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Nonverbal Number Knowledge in Preschool-Age Children

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Abstract
The process by which children develop number concepts is a topic of considerable debate. Children progress through proficiency stages, beginning as subset-knowers and ending as cardinal principle (CP)-knowers, but the cognitive tools that facilitate this conceptual change are unknown and are the topic of this study. In a nonverbal number task, the Caterpillar Task, children's nonverbal exact number representations were analyzed by asking children to retrieve "just enough socks" for caterpillars of varying quantities of feet. The two greatest predictors of success on this task were the decision to count and a child's existence as a CP-knower. These data do not fit within the existing frameworks by which past research has articulated the development of number knowledge. The increased precision of exact nonverbal number representations in CP-knowers begins to explain the relationship between verbal and nonverbal number knowledge as well what is entailed in the transition to becoming a CP knower.

Introduction

Most children learn to count when they are two years old (Carey, 2004), but when asked to manipulate certain numbers in their count list, they perform quite poorly until around four years old. For example, Wynn's (1992) Give-a-Number task shows that even if children can count to ten, they may not be able to correctly give you five objects when asked. Based on this task, Wynn concluded that children usually start out as 1-knowers (i.e., they can give one object when asked for one) and progress to being 2-knowers, 3-knowers, and then 4-knowers. Children in these stages are collectively termed "subset-knowers." Once a child can accurately provide an experimenter with a requested number of objects in the Give-a-Number task for any number within their productive count range, they are labeled as cardinal principle (CP)-knowers.

CP-knowers can be further divided into two groups: mappers and non-mappers (LeCorre & Carey, 2006). Mappers are conceived of as being able to metaphorically map a somewhat accurate verbal number estimate to an observed array of objects while non-mappers can only do this for quantities under four. Mappers therefore are posited to have an intuitive sense of quantity for each mapped number word and thus an understanding of the logic of the count list. The Give-a-Number task implies that subset-knowers do not truly understand the concepts that the number words represent outside of a certain range, while CP-knowers do. The process of how children acquire the meaning of number words is still not fully understood, but recent studies suggest various theories.

Several consistent research findings support the idea that young children have a limited understanding of number. Humans have object files, also known as a system of parallel individuation (Feigenson & Carey, 2003). Object files are a system of core knowledge that can represent and track one, two, or three objects. In a study conducted by Feigenson and Carey (2005), infants were presented with a choice between certain quantities of graham crackers and allowed to crawl to the amount of choice. When presented with quantities of one vs. two, two vs. three, and one vs. three, the infants would perform as expected and crawl to the greater amount. When given the choice between one, two, or three vs. any higher quantity, the infant chose at chance. This is evidence that infants have a sense of the numbers one, two, and three before they can speak, but do not spontaneously track sets of objects with more than three items. If they did understand these higher numbers, then they would be able to discriminate between one vs. four crackers, which they failed to do in this study.

In addition to the object file system, preverbal humans and nonhuman animals can represent number through analog magnitudes (Dehaine, 1999). Analog magnitudes are a nonverbal approximate representation of number values. For example, when adults are told to tap 15 times with their finger while blocking out the counting system through verbal interference, they can usually tap around 15 taps, showing that humans can approximately map the number 15 to a value (Carey, 2004). As subjects tries to tap higher numbers, responses become less precise -a phenomenon known as scalar variability.

Xu and Spelke (2000) further supported this theory through a study in which infants were habituated to a screen containing either eight or sixteen dots and then presented with either the same display or a new display with a different number of dots. The results indicated that the infants recovered interest in the new number of dots and therefore could somehow represent that these displays contained different numbers of dots. From these results, it was deduced that infants possess an analog magnitude system that allows them to represent the approximate value of large numbers.

The two aforementioned nonverbal number systems (object files and analog magnitudes) cannot account for the ways in which number is conceptualized in most modern societies. These systems lack a sense of number exactness for quantities larger than four. How, then, can an individual conceptually represent exactly twelve or exactly seven? One hypothesis is the Whorfian view that language is necessary to produce thought. By this view, children are unable to think about exact number quantities without first learning and mastering verbal counting. Carey (2004), a supporter of this theory, hypothesizes that children use both analog magnitude and object files to understand number. However, these two tools are not enough to fully grasp number. Through induction (also known as bootstrapping), children acquire meanings for the verbal number words, which start out as meaningless placeholders in an ordered list (…three, four, five…). Specifically, the number words provide a mechanism to represent concepts like "exactly seven."

In line with Carey's bootstrapping theory is a study done by Gordon (2004) and replicated by Frank, Everett, Fedorenko, and Gibson (2008). Gordon (2004) and Frank et al. (2008) examined connections between language and number in their research with the Piraha people, an indigenous hunter-gatherer Amazonian tribe mainly located in Brazil. The Piraha have a counting system with words for "one," "two," and "many" but no exact verbal number words for numbers higher than two. Results from a series of numerical tasks showed that the lack of language for exact large numbers affected the Piraha's numerical cognition. Their performance with numbers higher than three was highly variable, showing evidence of analog estimation (Gordon, 2004), not exact quantity representation.

Opponents of this Whorfian or bootstrapping model put forward evidence for precise numerical representation in the absence of language. After all, the studies on object files and analog magnitudes show that one does not have to know language to understand number. Brannon and Terrace's (1998) research on rhesus monkeys suggests that language may have less of an effect on cognition than others propose. They were able to train rhesus monkeys to represent the numerals one through nine on an ordinal scale. Additionally, Gelman and Butterworth's (2004) study found through neuroimaging that language disorders and calculation abilities occur independently of each other. Most importantly, language-independent models of number processing state that number concepts exist prior to verbal counting and that language maps directly onto these concepts.

Even proponents of the Whorfian hypothesis concede that language is not necessary to represent small exact numbers or large approximate numbers. However, the Whorfian and anti-Whorfian models explicitly disagree on the representation of exact large numbers. Previous studies have looked for correlations between verbal (language dependent) and nonverbal number knowledge, and have generally reported a lack of correlation between the development of counting and performance on nonverbal number tasks (e.g., matching of visual stimuli). (Rousselle, Palmers, & Noel 2004.) These studies have looked for a general trend of concurrent increases in competence on verbal and nonverbal tasks. Consequently, those studies have not been designed in a way that would capture the hypothesized correlation between the acquisition of the cardinal principle and nonverbal representations of numbers above four. Some studies have found subset- and CP-knowers but only tested nonverbal stimuli up to four (Mix, 1999; Huntley-Fenner & Cannon, 2000). Other studies have tested a larger range of nonverbal stimuli, but have focused on children so young that none of the participants were CP-knowers. The current study focuses specifically on the representation of exact numbers larger than four, testing both subset- and CP-knowers on a nonverbal task involving numbers ranging in both small (less than four) and large (greater than four) numbers.

The purpose of our study is to explore the relationship between number language and the representation of exact large numbers. We thus tested children's number understanding using a nonverbal task (the Caterpillar Task). To assess verbal number knowledge we used the classic Give-a-Number task (Wynn, 1992) and a verbal number estimation task (Fast Cards; LeCorre and Carey, 2006). In the Caterpillar Task, the children were asked to bring just enough socks for all the feet of the caterpillars with numbers of feet ranging from one to nine. Number language was not used in describing the task to the children, and counting was not elicited. In order to perform well on this task, the children would have to represent large numbers, but the method for achieving this was each child's choice. Either they could somehow represent the exact large number in a nonverbal manner, or they could represent it using a verbal approach by counting.

In a broad sense, there are two possible performance trends that could emerge. On one hand, if language is not the source of large number representation, then CP- and subset-knowers will not differ on the nonverbal task because the number concepts required are developed independent of language. On the other hand, if language is the source of large number representation, then CP-knowers will outperform the subset-knowers because they will count and generate some verbal estimates. In addition, the latter model might include counting, estimation or neither. Furthermore it is possible that the children have developed a cognitive capacity for representing higher numbers or a higher attention to number.

Method

Participants

Forty-nine children participated in this study (age range 36-63 months, mean 50 months, 31 females and 17 males). Children were tested at the Wesleyan University Cognitive Development Laboratory or at five nearby preschools. Two testing sessions ensued, one session tested primarily at preschools in the spring of 2008, while the second session of testing occurred in the fall of 2008 primarily at the Wesleyan University location.

Elicited Counting

The experimenter placed a line of 12 rubber ducks on a table and asked the child to count them. The purpose was to establish if the child had a stable count list. Each child's highest count (allowing one error) was recorded.

Give-a-Number

The materials involved for the Give-a-Number task included 12 small yellow rubber ducks. They were kept in a green, medium sized bowl that was often referred to as a pond or a swimming pool. As in Wynn's (1992) study, we implemented the titration method in order to close in on the true knower level of each child. We first asked for one duck, then two ducks, then three ducks, and so on until the child had an incorrect trial. If this happened we requested the previous successful trial's number of ducks. If the child gave the correct amount, we increased our request by one; however, if they gave the wrong amount, we decreased our request by one. We continued this process until the child had three correct trials on a specific number and three incorrect trials on the number greater than the number correctly given three times. This means that the exact order and number of trials varied between the participants.

Unlike the study conducted by Wynn (1992), we continued testing until we found a level at which the child could not succeed. The following classifications were established: one-knowers are children who are consistently able to give the experimenter one item when asked and consistently unable to give any other number of items correctly; two-knowers are consistently able to give one or two objects correctly but are unable to give other numbers correctly, and so forth for all other subset-knower levels; and CP-knowers are children who can consistently give the experimenter any number of items requested up to ten. It is important to note that if children gave an incorrect number of ducks they were asked "Is that [number requested] ducks?" and allowed to correct their error to give them every opportunity to show what they really knew about the number being tested. They were also thanked and told "Good job" after every trial.

The Caterpillar Task

This task used seven caterpillars, 19" long, made from dark green soccer socks stuffed and sewn together. Each caterpillar had a different number of light green feet, either one, two, three, five, six, seven, or nine feet. Each caterpillar had a different face, with different color antennas and drawn-on mouths. Thirty-five identical, white, infant polo socks were used as socks for the caterpillar feet.

After being introduced to a caterpillar (each caterpillar had its own name), the child was told "[Caterpillar's name]'s feet are cold. Could you get just enough socks for [caterpillar's name]? Be careful though because [caterpillar's name]'s mother really doesn't like a messy room so we don't want extra socks laying around." The socks were in a pile across the room and the child was encouraged to pick out the correct number of socks for the caterpillar. It is important to note that the word "number" was never used during this task. The child then brought over some number of socks and the experimenter began to put the socks on the caterpillar's feet. When this was done, the experimenter asked the child if there were "just enough socks." The child was allowed to go back and get more socks or return extra socks to the pile if the child chose. All children were allowed to succeed on this task and could make as many trips to the sock pile as they needed in order to have one sock for each foot. If they brought too many and did not spontaneously correct their error, the experimenter pointed out that the room was now messy and asked the children to return the extra socks.

After the correct number of socks were put on the caterpillar's feet, the next caterpillar was introduced as the previous caterpillar's brother or sister. Each session began with a one-footed caterpillar and ended with a two-footed caterpillar to ensure that the child understood the task. The number of socks brought on each trial was recorded as well as the total number of trials the child took before arriving at the correct number of socks. In addition, it was noted whether or not the child counted the number of feet or socks for each caterpillar. The one-footed caterpillar was used as the practice trial for each participant. The remaining trials (three, five, six, seven, or nine feet) were administered in one of three pseudo-random orders, counterbalanced across children.

Fast Cards

This task was originally created by Le Corre and Carey (2006). We used a slightly modified version developed by Shusterman (personal communication, February, 2008). In this task children were seated next to an experimenter in front of a computer with a blank white screen. The show is in the format of a PowerPoint presentation so that the display time for each of the test items is exactly one second. To anchor the children, we showed them a series of pictures in order from one to fifteen fish. For this set the timing was manually controlled so that the children could become comfortable with the task with no time pressure. The experimenter encouraged the children to "say the number word that goes with this picture" but would make a guess herself (always correctly) if the child did not.

For the next four groups of stimuli, the times were automated to display for one second per picture. This approach allowed the experimenter to make sure the child was paying attention before the new picture came on the screen. Four sets of images were presented; trains, monkeys, snowflakes, and hats. Each set contained pictures with one, two, three, four, six, eight, and ten items in a fixed random order. Two of the sets were controlled for total surface area and two were controlled for density. Before the test trials began, the child's attention was drawn to the screen with "Ready?" and then the picture was flashed. They were then asked, "What number word goes with this picture?" If they did not appear to understand the task (e.g., saying "train" or "choo-choo" instead of a number word), the experimenter would use some extra trials for training purposes by modeling the correct response or asking the kids if it looked "more like two or more like ten?" Data from these trials was not included in the final analysis.

In total, 19 children completed all 28 test trials. The purpose of Fast Cards is to determine whether a child has mapped numerosity (actual understanding of number) to number words. Classification as a mapper or non-mapper was determined based on the slope of the recorded guesses compared to the ideal slope. The slope was determined by comparing the guesses with the correct number of items seen on the computer screen for each set.

Results

Elicited Counting

Thirty-eight of the 49 participants were able to count to ten without error, and all could count to eight without error.

Give-a-Number:

Nineteen children were classified as subset-knowers (mean age 47 months). There were three one-knowers, nine two-knowers, three three-knowers, three four-knowers, and one five-knower. Thirty children were classified as CP-knowers (mean age of 51 months).

Fast Cards:

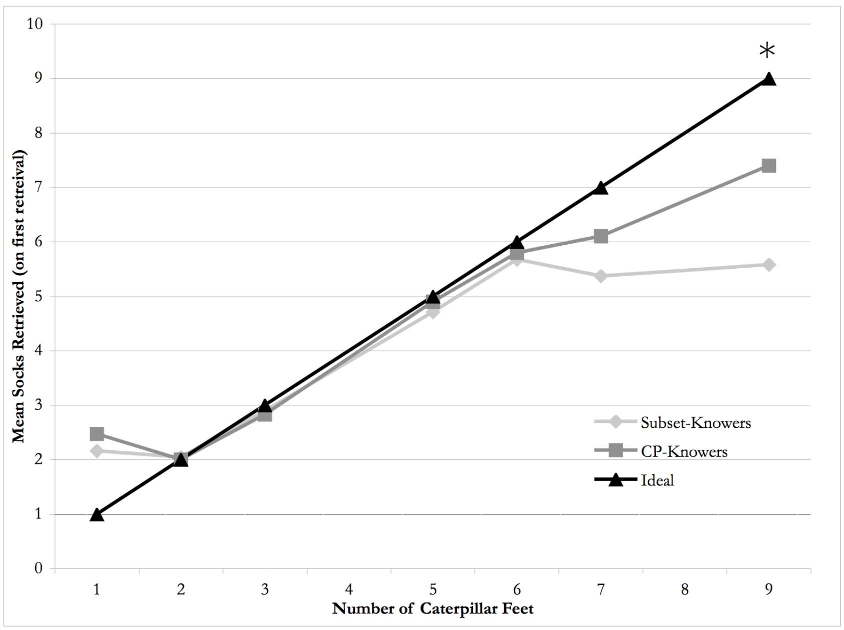
We found 14 non-mappers (mean age 51 months) and 16 mappers (mean age 52 months) in our CP-knower subgroup. We computed the slope of each child's responses on trials with six, eight, or ten items. Mappers had a slope of .96 and non-mappers had a slope of .12.

Caterpillar Task:

All analyses focused on first retrieval (i.e., number of socks brought back on the first attempt). Subset- and CP-knowers differed on three distinct measures: mean socks retrieved, magnitude of errors, and slope.

We first compared subset- and CP-knowers' performance. On the practice trial, subset-knowers brought a mean of 2.47 socks, while CP-knowers brought a mean of 2.35 socks. This is likely because this was a practice trial and most children expected the caterpillar to have two feet like themselves. Subset-knowers brought a mean of 2.05 socks for the caterpillar with two feet, 2.89 for three feet, 5.68 for six, 5.37 for seven, and 5.58 for nine. CP-knowers brought 2.00 socks for two, 2.83 socks for three, 5.80 for six, 6.10 for seven, and 7.40 for nine (Figure 1). The mean number of socks was significantly different between CP- and subset-knowers only for the nine-footed caterpillar ($t(47) = -2.35$, $p = .027$), reflecting the fact that only CP-knowers brought more socks for caterpillars with more feet in the large-number range.

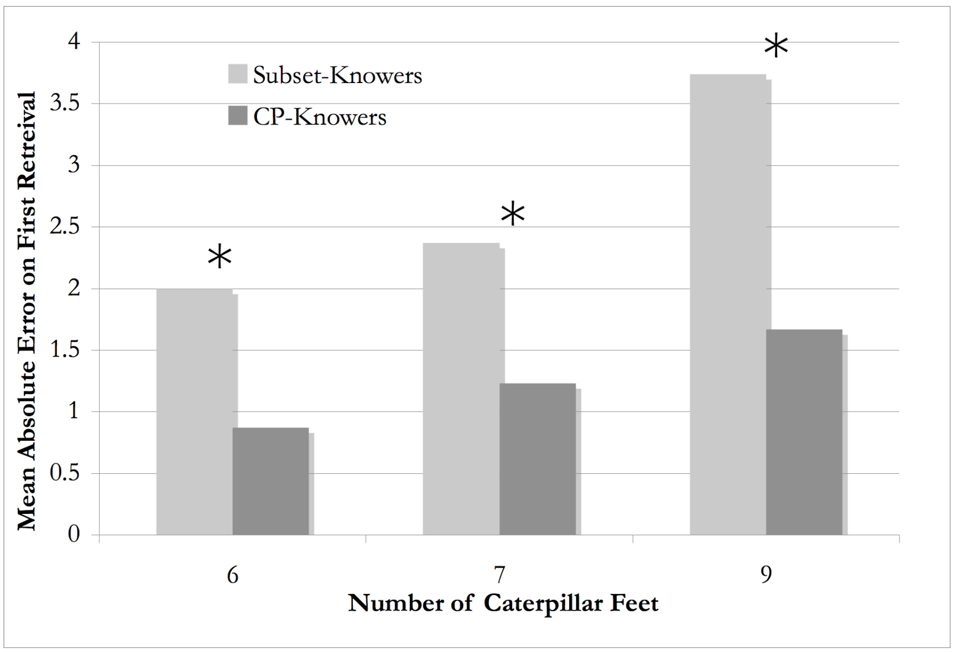
FIGURE 1
Mean Number of Socks Retrieved on the First Attempt



*$p < .05$

Second, CP- and subset-knowers differed in the magnitude of their errors in retrieving socks. Error rate was defined as the absolute difference between the number of socks brought on the first attempt and the number of feet on the caterpillar. For the six-, seven-, and nine-footed caterpillars, subset-knowers had significantly higher error rates than CP-knowers (Figure 2). In addition, a total error value, computed as the sum of the error values for six, seven, and nine, indicated that subset-knowers were off by approximately twice as many socks overall as CP-knowers, 8.11 vs. 3.77, $t(30) = 3.53$, $p = .001$ (equal variances not assumed).

FIGURE 2
Mean Absolute Errors on the 6-, 7- and 9-footed Caterpillars



*Significant difference between Subset- and CP-knowers, $p < .05$

To see whether errors varied as a function of the target number of feet, a Repeated Measures ANOVA examined effects of number of feet (six, seven, or nine) and Knower level (CP- vs. subset-knower). A significant main effect of number was observed, ($F(2,46) = 9.20$, $p < .001$), indicating that errors increase as the number of feet increases for both CP- and subset-knowers, consistent with a magnitude-based representation of number with scalar variability underlying performance. A main effect of Knower level was also significant, $F(1,47) = 14.27$, $p < .001$, indicating that CP-knowers have fewer errors overall. The interaction between number of feet and knower level was not significant, indicating that subset-knowers are not significantly more affected by the increase in number of feet than CP-knowers.

Third, we computed the slope of the number of socks retrieved for the six-, seven- and nine-footed caterpillars compared to the ideal number of socks that should be brought. The mean slope for CP-knowers (0.55) was significantly different from subset-knowers (-0.02), $t(47) = 2.66$, $p = .01$, which reflects the fact that only CP-knowers tended to bring more socks for caterpillar's with more feet.

Verbal estimation ability (i.e. mapping) had no effect on task performance. CP mappers did not choose to count more often than CP non-mappers (mappers: nine counted, seven did not; non-mappers: ten counted, four did not; $\chi^2(1) = .74$, $p = .389$). Additionally, on average, CP-mappers and CP non-mappers, made a similar number of total errors on the large-number trials (3.94 vs. 3.97, $t(28) = -0.29$, $p = .77$).

TABLE 1
Role of Estimation.

Estimation Task (Numerosities)	Mean Slope		
	Subset	CP non-mappers	CP-mappers
Fast Cards (6, 8, 10)	0.31	0.12	0.96
Caterpillar (6, 7, 9)	-0.02	0.56	0.54
p-value	0.19	0.03*	0.06

Note: Shows the difference in estimation ability as a function of knower level and as a function of task. Slopes were calculated using the numerosities tested in each task.

We then examined the role of estimation more broadly. The Caterpillar Task can be conceived of as a nonverbal estimation task whereas Fast Cards is a verbal estimation task. Accuracy is defined by a slope, where a child's responses are compared to target numerosities. Table 1 shows that subset-knowers show a small slope on Fast Cards and on the Caterpillar Task, and CP-mappers show a large, positive slope on both tasks. CP non-mappers show a poor slope on Fast Cards (verbal estimation) but a good slope on the Caterpillar Task (nonverbal estimation).

We next analyzed effects of counting. We defined children as counters if they ever showed evidence of verbal counting on any of the trials ($n = 26$) and non-counters if they did not count on any of the trials ($n = 23$). Of those who counted, only four brought exactly the right number of socks for each trial on which they counted, implying that counting does not guarantee success on this task. It does, however, improve performance. Counters made fewer total errors on average than Non-Counters, 3.27 vs. 7.91 ($t(29) = 4.10$, $p < .001$, equal variances not assumed). Counters also had a significantly more positive slope for responses to the six-, seven-, and nine-footed caterpillars (slope = .70) than non-counters (slope = -.08), $t(47) = 4.04$, $p < .001$.

We next explored whether the advantage that CP-knowers had over subset-knowers was dependent on counting. Of the 19 subset-knowers, seven sometimes counted while 12 never counted. Of the 30 CP-knowers, 19 sometimes counted while eleven never counted. CP-knowers were only marginally more likely to count than subset-knowers, $\chi^2(1) = 3.28$, $p = 0.07$.

An analysis combining knower level and counting suggested that these factors contributed independently to accuracy on the Caterpillar Task. An ANOVA using total error as the dependent measure, Counting (counter, non-counter) and Knower level (subset, CP) as fixed factors, and age as a covariate, showed main effects of Counting, $F(1,44) = 15.12$, $p < .001$, and Knower level, $F(1,44) = 9.59$, $p < .01$, and no interaction effect. Looking only at the sub-group of non-counters, CP-knowers still made fewer total errors in the large-number range than did subset-knowers, $t(47) = 2.38$, $p = .027$. This CP-knower advantage was also observed for counters, $t(47) = 2.18$, $p = .039$.

Three separate ANOVAs tested for effects of age, sex, and testing sessions (spring vs. fall) as covariates, with total accuracy as the dependent variable, subset vs. CP status as a fixed factor, and counting as an additional covariate. None of these factors were significant (main effect of age: $F(1,45) = 2.43$, $p = .126$; sex: $F(1,45) = .015$, $p = .905$; testing session: $F(1,45) = .103$, $p = .750$).

In sum, these results indicate that Counting and Knower level both affect accuracy on this task in the high-number range, but these effects are independent of each other: CP-knowers outperform subset-knowers even when the effects of counting are taken into account.

Discussion

The most crucial finding of this study was a correlation between number language and nonverbal number cognition. CP-knowers demonstrate nonverbal number knowledge that significantly exceeds that of subset-knowers in both numerosity and precision. This adds a critical component to the current literature, and its incongruity with current theoretical frameworks allows for a more accurate conceptual perspective. Additionally, these results implicate nonverbal number systems as qualitatively different in subset- and CP-knowers. This may help in understanding the conceptual shift that facilitates the transition to CP-knower status.

Verbal and Nonverbal Relationship to Caterpillar Success

Verbal and nonverbal number knowledge were both effective tools for success on the Caterpillar Task. Both subset- and CP-knowers who utilized a verbal strategy (counting) were more successful than were those who did not, but CP-knowers were significantly more successful with nonverbal strategies. This association reveals that CP-knowers have a more precise system for representing number nonverbally than do subset-knowers.

Children were profoundly successful at counting, a verbal ability. Children who counted on at least one of the seven caterpillar trials had increased success even on trials where they did not count. This is to say that children's performance would improve on the seven-footed caterpillar trial without counting if they counted during the six-footed caterpillar trial. These effects are not likely the result of sub-vocal counting because young children have difficulty with accuracy even while counting explicitly and pointing to the items one by one.

Additionally, it is important to remember that subset-knowers only mirror number words in their known number range with distinctly numerical content. It is therefore noteworthy that they perform better if they count even on trials outside their known number range. Since they do not have precise values for these numbers, this finding is consistent with what one would find in a child who counts incorrectly; counting could not help the child attain an exact number value. Thus, it seems that understanding of number words produced while counting does not explain the success of counters on the Caterpillar Task. Taken together, these results suggest that counting in-and-of itself does not directly enable access to number representations, and it is rather a child's predisposition to count (on at least one of the trials) that indicates proficiency.

The second variable that was correlated with success on the Caterpillar Task was a child's status as a CP-knower. CP-knowers were only marginally more likely to count during this task and the success of counting and CP-status were independent of each other. This indicates that there is something about being a CP-knower that is related to success on the Caterpillar Task.

The component of CP-status that is related to task success is most likely improved nonverbal number representations. As has already been mentioned, the Caterpillar Task tests nonverbal number knowledge only for children who are classified as non-counters because these children did not utilize verbal knowledge in addressing the task. When examining only non-counters, CP-knowers are still significantly more successful than subset knowers are. This provides evidence that CP-knowers have a more advanced system of nonverbal number knowledge than do subset-knowers.

The role of estimation ability supports this conclusion. The Caterpillar Task is very similar to the Fast Cards task, which is used to classify children as mappers or non-mappers. In each, the goal is to provide an estimate for a presented numerosity; in the Caterpillar Task it is (nonverbally) in terms of socks and in Fast Cards it is (verbally) in terms of providing a number word. CP non-mappers perform comparably to subset-knowers on Fast Cards (worse than CP-mappers) but CP-mappers and CP non-mappers perform equally well on the Caterpillar Task, yet better than subset-knowers. This is to say that estimation ability, albeit broadly defined, is not restricted to CP-mappers. Non-mappers are proficient nonverbal estimators on the Caterpillar Task but are poor verbal estimators on Fast Cards. Therefore, it seems that CP-knowers (mappers and non-mappers) possess nonverbal number proficiency that enables nonverbal estimation. Verbal estimation is a different skill that requires the greater degree of number proficiency exhibited by CP-mappers. The task used to identify knower level (Give-a-Number) is an inherently verbal task, and therefore, in theory, it only categorizes children by their verbal number proficiency. These results speak to the fact that CP-status has implications deeper than verbal proficiency.

Situating the Caterpillar Task in an Amended Language-Dependent Framework

Generally, the extensive body of research that has explored the development of children's number concepts can be categorized into two major conceptual camps: language-independent and language-dependent. The language-independent model claims that nonverbal number concepts are not shaped or created by verbal number understanding and abilities, and the language-dependent model claims that the use and development of number in verbal activities (such as counting) enables children to become proficient (conceptually and procedurally) with numbers.

Each would have different hypotheses about whether success on the Caterpillar Task would or would not differ as a function of knower level. The Caterpillar Task was designed to be a nonverbal task, because it tests nonverbal number accuracy, albeit only on trials where children do not count. Accordingly, the language-independent model would not predict the existence of performance differences on the Caterpillar Task (a nonverbal task) based on knower level (a verbal distinction). The language-dependent model identifies the subset-to-CP transition as a drastic conceptual shift, and would predict a subset-CP performance differential on the Caterpillar Task. Since this theory locates the origin of the conceptual shift to CP status as the result of verbal knowledge, it would presumably predict heightened performance of CP-knowers because these children would choose to utilize their enhanced verbal understandings by counting caterpillar feet before returning socks.

As has been discussed, the Caterpillar Task has exposed a relationship between knower level and the precision of nonverbal number knowledge. Additionally, the role of verbal number knowledge was not significantly related to knower level, but was significantly related to task performance. Therefore, the language-independent model may not be entirely accurate as it currently stands, and the language-dependent model predictions are only somewhat supported. This is to say that the language-dependent model predicted the result that CP-knowers would outperform subset-knowers, but they did so for the wrong reason. Supporters of this model claim that language is the tool by which people are able to represent large exact quantities (Carey, 2004) and that CP-knowers, as proficient number users, would succeed on this task because they choose to count.

The subset-CP performance differential was not related to differences in the employment of counting as a performance tool. While it is true that CP-knowers outperform subset-knowers, this is not due to CP-knowers disproportionately choosing to count. We can reach this conclusion because the difference in performance exists even when counting is controlled for, and because approximately one-third of subset-knowers chose to count as a tool to complete the task. Since some subset-knowers chose to count, choosing to count on this task is not a legitimate byproduct of CP-status.

The fact that the Caterpillar Task's results are incompatible with the predictions and assumptions of both the language-independent and the language-dependent perspectives (as they currently stand) requires the introduction of a new framework of analysis for understanding the development of number knowledge. We subscribe to the language-dependent model because counting (a verbal strategy) and knower-level (a verbal distinction) were most significantly related to task success. This framework must be amended, though, to acknowledge and incorporate nonverbal number concepts and their increased proficiency in CP-knowers.

Implication of Nonverbal Number Systems in Conceptual Change

The Caterpillar Task's greatest source of diversion from the current language-dependent model is that CP-knowers demonstrate more accurate nonverbal number concepts. Specifically, we believe the development of the nonverbal number system to be one (or a combination) of the following: a refined (more precise, less approximate) analog magnitude system, an expanded object files system, and/or chunking large untrackable quantities into smaller trackable sub-quantities ("seven" might become a "four" plus a "three")

Identifying the relationship between CP-status and nonverbal number concepts certainly contributes to understanding the induction that enables subset-knowers to become CP-knowers. The most critical question that this research poses is of the chicken-or-egg variety, which one comes first? Also, this research provides the following two interpretations: (I) the accumulation of verbal knowledge by a subset-knower leads to the development of more precise nonverbal number structures which scaffolds and enables the induction to CP-status, or (II) the accumulation of verbal knowledge by a subset-knower enables the induction directly, and this induction facilitates the development of non-verbal number concepts. This is a critical distinction to make because it has the potential to shape more effective number education for preschool-age children. Specifically, teaching subset-knowers would be based on the role of nonverbal number concepts in facilitating the induction. If interpretation I is true, verbal and nonverbal number proficiency should be emphasized, but if interpretation II is true, verbal number skills should be more heavily practiced and cultivated.

Children's predisposition to count on the Caterpillar Task may also be related to these two interpretations. If interpretation I is true, perhaps subset-knower counters are those whose nonverbal number systems have begun to develop but have not done so sufficiently to stimulate the induction. Perhaps counting is employed by these children because their nonverbal representations enable a visible and conceptual division between objects. Also, children's counting may be a byproduct of socio-individual factors, and the children who choose to count may do so because their parents and/or teachers more frequently request counting as an important skill to develop.

Future Directions

Future research should aim to identify the nonverbal system or systems that develop in association with a child's status as a CP-knower. Additionally, the causal direction between this development and the induction should be identified. We propose experiments to analyze chunking and refined analog magnitudes.

One idea for gauging possible effects of chunking on nonverbal task performance involves having one "chunking-prone" fleet of caterpillars (such as the ones used in the current study that have some feet on one side of the caterpillar's body and some on the other) and another fleet of "chunking-inhibitors" (that would have all of the feet on one side of the caterpillar's body). If children with the chunking-prone caterpillars outperform the others (controlling for knower level and counting), strong evidence would exist that the superior performance of CP-knowers in the current study was because they used chunking in some capacity.

Another idea involves longitudinally measuring children's Weber functions, a measure of analog magnitude acuity. In monitoring the progressive development analog magnitudes in relation to knower level and performance on the caterpillar task, the order in which nonverbal number systems develop and children become CP-knowers may become clearer.

Relating specific nonverbal number systems to task performance and to CP- vs. subset-knower status (whether through experimental design or careful analysis of correlational data) would likely prove quite useful in shedding light on the nature of the relationship between nonverbal and linguistic components of children's understanding of number.

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