a child who only knows "one" and "two." In other words, cardinal number-word learning is linked to better attention and memory for cardinal number information overall, not only for cardinalities the child can name.

Another interesting finding was the link between number replication and type/color replication. In other words, children who were more successful at copying/remembering the number of items in the target set were also more successful at copying/remembering the type and color of items. Yet, only number performance was related to number-word knowledge. Because the experimental setup required children to handle both types of information simultaneously, this effect may indicate a sharing of mental resources. It could be that as the child's ability to encode and recall number information improves, resources might be freed up for handling type and color information. An interesting direction for future studies would be to replicate the present study with additional measures of common-noun and color-word knowledge, analogous to the measure of number-word knowledge used in the present study.

The limitation of the present study is that all data are correlations; the directions of causality remain unknown. It is possible that all of the developmental changes described here are driven by maturational improvements in attention and memory. Just as children grow taller over time, they develop better attention and memory resources. These resources might allow children to handle number information as well as type/color information better, and also to learn number-word meanings.

However, a careful examination of the data suggests that the attention/memory improvement is local or specific to number in some sense. If the improvement affected every domain of cognition equally, then increases in number-word knowledge would be equally correlated with improvements in number performance and type/color performance. But in fact, the link is only between number-word knowledge and implicit number performance.

Perhaps a more promising explanation comes from the idea of expert memory. Studies with chess experts have famously shown that familiarity with a particular domain allows people to encode and recall information from that domain more effectively (e.g., Holding, 2002; Ericsson, 2005). It's possible that between the ages of 2 and 4 years, children gain 'number expertise' in the same way that chess masters gain chess expertise. This 'number expertise' may contribute to better attention and memory for numerical information, which in turn allows children to learn number-word meanings, and simultaneously frees up cognitive resources to handle type and color information.

Another possibility is that number-word learning itself drives improvements in number replication performance. Frank, Fedorenko and Gibson (2008) described this type of language-on-thought effect as follows: "Rather than altering underlying representations, languages instead help their speakers accomplish difficult or intractable cognitive tasks by providing abstractions which allow for the efficient storage and processing of information." It's possible that number-word learning helps children encode and recall implicit number information more efficiently. This is consistent with the idea that preverbal infants have inefficient, implicit representations of numbers and use number language to create efficient, explicit replacements (e.g., Le Corre & Carey, 2007).

This explanation, however, requires a view of number-word acquisition that is less discrete and more continuous than the view usually associated with the knower-levels framework. The present study found that "three"-knowers were better at attending to and remembering sets of even 1 item than "two"-knowers were. If this is occurs because of number-word learning, then a "three"-knower must somehow know "one" *better* than a "two"-knower knows "one". It's not clear what the nature of this difference would be.

The present study makes it clear that small-number processing has a place in the discussion about number language and number concepts. On the one hand, preverbal infants and nonhuman primates can track up to 3 or 4 individuals. On the other hand, when children learn the words for these small set sizes, their performance clearly improves. Future research will be needed to describe how this works in greater detail.

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