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A picture of eight turtles: the child's understanding of cardinality and numerosity

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Find the picture of eight turtles: A link between children's counting and their knowledge of number-word semantics

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Abstract [195 words]

An essential part of understanding number words (such as *eight*) is understanding that all number words refer to the dimension of experience we call numerosity. Knowledge of this general principle may be separable from knowledge of individual number-word meanings. That is to say, children may learn the meanings of at least a few individual number words before realizing that all number words refer to numerosity. Alternatively, knowledge of this general principle may form relatively early and proceed to guide and constrain the acquisition of individual number-word meanings. The present paper describes two experiments, in which 116 children (ages 2-1/2 to 4 years) were given a number-word-extension task as well as a standard Give-N task. Results show that only children who understood the cardinality principle of counting successfully extended number words from one set to another based on numerosity – with evidence that a developing understanding of this concept emerges as children approach the cardinal principle induction. These findings support the view that children do not use a broad understanding of number words to initially connect number words to numerosity, but rather make this connection around the time that they figure out the cardinality principle of counting.

Keywords: Language Acquisition; Number Words; Numerosity; Children; Cardinality; Counting

Find the picture of eight turtles: A link between children's counting and their knowledge of number-word semantics

Generally speaking, number words refer to the dimension of experience we call numerosity. That is, number words answer the question, *how many*. Of course, individual number words (e.g., *ten)* pick out precise cardinalities. But knowing that number words (as a group) pick out numerosity (as a dimension), is not the same thing as knowing the particular cardinality associated with each number word.

For example, imagine that you (the reader) were shown a picture of four smiling turtles and were told, "This is a picture of *hachi* turtles. Show me another picture of *hachi* turtles." You then had to choose between two other pictures: One with four frowning turtles; the other with eight smiling turtles. Which picture would you choose? If you assume *hachi* is an adjective (perhaps meaning *happy*) you would choose the second picture. If you assume *hachi* is a number word, you would choose the first. You don't have to know what *hachi* means in order to choose correctly, you need only know what *kind* of word it is—a number word or an adjective. Thus, children's acquisition of number-word meanings involves two conceptually separable tasks: The task of identifying the dimension of experience denoted by all number words (i.e., the dimension of numerosity) and the task of learning the specific meaning of each individual number word.

The latter task is particularly challenging. In fact, it often takes around 6 months after learning to recite a partial count list ("one, two, three, four, five, six…") to acquire the exact meaning of the word "one", and another year to learn the exact meanings of "two" and "three". Only then, around age four, do children begin to understand how counting can be used to assess cardinality (Briars & Siegler, 1984; Frye, Braisby, Lowe, Maroudas, & Nicholls, 1989; Fuson, 1988; Le Corre, Van de Walle, Brannon, & Carey, 2006; Wagner & Walters, 1982; Wynn, 1990, 1992). It is possible then that children understand number words denote numerosity before they have assigned any number words with precise meaning and well before they become competent counters (see Bloom & Wynn, 1997). If this is the case then understanding that number words denote numerosity may facilitate the acquisition of individual number-word meanings. Alternatively, it is possible that children infer that *all* number words denote numerosity from their understanding of the first few number words. In this case, children could not connect number words to numerosity until after they have acquired the specific, cardinal meanings of at least some subset of number words. Clearly, identifying which of these two alternatives accurately describes children's number-word learning will offer insight as to how children infer semantic constraints and how these constraints can be used to facilitate language acquisition and conceptual learning. To date, however, the order in which these principles unfold is uncertain.

On the one hand, Condry and Spelke (2008) found support for the view that some individual number-word meanings (specifically, "one", "two", and "three") are learned before children connect number words (as a class) to numerosity. In one of their tasks, the experimenter showed 3-year-olds two sets of objects (e.g., two trays, each containing five sheep) and labeled one set with a number word (e.g., "This tray has *five* sheep."). Then the experimenter transformed the labeled set (by rearranging the objects, or by adding an object) and asked them to either "point to the tray with five sheep" or to "point to the tray with six sheep." Condry and Spelke's participants, none of whom demonstrated an understanding of how to count in order to determine the number of items in a set (a concept referred to as the *cardinality principle*, R. Gelman & Gallistel, 1978; Wynn, 1992), performed at chance on this task. In other words, they showed no understanding that the number word applied to a set changes when (and only when) the numerosity changes.

Another of Condry and Spelke's (2008) tasks began with two sets of objects, though this time one set contained twice as many objects as the other (e.g., a set of five sheep and a set of ten sheep). Again, one set was labeled with a number word (e.g., "This tray has *five* sheep."). The experimenter either performed some action on the labeled set (rearranging, doubling the number, or halving the number of objects) or left it alone. The child was then asked to point to the tray with either the original number or a different number of objects (e.g., "Can you point to the tray with *five* sheep?" or "Can you point to the tray with *ten* sheep?"). On this task, the children only succeeded when the trial had not included any kind of transformation to the labeled set. On trials with any kind of action (including rearrangement), children assumed that the original number word had changed. These findings led Condry and Spelke to conclude that children who have not yet learned the cardinality principle do not see high number words (e.g., five and ten) as denoting specific numerosities. (Cardinal-principle-knowers, however, demonstrate robust success on similar tasks, see Lipton & Spelke, 2006.)

Against this position, some have argued that children understand that number words denote numerosity very early in development (R. Gelman, 1977; R. Gelman & Gallistel, 1978). Two studies using the knower levels framework (Sarnecka & S. Gelman, 2004; Wynn, 1992) concluded that by the time children have learned the meaning of the word "one" (long before they figure out the cardinality principle of counting) they see higher number words as referring to specific numerosities. In fact, these studies make an even stronger claim—that children understand each number word to pick out a specific, unique numerosity even though they don't yet know the particular numerosities associated with each word.

The study by Wynn (1992) began by identifying 2- and 3-year-old children who understood the meaning of "one," but no other number words. Wynn presented each of these children with a pair of pictures, one showing a single item and the other showing between two and six items. Experimenters then asked the child to, for example, “Show me the *four* fish.” Children reliably chose the multiple-object picture, indicating that they understood the higher number word to contrast with *one*. Wynn concluded that by the time they know *one*, children already understand that all number words refer to specific, unique numerosities.

The study by Sarnecka and S. Gelman (2004) replicated and extended Wynn’s finding, showing that children (2 ½ to 4-years-old) also expect two higher number words (*five* and *six*) to contrast with each other. Sarnecka and S. Gelman used a transformation task, in which children were presented with a set of five or six objects. Each set was first labeled with a number word (e.g., “I’m putting *six* buttons in this box.”). Then some action was performed on the set (adding a button, subtracting a button, shaking the box, or rotating the box), the lid was closed to hide the objects, and the child was asked, “Now how many buttons? Is it *five*, or *six*?” Children (even those who did not yet understand the cardinality principle) judged that the number word should change only on trials when an item had been added or subtracted from the set. On trials where the set had been shaken or rotated, they understood that the number word should not change.

In another task, children were presented with two sets of six objects, either labeling both sets as “six” or labeling both sets as “a lot.” Then, many more items (100 or more) were added to one of the sets and the child was asked which set had “six” or “a lot” (repeating the word used earlier in the trial). On trials asking about “a lot,” children (even those who knew only the meaning of “one”) chose the set that had gained 100 items. On trials asking about “six,” they chose the set that had remained untouched. Sarnecka and S. Gelman concluded that the children understood that number words, in contrast to the phrase *a lot*, refer to specific, unique numerosities by the time they know the meaning of “one”.

However, Sarnecka and S. Gelman's (2004) study included a third task, which children did not pass until they understood the cardinality principle. In this task, children were presented with two sets, which were either identical (e.g., five peaches and five peaches) or differed by one item (e.g., five cookies and six cookies). Although all children correctly identified sets as 'the same' or 'not the same,' only cardinality-principle knowers succeeded on the test question, of the form "This is *five* peaches. Is that *five*, or *six*?". This finding suggests that although young children may see number-words as contrasting with each other in meaning, and may even know that a single set should retain its number word unless it gains or loses items, they may not know how to extend a number-word from one set to another. This could reflect a gap in their conceptual knowledge (see Sarnecka & Wright, 2011) or could be a result of different pragmatic demands made by the various tasks (see Brooks, Audet, and Barner, 2011).

The present paper attempts to contribute to this debate by investigating when children understand a property common to all number words (i.e., that they denote numerosity.) Specifically, do children understand this property of numbers *prior* to figuring out the cardinality principle of counting, as Sarnecka & S. Gelman (2004) would have it? Or do they understand it only upon or after inducing the cardinality principle, as Condry and Spelke (2008) suggest?

Experiment I

Method

Participants

Participants included 58 children (33 girls, 25 boys) ranging in age from 2;6 to 4;0 (mean 3;4). All children were monolingual and native speakers of English, as determined by parental report. Participants were recruited from preschools and day-care centers in and around Irvine, California. No questions were asked about socio-economic status, race, or ethnicity, but children were presumably representative of the community from which they were drawn. In this community, 96% of adults have a high-school diploma and 64% have a bachelor's degree; and most residents identify as white (47%), Asian (37%) or Hispanic (9%) (U.S. Census Bureau, 2008).

Procedure

Word-Extension Task. The purpose of this task was to determine when, in relation to their understanding of specific, low-number words, children extend high-number words from one set to another based on numerosity. Stimuli were created so as to measure whether children are similarly inclined to extend number words to other properties of a set, such as continuous spatial extent, or properties of the individuals within a set, such as color.

Stimuli included cards (18 x 11 cm) depicting sets of 4, 5, 8 or 10 identical cartoon objects (e.g., turtles, flowers, etc.) on a white background. Each object had eyes and a mouth, plus at least one other feature (e.g., a tail or leaves) that could reflect a happy or sad mood. ('Happy' objects had forward-looking eyes, a smile, and a perky, upright tail or leaves; 'sad' objects had downward looking eyes, a frown, and a drooping tail or leaves.) Each object was drawn in one dominant color (red, orange, yellow, green, blue, purple, brown, black, or gray).

Two-dimensional pictures allowed for rigorous controls for total spatial extent (see Clearfield & Mix, 1999; Feigenson, Carey, & Spelke, 2002). On trials controlling for total area, each large object covered twice the area of a small object; on trials controlling for total contour length, each large object had twice the contour length of a small object. For each trial type, half the trials showed sets of 4 and 8 objects; the other half showed sets of 5 and 10 objects.

Each child completed 12 trials, presented in one of two pseudorandom orders. Six of the trials were 'number' trials. On these, the experimenter showed the child a sample picture, saying, (e.g.) "This picture has *eight* turtles." The experimenter then placed two more pictures (the response pictures) on the table, saying, "Find another picture with *eight* turtles." One of the pictures (the correct response) had the same number of items as the sample. The other picture (the distracter) had either half the number or twice the number of items as the sample, but matched the sample either in total area or in total contour length, depending on the condition to which the child was assigned. On some number trials, the distracter pictures matched the sample picture only on summed spatial extent (Trial Type A) while on other number trials objects in the distracter picture also matched the sample in either color or mood (Trial Type B). See Table 1 for a complete breakdown of trial types; see Figure 1 for an example. The number word included in the prompt was counterbalanced such that the words 'four, 'eight', 'five' and 'ten' were evenly distributed.

The other six trials were color/mood trials. Here, the experimenter would ask, for example, "This picture has *happy* turtles. Find another picture with *happy* turtles." Depending on the trial type, the distracter set matched the sample in number (Trial Type C); in color or mood—whichever was *not* asked for in the prompt (Trial Type D); or did not match in any dimension (Trial Type E). See Figure 2 for an example.

Because the purpose of the task was to evaluate whether children extend high-number words to numerosity (rather than exact cardinality) sets always differed by a ratio of 1:2. For that reason, counting was not necessary to solve the task. Accordingly, children were discouraged from counting the objects in the pictures. If a child did try to count, the experimenter removed the pictures and said, "This isn't a counting game. You can just guess." Attempted counting (either counting aloud or pointing silently) was only observed for a total of four children in Experiment I (two CP-knowers, one three-knower, and one two-knower) and seven children in

Experiment II (six CP-knowers and one three-knower), each of whom attempted to count on fewer than three trials.

Give-N task. A standard Give-N task was used to determine which number-word meanings each child knew, and whether the child understood how counting determines numerosity. (For other studies using the Give-N task in this way, see Barner, Chow, & Yang, 2009; Barner, Libenson, Cheung, & Takasaki, 2009; Condry &Spelke, 2008; Frye et al., 1989; Le Corre & Carey, 2007; Le Corre, Van de Walle, Brannon, & Carey, 2006; Sarnecka & Carey, 2008; Sarnecka & S. Gelman, 2004; Sarnecka & Lee, 2009; Schaffer, Eggleston, & Scott, 1974; Wynn, 1990; 1992). The Give-N task was given immediately after the Word Extension Task.

Materials for this task included a stuffed animal (approx. 21 cm tall) a red plastic plate (approx. 11cm in diameter), and 15 small plastic bananas (approx. 6 cm x 1.5 cm each). The experimenter began the task by placing the animal on the table and saying, "This is Peter the Anteater. In this game, you will give him some bananas." The experimenter then placed the plate on the table and said, "When you are finished, slide the plate over to him, like this." The experimenter then placed a bowl of 15 bananas on the table and asked the child, "Can you give Peter *one* banana?" After the child slid the plate over to Peter, the experimenter asked the follow-up question, "Is that *one?*" If the child said "yes," the experimenter said, "Thank you!" and placed the bananas back in the tub. If the child said "no," the experimenter restated the original prompt ("OK, Can you give him *one*?") and continued with the follow-up question, as before. Children were allowed as much time as they needed to complete the trial with ample opportunity to fix a set or change their response. And, unlike the previous task, children were perfectly free to count when doing this task (in fact, counting was necessary to reliably generate sets of five or six items because such sets are too large to be enumerated nonverbally).

Children were always asked for 1 and 3 bananas on the first and second trials, respectively. If the child succeeded on both of these, the next request was for 5 bananas. If not, the next request was for 2 bananas. Subsequent requests depended on the child's responses. If the child succeeded at giving a number N, the next request was for N+1, with 6 being the highest number requested. If the child failed to give N, the next request was for N-1, with 1 being the lowest number requested. The task continued in this way until the child had at least two successes at a given number, N, and at least two failures at N+1. Errors counted against both numbers involved. For example, if a child was asked for "three bananas" but gave five, this was counted as evidence against the child's understanding either the number three or the number five.

Results and Discussion

Give-N Results

A child was given credit for "knowing" a number if he or she produced at least twice as many correct responses as errors for that number (including both types of error, as described above). Each child was then assigned a number-knower level, reflecting the highest number reliably generated. For example, children who reliably generated sets of 1 or 2, but not 3 objects, were called two-knowers. Children who succeeded at the highest set sizes (5 and 6) were called cardinality-principle (CP)-knowers. Children who failed to give even one object upon request were excluded from further analysis. (For detailed discussion of these coding categories and of number-knower levels as an analytical framework, see Carey, 2009; Sarnecka and Lee, 2009; Lee & Sarnecka, 2010; in press.)

This sorting yielded 8 one-knowers, 10 two-knowers, 14 three-knowers, 5 four-knowers, and 12 CP-knowers. Nine children failed to produce even sets of one; these children's data were excluded from further analyses. There was a correlation between knower level and age, Spearman's rho=.360, p=.006, one-tailed, reflecting the fact that older children knew more number words than younger children.

Word-Extension Results

Number trials. A univariate ANOVA looking at performance on number word trials (collapsed across Trial Types A and B) with age as a covariate shows a significant effect of knower level, reflecting the fact that children at higher number-knower levels were better able to match pictures by number, $F(4, 43)=2.43$, $p=.05$, $\eta^2=.22$ (meaning, approximately 22% of the variability was accounted for by knower level). The tendency for older children to perform better than younger ones, independent of knower level, was not significant, Pearson's $r=.16$, $p=.13$, one-tailed.

Tukey post-hoc comparisons indicate that performance did not differ between one- and two-knowers or between three- and four-knowers, ps<.05 ns. The following analyses merge across these non-significant distinctions creating a total of three groups: one- and two-knowers (n=18), three- and four-knowers (n=19), and CP-knowers (n=12).

When comparing performance to chance we see that the only group to succeed robustly on the number trials were CP-knowers, $t(11)=4.78$, $p=.001$, $\eta^2=.68$. The three- and four-knowers answered correctly approximately 60% of the time, $t(18)=2.07$, $p=.053$, $\eta^2=.19$, a rate that is not quite higher than chance using a Bonferroni adjusted alpha level of .017 ($\alpha=.05/3$ groups). One- and two-knowers' performance was firmly at chance, $t(17)=.60$, $p=.55$ns, $\eta^2=.02$. See Figure 3.

Color/mood trials. A univariate ANOVA controlling for age shows no significant difference in performance (collapsed across Trial Types C, D, and E) between the three knower-level groups, $F(2, 43)=1.02$, $p=.39$ns, $\eta^2=.06$. Children in all groups succeeded at matching pictures by mood and color, ps<.001, $\eta^2\geq.80$ (see Figure 3).

Within-subjects analyses show that children in all groups were more likely to succeed on color trials (M=.99, SD=.05) than mood trials (M=.82, SD=.31),t(48)=3.87, p<.001, η^2=.24. Furthermore, when looking at all trial types in which color or mood was presented as a distracter variable (Trial Types B and D) children found it more difficult to ignore color (M=.57, SD=.38) than mood (M=.84, SD=.26), resulting in poorer performance on those trials where color was a distracter, t(48)=3.87, p<.001, η^2=.24. This finding raises the question of whether the high salience of color might have prevented the children in the lower knower levels from displaying their nascent number knowledge. That is, the children's attention may have been drawn to the dimension of color, so much so that they did not express any number knowledge they may have. Experiment II sought to replicate the results of Experiment I, using pictures where mood was more salient and color less so. Experiment II also included several new number trial types to further investigate children's extension of number words to numerosity.

Experiment II

Method

Participants

Participants included 58 children (29 girls, 29 boys) ranging in age from 2;6 to 4;0 (mean 3;4) drawn from the same population as in Experiment I.

Procedure

Word-Extension Task. This task was the same as Experiment I, but with three changes. First, the stimuli were altered. To make color less salient, only certain features of the drawing were colored (such as the fish's fins or the flower's petals) instead of the entire item. To make mood more salient, larger and more expressive eyes were used. Happy drawings had large, open eyes with high eyebrows. Sad drawings had downward-turned eyes and small tears.

The second change was in the assignment of area- and contour-length-distracter trials. Whereas in Experiment I each child was assigned to one of two conditions (one with area distracters, the other with contour-length distracters), all children in Experiment II received both types of trial. This allowed for a within-subjects comparison of area vs. contour length as a distracter dimension. (Indeed, comparisons of performance across Condition A and B from Experiment I suggest that CP-knowers were more likely to extend number words to matches on summed area than to matches on summed contour length, $t(10)=4.74$, $p=.001$, $\eta^2=.69$. Although likely the result of a random effect caused by small sample sizes, n=9 CP-knowers in the contour-length condition; n=3 CP-knowers in the area condition, the design for Experiment II was modified to further address this finding.)

The third change was the addition of several new types of number trials with different combinations of distracters (see Table 1 for descriptions and number of trials for each Trial Type). Each child received a total of 24 trials, presented in one of two pseudorandom orders.

Give-N Task. This task was the same as in Experiment I and was administered immediately after the Word-Extension task.

Results and Discussion

Give-N Results

First, children were sorted into knower levels using the same criteria as in Experiment I. Among the 58 children, there were 13 one-knowers, 7 two-knowers, 11 three-knowers, 4 four-knowers, and 14 CP-knowers. Seven children failed to give even 1 object reliably, these children's data were excluded from further analyses. Two additional children were tested but decided to stop playing before completing the Give-N task; these children's data were also excluded from subsequent analyses. As in Experiment I, knower level was correlated with age (reflecting the fact that older children tended to know more numbers), Spearman's rho=.41, p=.002, one-tailed.

Word-Extension Results

Similar to Experiment I, there was a significant main effect of knower level (controlling for age) on performance on the number trials, indicating that children at higher knower levels were more successful at matching pictures by number, $F(4,43)=8.06$, $p<.001$, $\eta^2=.48$. There was a non-significant tendency for older children to perform better than younger ones, independent of knower level, Pearson's $r=.21$, $p=.07$, one-tailed. Tukey post-hoc comparisons show that performance did not differ between one- and two-knowers, or between three- and four-knowers, $ps<.05$. In subsequent analyses these levels were merged, forming a total of three groups: one- and two-knowers (n=20), three- and four-knowers (n=15), and CP-knowers (n=14).

Replicating Experiment I, we see that all groups performed above chance on trials where pictures were matched by color or mood ($ps<.001$, significant with adjusted alpha levels of .017 ($\alpha=.05/3$ groups), $\eta^2\geq.70$).

On number trials, CP-knowers again performed significantly above chance, $t(13)=3.06$, $p=.009$, $\eta^2=.42$. However, one- and two-knowers as well as three- and four-knowers performed *below* chance on number trials, $t(19)=-5.12$, $p<.001$, $\eta^2=.58$ and $t(14)=-2.49$, $p=.026$, $\eta^2=.31$, respectively. These results indicate a significant (or at least marginally significant, using an adjusted alpha level of .017) tendency to actively match pictures on the distracter dimension (color or mood, when either was available) rather than on number. See Figure 4.

Analyses of different trial types. Of particular interest was the performance on Trial Type G, where children were prompted to match pictures by number and where the correct response picture matched the target not only in numerosity, but also in area and contour length. In other words, all three quantitative dimensions of interest (i.e. area, contour-length, and numerosity) were allowed to covary, so that children could have succeeded by matching on any of them. These trials were important because they offered a test of the hypothesis that non-CP-knowers may understand number words as referring to *some* quantitative dimension, but are unsure exactly what specific dimension that is. However, the results did not support this interpretation. On Type G trials, only CP-knowers showed any sign of succeeding, $t(13)=2.47$, $p=.03$, $\eta^2=.32$, (see Figure 5), marginally significant when compared to an adjusted alpha level of $\alpha= .017$ ($\alpha=.05/3$groups). One- and two-knowers, as well as three- and four-knowers, performed significantly below chance, $t(19)=-2.97$, $p=.008$, $\eta^2=.32$ and $t(14)=-3.15$, $p=.007$, $\eta^2=.41$, respectively, indicating that they actively matched pictures on color or mood rather than number.

Also interesting were trials of Type F. On these trials, number was the *only* possible basis for matching, because neither of the response pictures matched the target in area, contour-length, color or mood. On these trials, CP-knowers were again the only group to succeed, $t(13)=3.80$, $p=.002$, $\eta^2=.53$ (see Figure 6). With no distracter variable, one-, two-, three- and four-knowers all performed at chance, $t(19)=-.698$, $p=.49$ns, $\eta^2=.03$ for one- and two-knowers; $t(14)=.000$, $p=1.00$ns, $\eta^2=.000$ for three- and four-knowers.

No group (including the CP-knowers) performed above chance on trials where number was pitted against both mood and color at the same time (Trial Types I and J). In other words, although CP-knowers could ignore matches on either color or mood in order to attend to number, a match on both color and mood together overwhelmingly drew their attention.

Within-subjects analyses comparing trials with area distracters to those with contour-length distracters found no significant differences ($ps>.05$ns) for any group. Thus, the finding from Experiment I (that CP-knowers were more likely to extend a number word to sets with matching in area than to sets in matching contour length) was not replicated. Indeed, there was no evidence that children (of any knower-level group) actively matched pictures according to spatial extent (area or contour length) when given a number word.

Finally, it may be worth noting that, as in Experiment I, all knower-level groups successfully matched sets by color and mood ($ps<.001$, $\eta^2 \geq .45$) even when they had to ignore the other dimension (i.e., they had to ignore color on the mood trials, and mood on the color trials), $ps \leq .001$, $\eta^2 \geq .70$, significant with an adjusted alpha level of .017. The changes to stimuli for Experiment II (making mood more salient and color less so) had the intended effect: children were actually more successful at matching pictures by mood than by color, $t(48)=3.39$, $p=.001$, $\eta^2=.19$, and they were able to ignore both color and mood as distracters.

General Discussion

Results from the present study show that children fail to extend number words (*four, five, eight* and *ten*) from one set to another based on numerosity until they understand the cardinality principle of counting. Importantly, their difficulty was not in understanding the task or in extending words in general, as these same children did extend color and mood words appropriately. Cardinal-principle-knowers, on the other hand, succeeded robustly on this task. Even without counting the items, CP-knowers understood that two sets of the same numerosity should be labeled by the same number word, whereas sets of different numerosities should be labeled by different number words.

Although these findings are inconsistent with the idea that the link between number-words and numerosity may guide and constrain the acquisition of individual number-word meanings, it is entirely possible that, prior to learning the cardinality principle, children may understand number words are contrastive and change only when items are added or removed from a set (by these means consistent with Wynn (1992) and Sarnecka and Gelman's (2004) findings). For example, if a child is told that a set of items is *five*, that child may know (because they know that number words are about quantities) that adding or subtracting items will change the number word label, whereas rearranging the items will not. Extending the word *five* to another set, on the other hand, requires an understanding about one-to-one correspondence between sets and its role in making sets numerically equal (see Sarnecka & Wright, 2011 for a detailed discussion). Thus, children could know that number words pertain to quantity without understanding how to assign a number word to a set, or how to extend a number word from one set to another. Then, as they figure out the cardinality principle of counting, children come to understand how a number words are assigned (i.e., through counting). Perhaps at the same time, they also come to see how two sets with the same number are related.

This demonstration of within-child consistency on two very different tasks (the Give-N task and the Word-Extension task) is one form of evidence that the shift from the earlier to the later conceptual system (i.e., from non-cardinal-principle-knower to cardinal-principle knower and thus from failure to success on the numerosity-based word-extension task) is an example of real conceptual change (Carey, 2009). As such, it is intrinsically interesting. But, needless to say, describing a case of conceptual change is not the same as explaining how it occurs. Indeed, the present, correlational findings leave open the question of whether children's understanding of the cardinality principle of counting (a) causes, (b) is caused by, (c) coincides with, or (d) *is the same thing as* their understanding that number words pick out numerosities.

Some support for (c) or (d) is suggested by the present study's finding that three- and four-knowers may have some nascent and fragile grasp of the idea that number words pick out numerosity during the period leading up to the cardinality-principle induction. This is indicated by non-significant trends of better performance on number trials by children at higher knower-levels (that is, a trend of three- and four-knowers performing better than one- and two-knowers). (See Sarnecka & Carey, 2008 for a similar finding of partial-cardinality knowledge in four-knowers.) While their performance hardly compares to the robust success by cardinality-principle knowers, it does confirm the commonsense observation that the shift from one conceptual system to another does not happen in a single instant. Although cross-sectional studies inevitably give the impression of a sharp boundary between children before and after the shift, this shift is a process that takes place in real time.

Regardless of how suddenly or gradually it is acquired, however, the present study shows that the acquisition of cardinality/numerosity brings profound changes the child's understanding of number. The evidence presented here will contribute to the discussion, but it is left to future studies to determine *how* children move from the earlier understanding of numbers and counting to the later one and to determine how the concepts of cardinality and numerosity (if indeed they are two separate concepts) are related in development.

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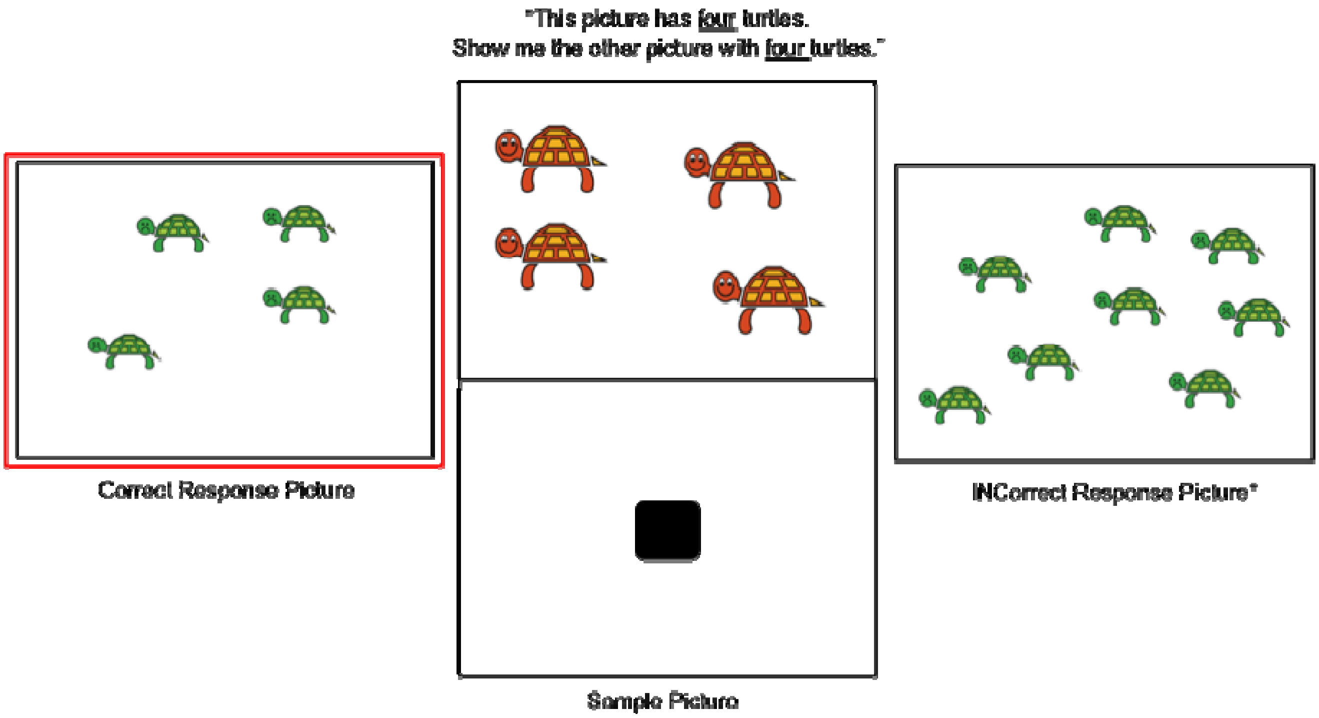
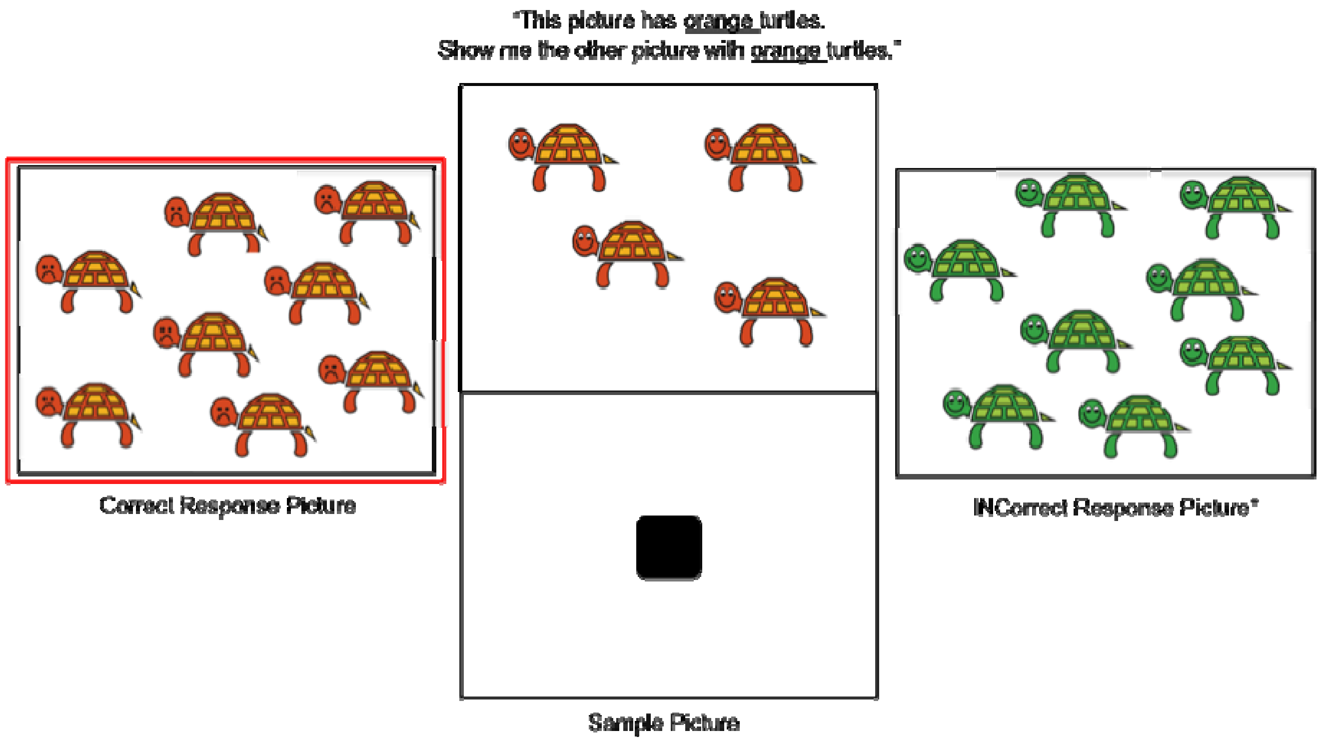
Figure 1. Example of Number Trial (Trial Type B).



* *For this example the incorrect response picture matches the sample picture on total area. Other number trial types included a response picture that either did not match the sample picture on any dimension (Experiment II only) or matched the sample picture on total contour length, color, and/or mood.*

Figure 2. Example of Color Trial (Trial Type D).



** In this example, the incorrect response picture matches the sample picture on mood. Other color trial types included a response picture that either did not match the sample picture on any dimension, or matched the sample picture on number.*

Figure 3. Results of Experiment I (includes mean results from all six color/mood trials and all six number word trials).

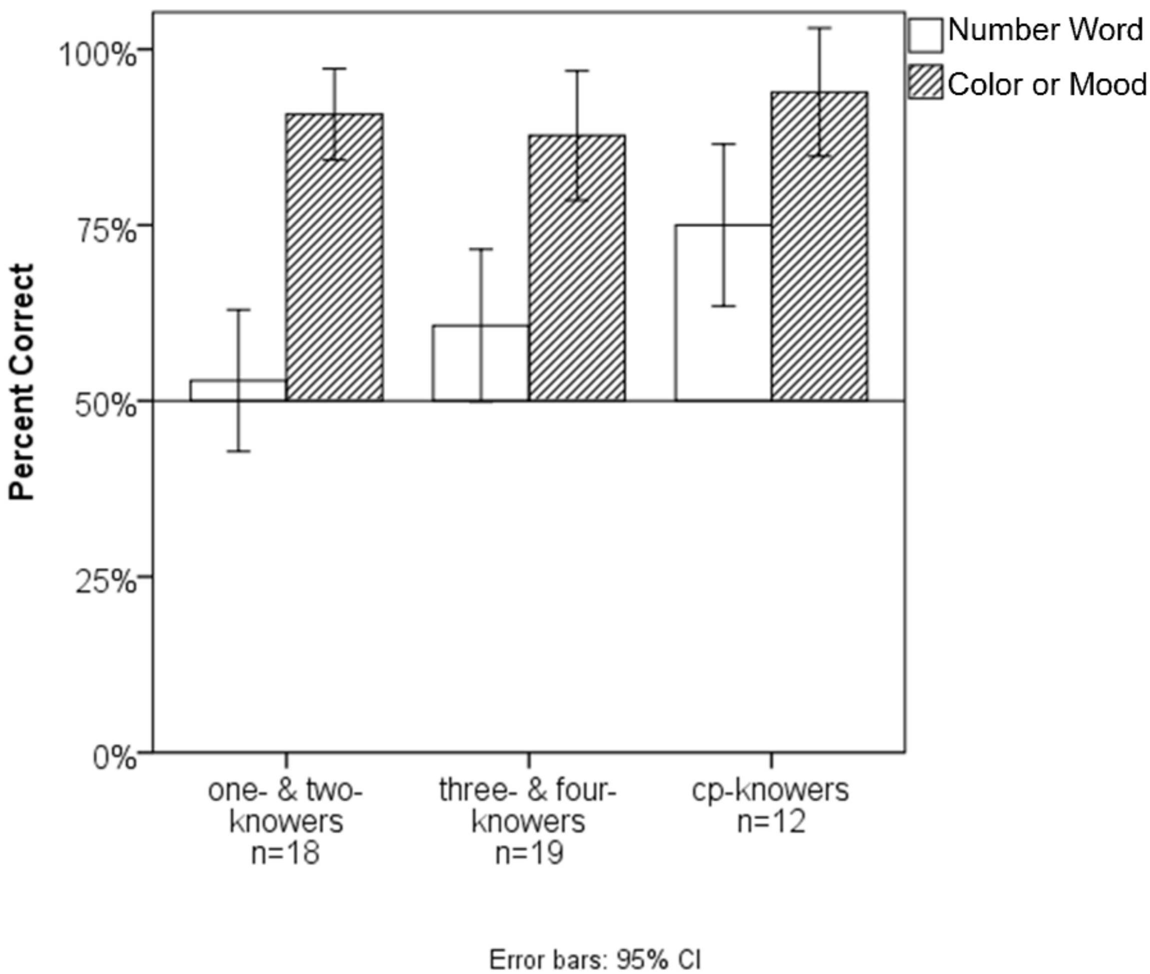


Figure 4. Results of Experiment II (includes mean results from all six color/mood trials and all 18 number word trials).

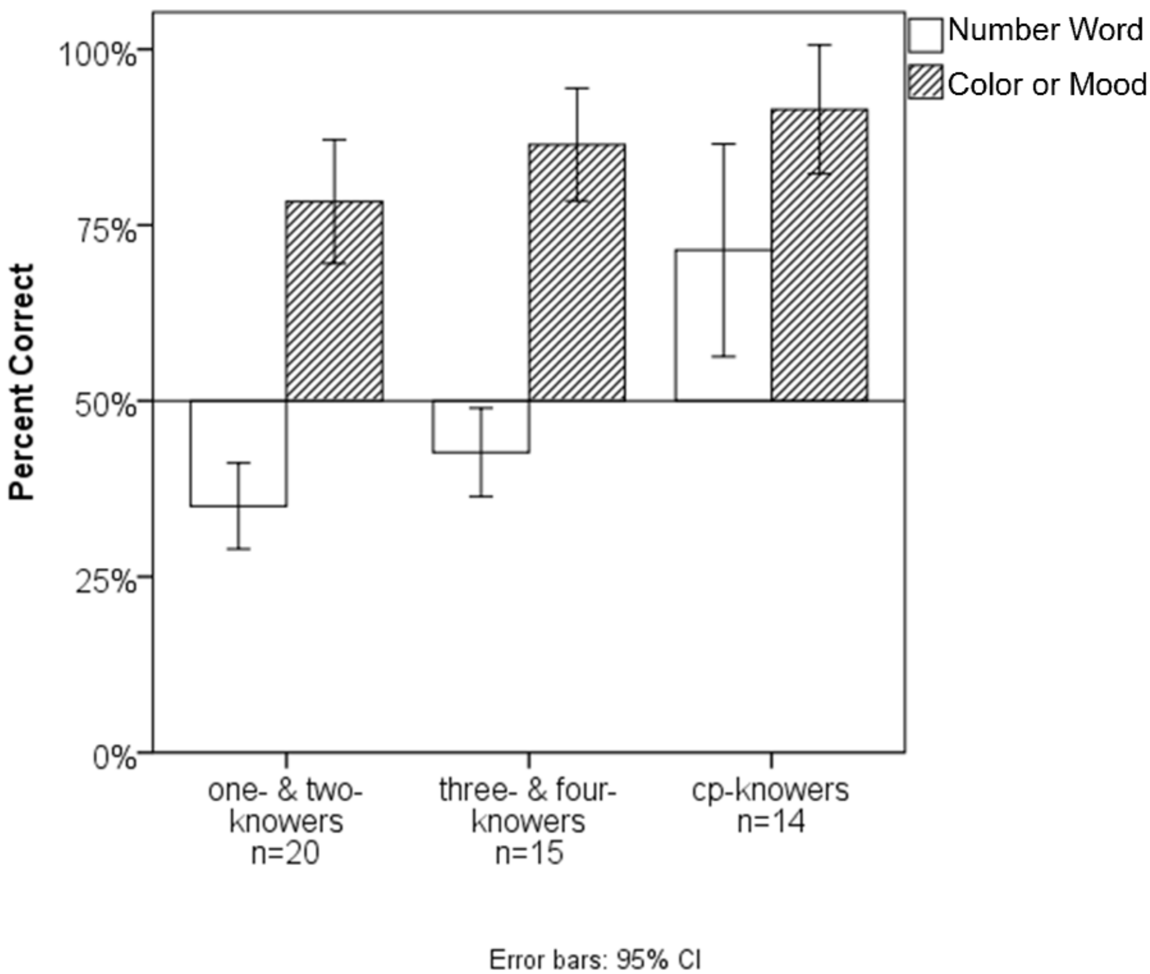
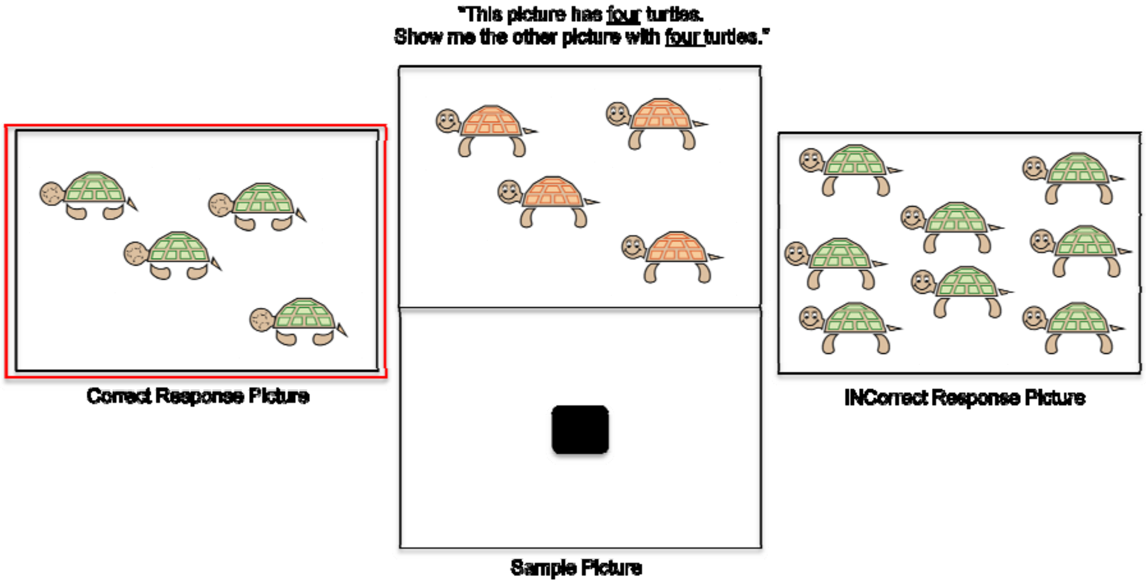


Figure 5. Results of Trial Type G (Correct choice matches on number, area and contour length. Distracter matches on color or mood). Mean results from all four trials.



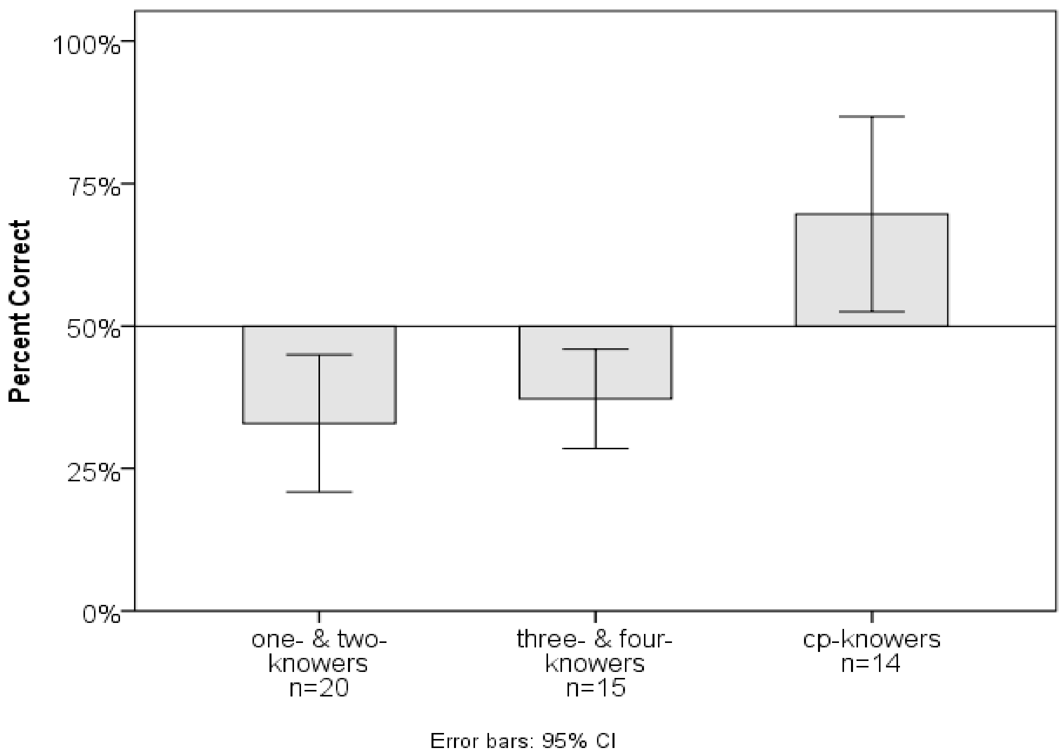


Figure 6. Results of Trial Type F (Correct choice matches on number only. Distracter does not match on any dimension). Mean results from both trials.

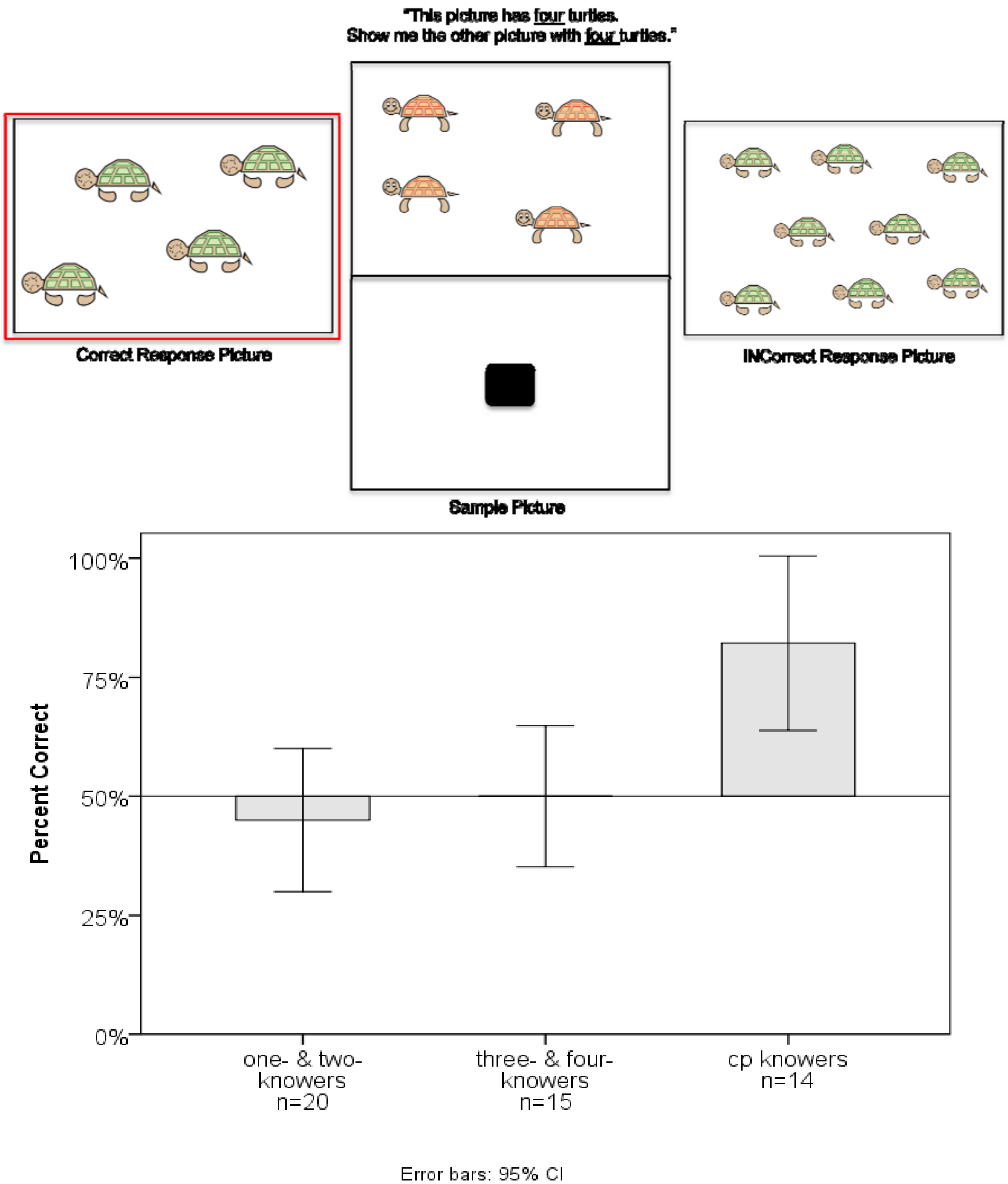


Table 1. *Trial types (Experiments I and II).*

Trial Type	**Requested Match**, Distracter	Experiment (Number of Trials)	Response Pictures Match on: Color or Mood	Contour or Area*	Number
A.	**Number** Area or Contour-Length Distracter	I (4 trials) II (2 trials)		✓	(✓)
B.	**Number** Area or Contour-Length *and* Color or Mood Distracter	I (2 trials) II (4 trials)	✓	✓	(✓)
C.	**Color or Mood** Number Distracter	I (2 trials) II (2 trials)	(✓)		✓
D.	**Color or Mood** Color or Mood Distracter	I (2 trials) II (2trials)	✓/(✓)		
E.	**Color or Mood** (distracter does not match)	I (2 trials) II (2 trials)	(✓)		
F.	**Number** (distracter does not match)	II (2 trials)			(✓)
G.	**Number *and*** **Area/Contour Length** Color or Mood Distracter	II (4 trials)	✓	(✓)	(✓)
H.	**Number** Color or Mood Distracter	II (2 trials)	✓		(✓)
I.	**Number** Color *and* Mood Distracter	II (2 trials)	✓		(✓)
J.	**Number** Color *and* Mood *and* Area or Contour Length Distracter	II (2 trials)	✓	✓	(✓)

NOTE. Check marks indicate that one of the response pictures matched the sample on that dimension. Circled check marks show the correct (requested) match; plain check marks show the alternative (distracter) match.

*In Experiment I, children were assigned to one of two conditions— in one condition, area was controlled; in the other condition, contour length was controlled. In Experiment II, each child received both types of trial.

Appendix A. *Mean performance (percent correct for each trial type.*

Trial Type	Description	Experiment (Number of Trials)	Knower level One- & Two-	Three- & Four-	CP
A.	**Number** Area or Contour-Length Distracter	I (4 trials) II (2 trials)	57% 50%	61% 67%	83%* 68%
B.	**Number** Area or Contour-Length *and* Color or Mood Distracter	I (2 trials) II (4 trials)	44% 36%†	61% 37%	58% 75%
C.	**Color or Mood** Number Distracter	I (2 trials) II (2 trials)	94%* 78%*	87%* 80%*	96%* 86%*
D.	**Color or Mood** Color or Mood Distracter	I (2 trials) II (2trials)	86%* 73%*	87%* 90%*	88%* 93%*
E.	**Color or Mood** (distracter does not match)	I (2 trials) II (2 trials)	92%* 85%*	89%* 90%*	96%* 96%*
F.	**Number** (distracter does not match)	II (2 trials)	45%	50%	82%*
G.	**Number *and*** **Area / Contour Length** Color or Mood Distracter	II (4 trials)	33%†	37%†	70%
H.	**Number** Color or Mood Distracter	II (2 trials)	28%†	40%	75%*
I.	**Number** Color *and* Mood Distracter	II (2 trials)	18%†	33%	57%
J.	**Number** Color *and* Mood *and* Area or Contour Length Distracter	II (2 trials)	20%†	33%	68%

* Performance is significantly above chance, $p<.017$ (Bonferroni alpha adjustment, $\alpha=.05/3$ groups)

† Performance is significantly below chance, $p<.017$ (Bonferroni alpha adjustment, $\alpha=.05/3$ groups), indicating that children were actively choosing the distracter.