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Children's Acquisition of the Number Words and the Counting System

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This paper examines how and when children come to understand the way in which counting determines numerosity and learn the meanings of the number words. A 7-month longitudinal study of 2 and 3 year olds shows that, very early on, children already know that the counting words each refer to a distinct, unique numerosity, though they do not yet know to *which* numerosity each word refers. It is possible that children learn this in part from the syntax of the number words. Despite this early knowledge, however, it takes children a long time (on the order of a year) to learn how the counting system represents numerosity. This suggests that our initial concept of number is represented quite differently from the way the counting system represents number, making it a difficult task for children to map the one onto the other. © 1992 Academic Press, Inc.

INTRODUCTION

How humans come to learn about the counting system of their culture is closely related to the nature of our initial representation of number, because in order to understand counting we must somehow relate it to our prior number concepts. Thus, studying children's developing understanding of counting may shed light on the nature of our early mathematical knowledge. In order to understand the counting system—that is, to know how counting encodes numerosity—children must know the meanings of (some of) the number words. They must also know, at least implicitly, that each word's position in the number word list relates directly to its meaning—the farther along a word occurs in the list, the greater the numerosity it refers to. Without this knowledge, though children might

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understand the meaning of a given number word, they would not understand how *counting* determines which number word applies to any given collection of counted entities. Thus children's developing knowledge of the meanings of the number words is a central part of their understanding of the counting system.

We know that children have some concept of numerosity, which they must have in order to learn the meanings of the number words. Infants are able to discriminate small numerosities; when habituated to pictures of three objects, they will dishabituate when shown a picture of two objects, and vice versa (Antell & Keating, 1983; Starkey & Cooper, 1980; Strauss & Curtis, 1981), and under some conditions will also distinguish 3 from 4 (Strauss & Curtis, 1981). Furthermore, Starkey, Spelke, and Gelman (1983, 1990) showed that they are able to match a number of sounds heard with a visual display depicting the same number of items (but see Moore, Benenson, Reznick, Peterson, & Kagan, 1987, for contradictory evidence). There is also evidence that 2½ year olds can perform inductions over small numerosities. In one experiment, children of this age were shown two plates, one with three toy mice on it identified as the "winner" plate, and one with two mice identified as the "loser" (Gelman, 1977). Children were capable of identifying the winner plate, and sometimes even changed a two-item plate to be a winner plate by adding an extra mouse, showing that they had represented the number of the array.

The problem that children must solve, then, is that of mapping these number concepts onto words. In this, children are faced with the problems inherent to any word-learning task—from an infinity of logically possible meanings, they must somehow infer the correct meaning of a word. This is made more difficult for children by the fact that the number words do not refer to individual items, or to properties of individual items, but rather to properties of sets of items. Yet when we count, we assign a number word to each item, so the child sees an individual item labeled "one," another "two," another "three," etc. Given children's tendency in such situations to take novel words as names for kinds of *individual* objects or their properties (e.g., Markman, 1989), it would seem an especially difficult hurdle for children to learn that the number words refer to properties of sets of entities.

Of course, children hear number words not only in the context of counting; they also hear them uttered in sentences, with all the accompanying semantic and syntactic cues. It has been shown that children can (at least sometimes) learn about the meanings of words when those words are contrasted with known words in the same domain. For example, when asked to "get the tray; not the red one, the chromium one," about half the children inferred that the word "chromium" refers to a color, since it was contrasted with "red," which the children already knew was a color word

(Carey & Bartlett, 1978). But this only helps when children *already* know the meaning of one of the words in a domain. It will not explain how children learn their first word or words belonging to that domain.

It could be that the syntax of the number words tells children that they refer to properties of *sets* of entities, not of individual entities. But when number words are used in sentences, their syntax, at least at first glance, would seem to support the hypothesis that they refer to properties of individual objects, since number words usually occur in the same position as adjectives (e.g., "see the *big* dogs" versus "see the *three* dogs"). Thus, if the syntax of the number words helps children to determine their meanings, it must be through their possession of a unique configuration of several syntactic properties, not of some single syntactic property, and as such will entail sophisticated knowledge on the part of the child.

1. Some Theories of Number Word Meaning Acquisition

"Counting Principles" Theory

Gelman and colleagues (e.g., Gelman & Gallistel, 1978; Gelman & Greeno, 1989; Gelman & Meck, 1983; Gelman, Meck, & Merkin, 1986) have proposed that young children possess an innate concept of number consisting of a set of counting principles that define correct counting. The three "how-to-count" principles are as follows: The *one-to-one correspondence* principle states that items to be counted must be put into one-to-one correspondence with members of the set of number tags that are used to count with (e.g., a set of number words); the *stable-order* principle states that the number tags must have a fixed order in which they are consistently used; and the *cardinality* principle states that the last number tag used in a count represents the cardinality of the items counted. Children do not possess innate knowledge of the number *words,* of course; they must learn the number words of their language, and map them onto their own innately given ordered list of mental number tags. This task is, however, made easy for children by the fact that number words are used in accordance with the same principles as their mental number tags—they have a fixed order in which they are consistently used, and they are applied to items in one-to-one correspondence. This allows children very early on to identify the linguistic, culturally supported counting activity as *counting* (i.e., as the same kind of activity as their own innate, nonlinguistic counting activity), and to relate the list of number words to their list of mental number tags. They are still, of course, faced with the task of learning which word goes with which tag, which requires memorizing the order of the number words. Once children relate overt counting to the nonlinguistic, innate counting activity, the counting principles allow children to develop their skills in the overt counting activity, by serving as guidelines for correct counting so that children can monitor their counting performance.

However, contrary to what would be expected on this view, there is converging evidence that children learn how to count quite well, and learn the meanings of some of the number words, *before* learning that counting determines the numerosity of a set—before connecting overt counting with any algorithm for determining numerosity that they might possess (e.g., Frye, Braisby, Lowe, Maroudas, & Nicholls, 1989; Fuson, 1988; Wynn, 1990). It thus appears that children do not start out with unlearned counting principles that lead them to the meanings of the number words and guide the acquisition of their counting skills. Rather, children must learn how to count, and must learn the meanings of the number words by some means other than their correspondence to a set of mental counting tags.

A note about terminology is in order here. Gelman and Gallistel's (1978) "cardinality principle" specifies that the last number *tag* used in a count represents the number of items counted, be it a verbal tag such as a number word, or a nonverbal tag used in a mental counting procedure. I distinguish these two senses of the cardinality principle, calling the former the "cardinal *word*" principle and the latter the "cardinal *tag*" principle (Wynn, 1990), for the following reason: We may be equipped with an innate counting procedure that honors the cardinal tag principle, yet which is not available to conscious inspection and so cannot inform the linguistic, culturally supported counting activity. These principles should also be distinguished from what Fuson (e.g., 1988) has termed "last-word responding," which describes the behavior of repeating the last number word used in a count when asked "how many" after counting, whether or not this behavior is due to knowledge of the cardinal word principle.

"Different Contexts" Theory

Fuson and colleagues (e.g., Fuson, 1988; Fuson & Hall, 1983; Fuson & Mierkiewicz, 1980; Fuson, Richards, & Briars, 1982) have argued that the number words have different meanings in different contexts, and that children sequentially acquire these different meanings, learning each number word at first as several different context-dependent words. These different meanings gradually become interrelated. Of most relevance here are the *sequence, counting,* and *cardinal* "meanings," or contexts, of number words. *Sequence* meanings occur in contexts in which the number words are recited in sequence, but not used to count actual items or to refer to the numerosity of some set of items. The "meaning" of a number word in this context is that it comprises part of this sequence; the words have no referents. The evidence for such a stage is that in children's earliest productions of the number word list, they treat the words as an unbreakable string, a sequence of sounds with no intrinsic meaning, recited by rote. The number words take on a *counting* meaning when used to count a group of items. The "meaning" of number words in this context is their successive assignment to items in a one-to-one correspondence, and the referent of a number word is the item it is paired with; thus, the referent of a particular number word differs with each count, in the same way the referent of a pronoun differs from sentence to sentence. The evidence that children go through such a stage in their understanding of the number words is that 2 and young 3 year olds can count correctly (can segment the number words and assign each one to a unique object) before knowing that the last number word indicates the numerosity of the counted set (Fuson & Mierkiewicz, 1980; Wynn, 1990). A number word is used in a *cardinal* context when it is used to describe the cardinality, or numerosity, of a set of discrete objects or events; in this context, the referent of a number word is the numerosity described. Children do not come to this understanding of the meanings of number words until well after they are able to count correctly. (Note that knowledge of the cardinal meaning of a number word does not necessitate knowledge of the cardinal word principle. A child can know about the cardinality three, for example—that it is more than two, less than four, that its name is "three", and so on—without knowing that the last number word in a count indicates the numerosity of items counted.)

However, there is evidence that children do *not* undergo a stage where they believe the referent of a number word is the object to which it is assigned. In the "Give-a-number" task of Experiments 2 and 3 of Wynn (1990) 2½ to 3½ year olds were asked to give a puppet one to six items from a pile of toy animals. If children consider the meaning of the word "three" (for example) to be an object to which it is assigned during a count, then they presumably should count some objects and, when they get to "three," give the puppet the item labeled "three." Alternatively, they might choose to give the puppet a single animal while labeling it "three." But not a single child behaved this way. Instead, the younger children tended to simply give the puppet a handful of animals, almost never by counting them; the 3½ year olds tended to count items from the pile as they gave them and to stop at the number word asked for, thus giving the correct number. Even children who were just learning to count almost never gave the puppet a single item when more than one item was asked for. In contrast, children *always* gave the puppet a single item when asked for one item. Thus, the children imputed a different meaning to number words than their assignment to an object.

It might be argued that it was the syntactic cues of plurality or singularity ("Give Big Bird three anim*als*/one anim*al*") which caused children to give one when asked for one, and more than one otherwise, rather than an understanding of the number words. Children of this age do use plural marking correctly in their spontaneous speech (Brown, 1973). However, when asked to "give me the pencil/pencils", children of this age perform at chance, indicating that they do not attend to the English plural markers in the speech of others (Brown, 1973, p. 331). Thus, children's ability to give a single item when asked for one, and more than one item when asked for more than one, is probably due to an understanding that the number words other than "one" refer to pluralities of entities.

In apparent contradiction with this conclusion, when asked to count the items they had given, about half the children in the Give-a-Number task in Experiment 2 of Wynn (1990) labeled the last item in the count with the number word asked for when that was not the next count word they should have said. For example, when asked for five objects one girl gave three; when she was then asked to count them, she did so saying "one, two, five." This kind of response could have occurred because children thought the referent of the number word was a single item, and since the puppet had asked for, say, "five animals," they knew they had to label one of the animals "five." However, it is more likely that children simply knew that the last number word in their count should correspond to the word asked for, without knowing why—this would explain why they tended to label the *last* item in the count with the number word asked for, rather than just labeling any one of the items. Seeing parents and teachers emphasize the last word in a variety of counting activities could be enough for children to realize this. Two children (of 22) occasionally *labeled* one of the items they had given with the number word asked for, clearly assigning a single item as the referent of the number word. This would seem to suggest that, at least for these children, the meaning of the number word was either some aspect of, or a label for, the item to which it was assigned. However, these two children did so on only one and two of their four trials respectively, and they *always* honored the distinction between being asked for one item versus more than one, showing that at some level they knew that number words do not refer to properties of a single item. Clearly, more research is needed to resolve the question of what meaning children ascribe to a number word before acquiring the adult understanding.

2. Focus of the Study

Components of Meaning of Number Words

This study investigates how children's understanding of the meanings of number words develops—whether there is a stage at which children believe the number words refer to individual items, and if children's knowledge of a particular number word comes in all at once or if they acquire different aspects of the meaning of a number word at different times. Acquisition of the cardinal meaning of a number word may not come all in one piece; there may be different components of meaning (as opposed to different usage contexts) that children acquire at different times. There are two essential components to understanding the cardinal meaning of a particular number word:

(1) The knowledge that a number word refers to a *numerosity*, regardless of *which* numerosity it refers to;
(2) The knowledge of the precise numerosity a word refers to (its "cardinal meaning").

Furthermore, to learn the cardinal meanings of all the number words, one must also know that it is a word's position in the number word list that determines the numerosity it refers to (the cardinal word principle). This specifies the *way* in which the number words are assigned their meanings, rather than some aspect of meaning of individual words. One need not have knowledge of this last component in order to know the cardinal meaning of a particular number word. However, at some point every person must induce the general rule for how number words attain their cardinal meanings, in order to understand the iterative structure of the number word system and be able to generate the name for any number.

The "counting principles" theory predicts that children will possess the first item of knowledge at a very early age—as soon as they have made the connection between the list of number words and their own list of mental number tags. It also predicts children will have the second item of knowledge for all and only the number words within their counting range. A child could not be expected to know which numerosity the word "five," for example, refers to, if that child doesn't know where in the number word list the word "five" falls. But a child who can count up to five, and who knows that the words refer to numerosities, must know the specific numerosity that the word "five" picks out. The predictions of the "differing contexts" theory are less clear, but there should be a stage at which children know neither of the two items of knowledge, but think the meaning of a word is the individual item to which it is assigned.

Time Span of Acquisition of Number Words

There is also the question of how long it takes children to acquire the cardinal meanings of the number words and learn the counting system. It has previously been shown (Wynn, 1990) that by roughly 3½ years of age, children understand how the counting system determines numerosity (have learned the cardinal word principle), and have acquired the cardinal meanings of all the number words within their counting range (know which numerosity each word picks out). There are several stages along the way to this knowledge. Children appear to learn the cardinal meanings of smaller number words sequentially before learning the cardinal meanings of larger number words within their counting range—they can give 1 item from a pile when asked before they can give 2, can give 2 items before they can give 3, and can give 3 items before they can give higher numbers. However, before they can give larger numbers, children successful at giving these smaller numbers virtually *never use counting* to do so; they still do not know that counting is the general solution to the task. They appear instead to have directly mapped particular small numerosities onto their correct number words, and so can succeed at giving those numerosities, but have no general solution. Once they learn the way in which counting determines the numerosity of a set of items (the cardinal word principle), they acquire the cardinal meanings of the rest of the number words within their counting range, and so can give any number of items they are asked for.

It is not known how long it takes individual children to go through the above stages, because the data obtained so far are cross sectional and there is much individual variation—some children have acquired the cardinal word principle before their third birthday, while others nearing their fourth have yet to learn it. Knowing how long it takes children to understand this can give us an idea of how easy or difficult a task it is for children to acquire an understanding of the counting system. This in turn reflects on the nature of young children's initial representation of number, since their task in learning the counting system is to map their own concept of number, whatever it may be, onto the counting system. On the above "counting principles" theory, this should be a relatively short, straightforward process, since the linguistic counting system embodies a representation of number very similar in form to that which children are proposed to possess innately, making it a simple task for children to map their own list of mental number tags onto the number words.

If, however, acquiring an understanding of the linguistic counting system entails a very long, protracted period of learning, that would suggest that the counting system embodies a very different form of representation of number than the one the very young child possesses. The "accumulator" theory of representation of number (Wynn, in press) predicts that it should be a much more difficult process for children to learn the counting system. This theory posits that infants possess the same mechanism for determining numerosity that has been proposed (Meck & Church, 1983; see also Gallistel, 1990) to account for other animals' numerical abilities. In brief, the proposed mechanism works as follows: a pacemaker puts out pulses at a constant rate, which can be passed into an accumulator by the closing of a switch. Every time a new entity is experienced that is to be counted, the switch closes for a fixed brief interval, passing energy into the accumulator. Thus the accumulator fills up in equal increments, one for each entity counted. This mechanism represents numerosity in a very different way than do the number words in linguistic counting. It is the entire fullness of the accumulator, not the final increment alone, that represents the numerosity of the items counted. In this way number is *inherently* embodied in the structure of the representation, which is itself a magnitude value (the output value of the accumulator). In linguistic counting, number is not inherently represented in the structure of each individual linguistic symbol; rather, the symbols obtain their numerical meaning by virtue of their positional relationships with each other, and the final word alone represents the numerosity of the items counted. The way in which the linguistic counting system represents number is therefore quite different from the way in which the accumulator mechanism represents number, and it would be expected for children to take quite some time to learn how to map the one kind of representation onto the other.

This study investigates both how long individual children know the cardinal meanings of some of the number words before going on to learn the rest and learn how counting represents number, and when and how children learn different components of the meanings of number words.

METHOD

Subjects

Twenty 2- and 3-year-old children were tested. Fourteen (6 girls, 8 boys) were tested for a period of up to 7 months, with 5 to 8 weeks between each session; their mean age at the start of the study was 3;2, range 2;6–4;2. The remaining 6 children (3 girls, 3 boys) were tested for a period covering 2 months, with 1 month between sessions; their mean age at the start of the study was 2;11, range 2;7–3;3. Seven additional children were tested but not included as subjects; 4 because their attention span was too short for them to sit through the Point-to-*x* task described below, 2 because they did not satisfy the criteria necessary for participating in the Point-to-*x* task, and 1 because he was not available for testing beyond the first session and so did not contribute to the longitudinal aspect of the study.

Procedure

Four tasks were given to subjects. The Give-a-Number, How-Many, and Color Control tasks were given on one day, in counterbalanced order across children; the Point-to-*x* task was typically given one to three days (never more than 1 week) later.

"Give-a-Number" task. This task determined which number words children knew the cardinal meanings of. Twenty-seven toy animals (cows, donkeys, and two kinds of dinosaurs) 5 to 7 cm in length were placed in front of children in a pile. They were asked several times to give a puppet one to five items, and the highest number word they could succeed at consistently was determined. Children were given a sticker after each trial. They were first asked for 1 item and then for 2 items; depending on their success, they were then asked for 3 items, or asked again for 1 or 2 items. What children were asked for on a trial depended partially on their success in the previous trial; children who failed on a trial were next asked

for a numerosity at which they had previously succeeded. This served to determine the consistency of a child's performance on a particular numerosity, as well as to avoid discouraging children. The experimenter concentrated on the highest number a child succeeded at reliably and on the next highest number, to accurately determine that child's level of knowledge. Typically, children were asked three times for each of these numerosities, and once or twice for each of the others; the exact number of trials a child got depended on his or her consistency on particular numerosities.

The experimenter followed up children's responses by asking questions such as "Is that three?" and then "Can you count and make sure?" to give children every opportunity to correct their responses and exhibit knowledge of the cardinal meaning of a number word. Children were placed into one of four groups on the basis of their performance. Those who could give only a single item consistently were placed into Group 1; those who could give up to two items were placed into Group 2; those who could give up to three items went into Group 3; and those who could give up to four or more items went into Group 4.

"How-Many" task. Children were asked to count sets of two to six items, once for each set size, and were asked, immediately after counting, "so how many are there?" This tested children's knowledge of the cardinal word principle—whether they know that the last number word they used in the count indicates how many items there are. It also served as a measure of children's counting ability. Items were toy animals 4 to 7 cm long, glued 3 cm apart to a board in a linear arrangement. They were homogeneous within a set, different across sets.

"Point-to-x" task. Only children who succeeded at giving at least one item when asked in the Give-a-Number task, and who knew the four color words or the words "top" and "bottom" as tested for in the Color Control task below, participated. Children were shown cards (14 by 18 cm), each containing two pictures with different numbers of items on them, and were asked to point to the picture depicting a particular number of items (see Fig. 1 for examples of the stimulus design). Items on a card were the same kind in both pictures, but different colors, e.g., red dogs in one picture and blue dogs in the other. Items differed from card to card.

To test whether children knew the *precise* numerosity a word refers to, children were shown that numerosity paired with a numerosity one larger, and asked to point to the picture with that number of items. For example, to test if a child knew the cardinal meaning of the word "four," she was shown a picture of four balloons paired with one of five balloons and asked, "Can you show me the four balloons?" To test whether they knew that a particular word refers to a numerosity, even if they did not know to *which* numerosity the word refers, children were given a picture of that numerosity, paired with a picture of one item. Since all the children knew that the word "one" refers to a single item, then if they knew that, for example, the word "five" refers to a numerosity, they should infer that it does *not* refer to a single item since they already have a word for the numerosity *one*. (This reasoning assumes that children possess the *principle of contrast*, which states that no two words have the same meaning; see Clark, 1988 for discussion.) They should therefore be able to choose the correct picture by a process of elimination. In all of the pairs where one picture was of only a single item, the pictures depicted either sheep or fish, which have the same singular and plural syntactic forms, so children were given no syntactic cues as to which picture to choose (e.g., "Can you show me the three fish/the one fish?"). Because it has been shown that children have an inherent preference for choosing a container with more liquid over a container with less (Carey, 1977), suggesting there may be a more general underlying preference to choose something with "more," the individual items depicted in the "single-item" pictures were made larger than the individual items in the "plural-items" pictures, in an effort to increase their interest value. In the other pairs the proportionate difference in numerosity between the two pictures were less pronounced, so no such effort was made. (To

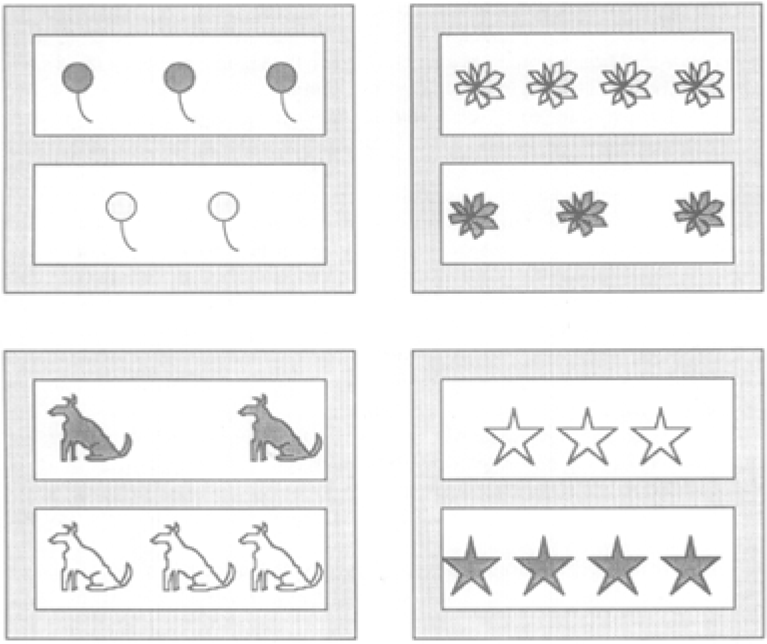

FIG. 1. Drawn examples of stimuli for Point-to-x task (not original stimuli).

preview the results below, it turned out that children had no inherent bias to choose either of the pictures over the other in any given pair.)

Each of the four groups were tested on different number pairs in the Point-to-x task, as shown in the first two columns of Table 1. For example, if a child could give up to two items in the Give-a-Number task, she was tested on the pairs (2, 3), (3, 4), (1, 3), (1, 4); so it was tested whether the child knew the *cardinal meanings* of the words "two" and "three," and whether the child knew *partial* meanings of the words "three" and "four" (whether the child knew they are *number* words).

For each number pair, children were asked twice to point to the smaller numerosity and twice to point to the larger (e.g., "can you show me the three flowers?"). They were also asked, twice for each pair, to point to the picture of a certain color (red, yellow, green, or blue), or to point to the top or bottom picture if that child had failed the color task (e.g.,

TABLE 1
Breakdown of Children into Groups and Pairs Tested on the Point-to-x Task

Group No. (determined in give-a-number task)	Pairs tested on in point-to-x task	Initial No. children	Mean ages	Total No. children
1	(1,2) (2,3) (1,3)	6	2;9	6
2	(2,3) (3,4) (1,3) (1,4)	6	2;11	9
3	(3,4) (4,5) (1,4) (1,5)	2	3;2	4
4	(4,5) (5,6) (1,5) (1,6)	6	3;6	11

"Can you show me the yellow sheep?"/"can you show me the bottom sheep?"). This served four purposes: (1) to prevent children who may not have known that, say, "five" is a number word from inducing that it must be, which might happen if all the questions were about numerosity and children were to pick up on this; (2) to help prevent children from becoming discouraged by giving them questions they definitely knew the answers to (since all children knew the meanings of these words from the Color Control task below); (3) to reveal whether children were attending to the task since, if so, they should get all these questions right; and (4) to make sure the task did not contain difficult task demands extrinsic to what was being tested for that would detract from children's performance (if so, children would be expected to perform below ceiling on the color questions). Finally, children were asked, twice for each number pair, a question with a nonsense word, e.g., "Can you show me the blicket elephants?", to measure any bias to point to a particular one of the pictures in any given pair. This made a total of 8 questions for each number pair altogether. There were two cards for each number pair, each picturing different items, for a total of eight cards (only six cards for Group 1). Thus, for each of the eight (or six) cards, children were asked to make four judgments; 2 number questions (once for the larger number, once for the smaller), 1 nonsense question, and 1 color (or top/bottom) question, for a total of 32 (or 24) questions altogether.

Order of presentation of cards and questions was randomized in the following manner: For each card, the questions to be asked about that card, and the order in which they were asked, were held constant. Cards were shuffled at the beginning of a session, and then were gone through in a first pass, asking the child the first question for each card. The cards were then shuffled and gone through a second time, asking the child the second question for each card; and so on in two more passes until all the questions were asked. After each pass through the "deck," children were given a sticker. Questions for the two cards of any given number pair were ordered such that the question for the smaller numerosity came before that for the larger numerosity on one card, and after that for the larger numerosity on the other.

Color control task. To make sure all children knew the meanings of the color words "red," "blue," "green," and "yellow" (or the words "top" and "bottom") for the Point-to-*x* task above, children were shown four balls simultaneously, one of each color, and were twice asked to point to the ball of each color (in one of two random orders). (Children who spontaneously named the colors correctly were asked to point to each of the colors only once, since correct production of a color word is a more definitive indication of knowledge than simply correct identification, which could be expected by chance 25% of the time). Children failing the color task were tested for knowledge of the words "top" and "bottom," by being shown four cards, each with two pictures on it, and being asked, for each one, to point to the picture on the top, or the picture on the bottom (twice the top, twice the bottom). Nineteen of the children knew the meanings of the four color words; the remaining child knew "top" and "bottom." Two additional children did not satisfy this criterion and were excluded from the study.

Each child was followed up until she could give up to five items when asked in the Give-a-Number task, succeeded on at least 75% of the questions for each of the number pairs in the Point-to-*x* task, and gave last-word responses a majority of the time on the How-Many task, or until the end of the school year.

RESULTS AND DISCUSSION

1. Scoring Criteria

Give-a-Number task. The following criteria were used to determine the highest number children could consistently succeed at giving:

1. On at least two-thirds of a child's trials for that numerosity, the child's response was either the correct number according to her own stably ordered count list,[1] or the correct number plus or minus one if the child had counted aloud from the pile to the number word asked for, but had erred in the counting by either double counting or skipping one item or by repeating or skipping one number word; and
2. The child responded with that number when asked for higher numerosities no more than half as often, percentage wise, as she did when asked for that number itself. For example, a child who gave two items 67% of the time (2 of the 3 trials) when asked for 2 was scored consistently correct on 2 only if she gave two items no more than 33% of the time when asked for three, four, and five items. This was to prevent children who had a preference for giving, e.g., two items no matter what they were asked for, from being considered to know the cardinal meaning of the word "two" (this happened on 12 of 58 trials).

Point-to-x task. A response was considered correct if the child pointed to the correct picture; *or* if she counted the items in one or both pictures in order to answer a number question, but made an error when counting the wrong picture such that the outcome of the count was the number she had been asked to show, and then chose that picture for her response (this only happened 10 times out of the total of 368 number questions given in the Point-to-x task where both pictures were of more than one item).

How-many task. Children were considered to give a "last-word" response if they gave the last number word they had used in the count, regardless of whether they had counted correctly or if that word was the correct answer. They were considered to have counted the set correctly if they made at most one of the following mistakes: double counting or skipping an item in the set, or repeating or skipping one number word of their own stably ordered number word list.

Color control task. If children failed one of the two questions for a given color, they were asked that question a third time (after some intervening questions). Children were considered to know the meaning of a color word if they got two questions for that color correct out of the two or three total questions for that word. They were considered to know the

[1] Some children have a stably ordered list of the counting words that differs from the standard list (Fuson & Mierkiewicz, 1980; Gelman & Gallistel, 1978). For example, a child may consistently count "one, two, five, six, ..." In this case, when asked to give, say, five items, the child would be considered correct is she gave three items, since "five" is the third word in her stably ordered list. As it turned out, all 20 children in this study used the standard count word list.

words "top" and "bottom" if they got both questions for each word correct.

The experimenter scored children's responses at the time of testing. Children's sessions were also videotaped, and then transcribed and scored later by an independent judge. Interscorer agreement was 97% for the Give-a-Number task, 97% for the Point-to-*x* task, and 93% for the How-Many task. Disagreements were resolved by discussion. Videotapes revealed that in three sessions (of a total of 58) children were originally miscategorized by the Experimenter into the wrong Group level, and hence tested with the wrong number pairs in the Point-to-*x* task; data for the Point-to-x task on these sessions were excluded from the analyses.

2. Preliminary Analyses

Performance on Nonsense and Color Control Questions

On the nonsense questions, children showed no preference to point to a particular one of the pictures on any given card, as determined by a series of t tests (one for each of the 30 cards) adjusted by the Bonferroni technique for the number of t tests performed. Nor was there any bias to choose a particular *number* in a number pair, when Bonferroni-adjusted t tests were conducted over number pairs rather than over individual cards. Nor, finally, did children have any bias to point to the larger or the smaller number of items, when a t test was conducted on the number of times children chose the larger numerosity as opposed to the smaller numerosity, across all cards and all number pairs (they chose the larger numerosity 194 times, the smaller numerosity 198 times). These results indicate that the children had no intrinsic biases affecting their responses that might contaminate the results of the questions asked about number.

In addition, individual children asked the experimenter for confirmation of their response (e.g., by saying "this one?" while pointing, or by asking before responding "which one is that?" etc.) on 13% of the nonsense questions on average, while doing this on only 2% of the color and number questions (there was no significant difference between color and number questions). For each child, the difference between these two percentages was computed. A t test showed they were significantly greater than zero, $t(19) = 4.149, p < .0001$. Children clearly distinguished between the nonsense words and the other words, indicating first that they were paying attention to the experimenter's questions, and second that even number words they do not know the cardinal meanings of are not considered in the same light as are nonsense words.

In the color questions of the Point-to-*x* task, children each made at most 1 mistake out of the 8 (or 6, for Group 1) such questions they were asked in each session. Altogether, only 12 mistakes were observed on the total of 392 color questions asked. This shows that the Point-to-x task does not contain severe task demands since even 2½ year olds can perform at ceiling, and that children were clearly paying attention to the task and giving answers that reflected their knowledge.

Breakdown of Children into Different Groups

The final three columns of Table 1 show the number and mean ages of children classified into each group in their initial session, and the total number of children observed at each Group level at least once during the study.

It was not poor counting abilities on the part of children in Groups 1–3 that prevented them from achieving a higher group level. In all cases, children could successfully count larger sets of items than they could give when asked. The largest set each child counted correctly in the How-Many task was determined for each session. Group 1 children's mean highest correct count was 4.8 items (range 3 to 6); Group 2 children's mean highest correct count was 5.7 items (range 4 to 6); and Group 3 children's mean highest correct count was 5.6 items (range 5 to 6). Thus children's ability to correctly give a certain number of items lags well behind their ability to successfully count that same number of items.

3. Acquisition of Components of Meaning

Children Know the Number Words Refer to Numerosities

For each of the Groups, individual children's percentages of correct number–question responses on each of the pairs $(1, n + 1)$ and $(1, n + 2)$ (where n is the group number of the child in that session) were determined. The percentage of correct responses expected if children do *not* know that the larger words are number words is 75%, because all children knew the cardinal meaning of the word "one" and so should succeed on the "show me the one . . ." questions, which made up half the number questions for these pairs. They should be expected to succeed on half of the larger-number questions by chance, for a total expected success rate of 75%. As it turned out, for both pairs in every group children succeeded significantly more often than this, as shown in Fig. 2. The t values are as follows: For Group 1, for the pair (1, 2), $t(5) = 8.301$, $p < .0001$, one-tailed; for the pair (1, 3), $t(5) = 2.764$, $p < .05$, one-tailed. For Group 2, all children performed perfectly on the pair (1, 3); for the pair (1, 4), $t(8) = 44.000$, $p < .0001$, one-tailed. For Group 3, for the pair (1, 4), all children performed perfectly; for the pair (1, 5), $t(2) = 5.250$, $p < .05$, one-tailed. For Group 4, for both pairs $t(10) = 21.917$, $p < .0001$, one-tailed. Thus, children know that the larger number words refer to numerosities before they know their cardinal meanings.

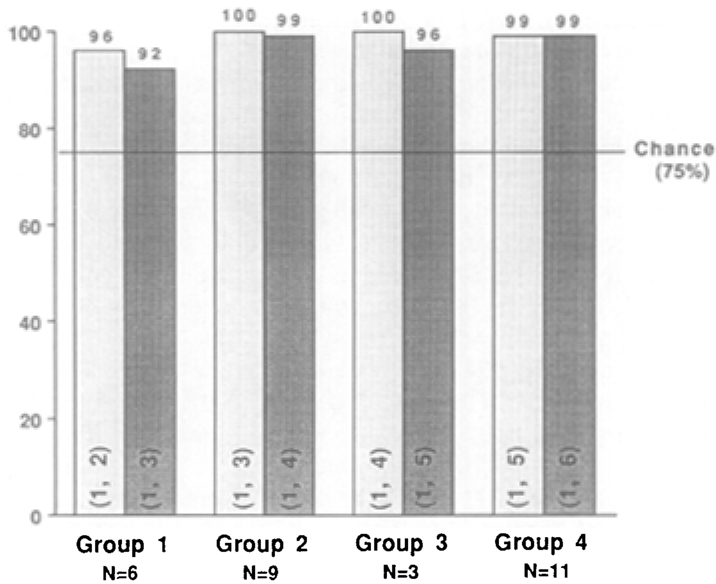

FIG. 2. Mean percentage of correct responses on number questions in Point-to-x task on ($1, n + 1$) and ($1, n + 2$) pairs.

What is really surprising is just how soon children seem to have this knowledge. Even the very youngest children (age 2;6), who could not successfully give even two items when they were asked to, could identify the picture of two items, and the picture of three items, when each of these was paired with one item. So even at a very early stage of counting, children know that the counting words refer to *numerosities*.

It appears that children know this well before knowing the cardinal meanings of the number words—their performance on the Point-to-x task, when tested for knowledge of the cardinal meanings of the number words, agrees with their performance on the Give-a-Number task. That is, in the Point-to-x task children show knowledge of the cardinal meanings of numbers they are consistently capable of giving in the Give-a-Number task, while they show no such knowledge of higher numbers.

To test this, in each Group individual children's percentages of correct responses were determined for each of the ($n, n + 1$) and ($n + 1, n + 2$) number pairs, and compared to the chance success rate of 50% by a separate t test for each number pair in each group. Performance on number *pairs*, rather than on individual numbers, was looked at because a child who knows the cardinal meaning of the word "two" (for example) should be able to not only get the questions for two items correct in the pair (2, 3), but also the questions for three items, since she knows already that "three" is a *number* word and therefore that it refers to some numerosity other than *two*.

The breakdown of these analyses by group level is shown in Fig. 3. As can be seen, each group succeeded more often than chance on the number pairs that tested knowledge of the highest number they could give in the Give-a-Number task, while performing at chance on the pairs testing knowledge of higher numbers. (Recall that children were placed in Group 4 even if they could give numbers higher than 4, and so they might be expected to succeed at identifying all the numbers tested for; analyses discussed below reveal that Group 4 children do indeed succeed on higher numerosities in the Give-a-Number task.) For Group 1's performance on the pair (1, 2), $t(5) = 18.183$, $p < .0001$, one-tailed. For Group 2's performance on (2, 3), $t(8) = 10.921$, $p < .0001$, one-tailed. For Group 3's performance on (3, 4), $t(2) = 4.000$, $p < .05$, one-tailed. For Group 4's performance on (4, 5), $t(10) = 6.516$, $p < .0001$, one-tailed; for their performance on (5, 6) $t(10) = 3.491$, $p < .005$, one-tailed. Thus, children are not succeeding at recognizing larger numbers in the Point-to-*x* task than they are capable of giving in the Give-a-Number task, though they are succeeding at the numbers they *can* give. This correspondence is evidence that both tasks really are valid indicators of the number words a child knows the cardinal meanings of.

An Alternative Explanation

The results from this part of the Point-to-*x* task might be explained without having to credit children with knowledge that the words other than "one" are number words. Children might know just enough about

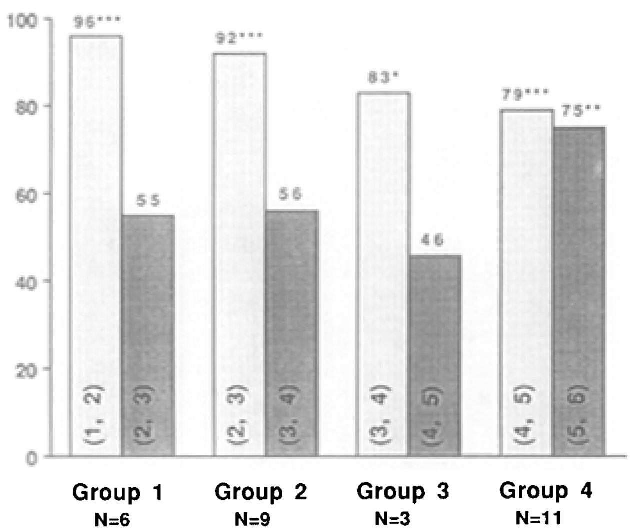

FIG. 3. Mean percentage of correct responses on number questions in Point-to-*x* task on (n, $n + 1$) and ($n + 1$, $n + 2$) pairs. *significantly greater than chance (50%) at .05 level, one-tailed; **significant at .005 level, one-tailed; ***significant at .0001 level, one-tailed.

the counting words to know that these words can only apply in the context of a plurality of entities (Fuson, personal communication). For example, a child might take the word "four" to refer to some property a single entity possesses when it is in the presence of other entities (something like "one in a bunch", for example), or to refer to some nonnumerical property that only applies to a collection of entities (like "crowded"). Alternatively, it could be that children believe that the words other than "one" refer simply to *any plurality,* like "several" or "bunch of," rather than each referring to a unique, specific numerosity.

The hypothesis that children are succeeding on this task because they know the words are *number* words (the "number word" hypothesis) makes a different prediction than do the alternative "individual-in-a-group" and "plurality" hypotheses. If children know that each of the number words refers to a specific, unique numerosity, then they will restrict the meanings of the number words so that no two refer to the same numerosity. For example, consider a child who knows the cardinal meanings of the words up to "two." This child's knowledge of the word "two" *also* gives her knowledge of the word "three"; she knows that "three" does not refer to 2. When shown pictures of two versus three items and asked to point to the three items, she will therefore succeed even though she doesn't know how many "three" does refer to. Similarly, a child who knows the cardinal meanings of the words up to "three" will restrict her space of the candidate meanings for the word "four," and so never point to a picture of three items when asked to show the "four" items.

In contrast, consider a child who believes that the number words she does not yet know the cardinal meanings of all refer to some property of an entity in a group of items, or simply knows that these words' satisfaction conditions entail a plurality of entities. If such a child knows the cardinal meanings of the words up to "two," for example, she should be equally likely to point to the picture of two items as to the picture of three items when asked to show the three items, as there will be no reason for her to restrict the space of possible meanings of the word "three." Similarly, children who only know the cardinal meaning of the words up to "three" should be equally likely to point to three items as to four items when asked to show four items. (It is not relevant to look at the children who only know the cardinal meaning of the word "one," since, by any of the hypotheses, they are presumed to know that the higher number words only apply in a context of a plurality of entities; so they should in any case never point to the picture of one item when asked to show the two items.)

This analysis did not include *all* the children who were classified into Groups 2 and 3. This is because, in the Give-a-Number task, if a child gave three items when asked for more than three, she was not credited with understanding the cardinal meaning of the word "three," and was placed in Group 2. But by the "individual-in-a-group" hypothesis, such a child could know the cardinal meaning of the word "three," and simply think that the words "four" and "five" apply to any plurality of items, including three. Such a child would of course never point to a picture of two items when asked to show three items, since she actually does know the cardinal meaning of "three." Including this child in the analysis would then spuriously make the results more consistent with the "number word" hypothesis. For this analysis, then, only those children who by *any* standards did not know the cardinal meaning of the word "three" were included–that is, those children who were classified into Group 2 who in the Give-a-Number task *never* gave three when asked for three. Similarly, only those children classified into Group 3 who certainly did not know the cardinal meaning of the word "four", that is, who never gave four items when asked for four, were included.

There were a total of 25 sessions with Point-to-x data (over 10 different children) in which children were classified as belonging to Group 2 or Group 3. Six of these sessions were excluded on the basis of the above concern, leaving 19 sessions (over nine children) relevant to the analysis. Each individual child's percentage of correct responses was determined over all sessions when shown the pair (n, $n + 1$) (where n is the group number of the child) and asked to indicate the $n + 1$ items (there were two such questions for each session). A t test was then performed on these percentages to see if they were significantly greater than the chance rate of 50% (the "number word" hypothesis predicts that they should be, while the "individual-in-a-group" and "plurality" hypotheses predict that they should not be). The mean of the nine children's percentages of correct responses was 88%, well above chance [$t(8) = 5.969, p < .0001$]. That is, children in Group 2 knew not to point to a picture of two items when asked to show three items, even though they did not know how many "three" was, and children in Group 3 knew not to point to a picture of three items when asked to show four items, even though they did not know how many "four" was. Children restricted the reference of number words they did not know the cardinal meanings of on the basis of number words whose cardinal meanings they had determined.

These results show that by the time they know the cardinal meaning of the word "two," and possibly earlier, children have already determined that the counting words each refer to a *specific, unique numerosity*.

4. Development over Time

Sequence of Acquisition

It can be asked if the results of the Give-a-Number task support the claim that children learn the cardinal meanings of smaller number words sequentially, and then simultaneously learn the cardinal meanings of the remaining number words within their counting range, when they learn the cardinal word principle (Wynn, 1990). This hypothesis results from the following reasoning: There is a wealth of independent evidence that infants and children have a means, other than consciously counting, of precisely determining the numerosities of sets of up to three items (Antell & Keating, 1983; Chi & Klahr, 1975; Silverman & Rose, 1980; Starkey & Cooper, 1980; Strauss & Curtis, 1981). But this ability does not apply to larger numerosities—the only apparent means children have of determining the exact quantity of a set of more than three items is to count it, and they do not possess this means until they acquire an understanding of how counting determines the numerosity of a set. Because they must be able to precisely quantify the numerosity a number word refers to in order to learn its cardinal meaning, the only way for them to learn the cardinal meanings of the larger number words is to understand counting. Once they understand counting, they should be able to determine the cardinal meanings of all the number words within their counting range.

Two predictions follow from this claim: (a) that children who succeed at giving larger numbers succeed at giving *all* the larger numbers within their counting range, and (b) that children who succeed at giving only smaller numbers do not know the cardinal word principle, while those succeeding at giving larger numbers do know the cardinal word principle.

(*a*) *Children learn the cardinal meanings of larger number words all at once*. Some children knew the cardinal meaning only of the word "one" (i.e., could only successfully give one item when asked), some knew the cardinal meanings only of "one" and "two," and some knew the cardinal meanings of only "one," "two," and "three." But all 11 children who knew the cardinal meaning of "four" also knew the cardinal meaning of "five,"[2] even the 5 children who had just moved into Group 4 from a lower group. Furthermore, of these 11 children, 8 were also asked to give six items at the end of the Give-a-Number task (including 4 of the 5 children who had just moved up to Group 4). A total of 6 of the 8 succeeded at this (including 3 of the 4 that had just moved into Group 4 from lower groups), showing that they knew the cardinal meaning of "six." The 2 who failed used counting in attempting to get the correct number,

[2] There was one exception to this. One child (not one of those who had just moved into Group 4) could give up to four items but failed to consistently give five items. She used counting to give the number asked for, and once gave five correctly, but on other trials made mistakes in her counting and, though she did adjust in the right direction, failed by the criterion of success laid out. The fact that she consistently used counting to solve the task, and adjusted in the correct direction, suggests that she did know the counting system, and that her difficulty with giving five was one of performance rather than of competence.

but made mistakes in their counting and so gave the wrong number, and then got lost in a swamp of recounting and adjusting (in the correct directions) which was hindered by further mistakes in counting, until they finally just gave up. The fact that in general children who knew the cardinal meaning of the word "four" (even those who had only just acquired it) also knew the cardinal meanings of the words "five" and "six" strongly suggests that children do learn the cardinal meanings of the larger number words within their counting range simultaneously.

(*b*) *All and only children who know the larger number words possess the cardinal word principle*. This prediction was tested by examining children's strategies in the Give-a-Number and Point-to-x tasks. If the 11 children who know the cardinal meanings of all the number words (Group 4 children) know the cardinal word principle while the other groups do not, they should use counting when giving items from the pile or identifying the picture of a certain number of items, while the 14 children in the other three groups should not.

Since there were no significant differences in amount of counting from the pile between any of the lower groups, results are collapsed across them. When asked for small numbers of items, Group 4 children counted aloud on an average of 42% of their trials, compared to 11% for lower-group children, $t(23) = 2.266$, $p < .02$, one-tailed. When asked for larger numbers, Group 4 children counted aloud on an average of 70% of their trials, while children in the lower groups did so only 5% of the time, $t(21) = 6.034$, $p < .0001$, one-tailed. (Two of the children in the lower groups were not asked for larger numbers because they very consistently failed to give even three items and were becoming discouraged; the analysis of counting for the larger-number questions therefore includes only 12 of the 14 children observed at these lower group levels.) In addition, on those few occasions when children in the lower groups did count aloud (5 children did so), they stopped at the number word asked for only 40% of the time on average, indicating that their counting was not due to knowledge of the cardinal word principle. In contrast, the 10 children in Group 4 who counted aloud (the 11th always gave the correct number of items silently one at a time, perhaps counting them in his head) stopped at the number word asked for 85% of the time, $t(13) = 3.583$, $p < .005$, one-tailed.

Similar results obtained in the Point-to-x task. Individual children in the Group 4 sessions counted aloud on 52% of the number questions on average (not including trials when asked to show "one"), compared to only 16% for children in Groups 1, 2, and 3, $t(22) = 3.124$, $p < .0001$, one-tailed (there was data for the Point-to-x task for only 13 of the 14 children observed in Groups 1 through 3). This result does not appear to be due to the fact that children in the lower groups were shown smaller numerosities in the Point-to-x task than Group 4 children. A comparison of Group 4 versus Group 3 children's percentages of counting aloud on the number questions for the pair (4, 5)—a pair common to both groups—reveals that Group 4 children counted aloud on 64% of the number questions for this pair on average, while Group 3 children counted aloud only 8% on average, $t(12) = 2.191$, $p < .05$, one-tailed.

The children who knew the cardinal meanings of all the number words, then, used counting in solving both the Give-a-Number and the Point-to-x tasks, showing a clear understanding of the cardinal word principle. In contrast, the children who knew the cardinal meanings of only some of the number words showed no such understanding. These results support the hypothesis that children determine the cardinal meanings of the larger number words via acquisition of the cardinal word principle.

Time Span of Acquisition

The time span of acquisition appears to be an extended one. Table 2 indicates how long it took children of each group level to move out of that group into a higher one, and their ages at the time of the change. Of the six children who were first observed at the Group 1 level, four were followed for up to 7 months each; only one of these achieved an understanding of the counting system in that time and had gone on to be classified in Group 4 (he did so after 5 months). The other three children had in all that time moved only to Group 2, being observed for an average of 4 months before doing so (and it is unknown how long they had already been at the Group 1 level before the study began). The two who were only followed up for two sessions did not change groups. Of the six children who were first observed at the Group 2 level, four were followed for up to 7 months each; of these, one had just made the transition to Group 3 *after 7 full months* at the Group 2 level. The other three made the transition to Group 4, taking an average of 4 months each to do so (again, it is not known how long they had already been at the Group 2 level before the study began). Of the two children initially observed at the Group 3 level, one made the transition in the second session to Group 4, while the other was observed for only two sessions and did not change groups in that time.

TABLE 2
Time Span of Knowledge Acquisition

Group No.	No. children	No. who changed groups	Mean No. months before change	Mean and range of ages at change
1	6	4	4.5	3;1 (2;10–3;3)
2	6	4	4.9	3;4 (3;1–3;8)
3	2	1	1.2	3;1 (–)

From this data, it can be estimated that children spend at least 10 months on average at the Group 1 and Group 2 levels of knowledge, before moving on to the Group 3 and/or finally the Group 4 level, though the time span of individual stages varies from child to child. That is, it takes close to a year for children who already know the cardinal meaning of the word "one," and who know that the number words refer to numerosities, to learn the cardinal word principle—that is, to learn the way in which the counting system represents numerosity.

The How-Many Task

Since the How-Many task and variations of it have been widely used as one measure of children's understanding of the cardinal word principle (e.g., Frye et al., 1989; Fuson, 1988; Gelman & Meck, 1983; Schaeffer, Eggleston, & Scott, 1974; Wynn, 1990), it is important to know whether it is a reliable indicator of this knowledge. There are reasons why it might not be. Children often recount a set of items when asked "how many" following counting. Recounting the items is, in fact, one means of indicating their numerosity—one way of asking a child to count some items in the first place is to ask how many there are. Thus children may understand that the last number word indicates the numerosity of the items, but prefer to indicate how many there are by counting again. Conversely, when counting is modeled for children, the last number word in the count is often emphasized and repeated ("So how many are there? There are *three!*"). Children might learn from this to give the last number word in response to a "how many" question, but without knowing that it indicates the numerosity of the items counted.

A previous study found that children who knew the cardinal word principle gave more last-word responses than those who did not (Wynn, 1990, Experiments 1 and 3). To see if those results replicate in this study, the relevant analysis is to look at children's performance on the How-Many task for their initial session only, since the previous experiments were not longitudinal. The mean of individual children's percentages of last-word responses was determined for each group. Children who knew the cardinal word principle—the Group 4 children—gave last-word responses on average 57% of the time, compared to only 16% for children in the other three groups, $t(18) = 2.441, p < .02$, one-tailed (the means for the lower three groups did not differ significantly from each other; they were 17% for Groups 1 and 2, 10% for Group 3). Thus, the finding that children who know the cardinal word principle give more last-word responses when asked "how many" following counting is a robust one.

However, when individual children are looked at over time, it is evident that the How-Many task should not be considered a definitive criterion of children's understanding of the counting system. A total of 5 of the 14 different children observed in Groups 1 to 3 began giving last-word responses a majority of the time *before* entering Group 4. This accords with previous findings (e.g., Frye et al., 1989; Fuson, 1988; Wynn, 1990) that some children learn a "last-word rule" (learn to give the last word without understanding its significance) before acquiring an understanding of the cardinal word principle. Conversely, 4 of the 11 children observed at the Group 4 level did *not* give last-word responses, but instead consistently recounted the set when asked "how many." Thus, some children who have acquired an understanding of the cardinal word principle evidently prefer to indicate the numerosity of a set by recounting it.

What about those children observed both at lower group levels and at the group 4 level—did their percentage of last-word responses increase when they acquired an understanding of the counting system? There were five such children. The mean of their individual percentages of last-word responses in the session immediately before entering Group 4 was only 8%, while their mean percentage immediately after entering Group 4 was 44%, $t(4) = 2.250$, $p < .05$, one-tailed. However, this result was due entirely to three of the five children, who immediately started giving last-word response rates of 80 to 100% upon entering Group 4. The other two children continued to recount the items in response to every "how many" question, as they had done in previous sessions. (It is possible that these two children had experienced the How-Many task enough times with the experimenter that they had made a routinized game of it, and so continued to give the same kind of response they had given before learning the counting system; they were each tested at lower group levels for three sessions before entering Group 4. In contrast, the three children whose percentages increased had been tested for only one or two sessions each before reaching Group 4 and had perhaps not become as accustomed to responding in a certain way.)

The How-Many task is therefore not as reliable an indicator of whether children understand the counting system as are the Give-a-Number and Point-to-*x* tasks. Although a high proportion of last-word responses is correlated with an understanding of the counting system, and in some children does seem to be precipitated by their acquisition of the cardinal word principle, it can also occur independently. Strong conclusions should therefore not be made about children's understanding of counting on the basis of this task alone.

GENERAL DISCUSSION

The results of this study offer confirmatory evidence for the proposal in Wynn (1990) that children learn the number words sequentially up to the words "two" or "three," and then acquire the cardinal meanings of the larger number words in conjunction with the cardinal word principle. The major new findings of this study are that children know that the number words refer to specific *numerosities* at a very early stage of counting (that is, by the time they know the cardinal meanings of the words "one" or "two"); and that despite this early knowledge, it takes children a surprisingly long time (on the order of a year) to learn how the counting system represents number. The import of these two findings is discussed below.

1. Components of Meaning of the Number Words

The finding that children know that the larger number words refer to numerosities before knowing which numerosities they refer to, *even for words that are well within their counting range*, conflicts with the prediction of the "counting-principles" theory that once children realize that the number words refer to numerosities, they will link them up with their own, already ordered list of mental number tags and hence will know the precise numerosity picked out by each word. The challenge for the "counting-principles" theory is to explain how children could simultaneously (a) know that larger number words refer to numerosities, and (b) fail to know which numerosities these larger number words refer to even though (c) they know the exact place of these words in the number word list. There is no obvious way to explain the co-occurrence of all these points. For example, (a) and (b) clearly must hold for number words whose exact position in the number word list a child is uncertain of, since it is the position in the list that determines the precise numerical meaning, both for number words and for mental number tags. But this account requires that point (c) be false. One could explain the co-occurrence of (b) and (c) by positing that it takes children some time to recognize that the list of number words is in fact a linguistic instantiation of their mental number tags—perhaps children learn the meanings of the first two or three number words and then use these instances as a basis for inducing that the entire list of words corresponds to their list of mental tags, and only at this point do they hook up linguistic counting with their mental counting process. However, this explanation would require that children not know that the larger number words refer to numerosities, contrary to (a). Points (a) and (c) together predict that the child knows the number words' cardinal meanings, contrary to (b). Thus, the three points do not appear to be mutually compatible within the counting principles theory. This adds to the growing list of problems for this theory (e.g., Frye et al., 1989; Fuson, 1988; Wynn, 1990).

The finding that even 2½ year olds know that the number words refer to numerosities and not to individual entities conflicts with the claim of the "different-contexts" theory that 2 and 3 year olds believe the referent of a number word is the individual object to which it is assigned during a count. There were several empirical findings that supported this "individual object" claim. In Wynn (1990), when children were asked to give a certain number of animals, and were then asked to count and make sure they had given the correct number, a significant number of children made the last number word in their count the number they had been asked for, even if the number they gave was different. For example, a child asked for five who gave three counted them, "one, two, five." The proposal that some children learn from observation that the last word in a count is in some way important within that routine, without knowing *why* it is important, explains these results and is consistent with the finding of the current study.

However, this proposal does not explain results from Fuson (1988), in which she asked children to count a row of, say, five soldiers. She then asked them either "Can you show me the five soldiers?" or "Can you show me the soldier where you said 'five'?" Children were forced to choose either the entire group of five soldiers, or just the fifth soldier, in response to the question. Children chose the fifth soldier most often in response to both questions, suggesting that when they heard the phrase ". . . the five soldiers" they did not interpret the word "five" as referring to a plurality of soldiers. This is in striking contrast to children's responses to the question of identical form in the Point-to-*x* task ("Can you show me the five balloons?"), in which they pointed to the plurality of items rather than the single item. The main differences between the two tasks are (1) that Fuson's task involved counting immediately prior to the question; and (b) that Fuson's task involved a forced choice between all the items and the last item in a single counted group, while the Point-to-*x* task involved a forced choice between two different groups, neither of which had been counted. It is possible that there is some pragmatic effect of asking "Can you show me the five soldiers?" right after the child has counted them—after all, they are sitting there in plain view. This may lead children to try to construe an alternative interpretation. They might then be especially inclined to choose the item that was paired with the last number word, and to which their attention was explicitly called as one of the possible response choices, if they believe the last word in a count is important in some way but without knowing why.

The finding that even very young children know the number words refer to numerosities indicates that there may never be a period at which children believe a number word refers to the object to which it is assigned. This requires some revision of the "different-contexts" theory, though does not refute the theory as a whole.

In whatever way children are learning so early that the counting words are *number* words, this is the key to how they are solving the learning problem described in the introduction—how they are able to learn that the number words refer to some property of *sets* of entities, rather than to some property of individual entities. Knowing that children learn this so early can help point to how children are in fact achieving this.

One possibility is that children induce from the syntax of the number words that they pertain to quantity. This is a particular case of what is known as "syntactic bootstrapping," an idea first discussed by Brown (1957), and later developed by Gleitman and colleagues (e.g., Gleitman, 1990). Studies have shown (e.g., Naigles, 1990) that children as young as 18 months can infer some semantic properties of novel verbs (whether they refer to a transitive or intransitive action) from the syntactic frames they occur in. Children can also infer the meaning of a novel noun in part on the basis of whether it appears with a determiner (the article "a") or not (Katz, Baker, & Macnamara, 1974), and also on the basis of whether it appears with count noun or mass noun syntax (Bloom, in press). Thus it is possible that the number words' syntactic status as determiners may give children information about their semantics. The hypothesis that young children use the syntactic properties of the number words to determine their semantics hinges on three assumptions:

1. Determiners have a common semantics, making it possible to predict certain aspects of the semantics of a word simply by knowing that it is a determiner. This correspondence need only be one-way; not all words possessing this semantic role need be determiners. All that is needed is that semantics be predictable from syntax.
2. Children are sensitive to the syntax of determiners by 2½ years of age—that is, they must be able to pick out determiners on the basis of their syntax.
3. Children are sensitive to the semantics of determiners by 2½ years of age, so they have the information necessary to infer the semantics of a novel determiner from its syntax.

Evidence for each of the above three points is discussed below.

1. Determiners Share a Semantic Role

Almost all determiners pertain to quantity, for example, "some," "all," "both," "many," "much," "little" (as in "a little bit"), "few/a few," "lots," "another," and the number words. Furthermore, "a," one of the most common determiners in young children's utterances, can only be used to pick out a single individual (similarly "another"), while "these," "those," "both," "all," and "a few" can only be applied to a plurality of individuals. Determiners are therefore intricately linked up to quantification.

2. Children Are Sensitive to the Syntax of Determiners

Determiners have a defining set of syntactic properties. They can only come before nouns or adjectives, not after them; and in English they cannot directly precede pronouns or proper names. Some determiners can also appear as noun phrases in their own right, unlike adjectives (e.g., "I want *three*", "I want *that*"). Also unlike adjectives, a determiner (and only a determiner) *must* appear before a singular count noun. Compare, for example, "A/the/this/that/some/one/another/no dog bit the mailman" with *"Dog bit the mailman," (Determiners that are limited to plural count or mass nouns, such as "all," "many," "a few," etc., obviously cannot fill this role.)

It has been shown that even 2 year olds possess knowledge of the syntactic category of determiners. Valian (1986) found that children as young as 24 months of age honored the word ordering of determiners relative to nouns and adjectives; in children's utterances, determiners never followed these parts of speech. Children's speech also obeyed the constraint that a determiner never precede a pronoun. Gordon (1987) further found that not only do children preserve the word ordering of determiners relative to adjectives, but they also distinguish between the two categories, contrary to the claim, proposed by Brown and Bellugi (1964), that children consider both adjectives and determiners to belong to a single category, "modifier."[3] Children clearly are sensitive to the syntax of determiners.

3. Children Are Sensitive to the Semantics of Determiners

Soja (1990) showed that 2 to 3 year olds understand some of the quantificational semantics of the determiners "a" and "some." When children were presented with a novel object and told "This is *a* blicket," they were more likely to choose a new object of the same shape but different substance as a referent of the word "blicket" (as opposed to several pieces of the original substance in a haphazard shape) than they were when presented with the object and told "This is *some* blicket" and "This is blicket." Either the presence of the word "a" in the first condition caused them to choose the individual object more than they otherwise would have, or the presence of the word "some" in the second condition caused them to choose the several pieces more than they otherwise would have, or both.

Further data obtained by Soja in several experiments (Soja, 1990; Soja, Carey, & Spelke, 1991; Soja, personal communication) suggest even more strongly that young children are sensitive to the singularity/plurality re-

[3] Note that simply preserving an ordering between two sets of words does not mean that they belong to different syntactic categories; among adjectives, some always come before others. We always say "the sweet little black puppy," never "the little black sweet puppy" (see Bever, 1970).

strictions of certain determiners. She elicited utterances of 96 2 to 2½ year olds by reading them stories during which they were asked such questions as "what is this?" or "what is that green stuff?" about pictures of various individual items, collections of items, and substances depicted in the stories. It was found that the determiner "a" accompanied 32% of children's "individual entity" responses, but only 3.7% of children's "plural" or "substance" responses. The children evidently knew that "a" describes *single* items, not pluralities or substances. A similar story obtains for the words "this," "that," and "some," though they were in general more rarely produced. One of the determiners "this" and "that" accompanied 1.5% of the 7798 "individual item" responses and only 0.5% of their 3257 "plural" or "substance" responses. In addition, the determiner "some" preceded 5% of their 1410 "plural" responses (and 4% of their "substance" responses) but only 0.5% of their "individual item" responses. These percentages suggest that these 2 and 2½ year olds knew the semantics of "a," "this," "that," and "some"—which ones apply to single items, and which to pluralities of items and substances.

Thus, 2 year olds know for several determiners that they pertain to quantity. This suggests that children of this age may possess general knowledge of the semantics of determiners. In any event, it reveals that children have a basis upon which they could infer that novel words with the same syntactic properties as these words might also refer to quantity.

How Do Children Learn That Each Number Word Refers to a Unique Numerosity?

How do children know not only that the number words pertain to quantity, but that each one, unlike other determiners, refers to a specific, unique numerosity? In this, both the syntax of number words and the contexts in which they are used may play a crucial role. Number words are applied to pluralities of items, never a single item (except of the word "one," for which the opposite holds), and they are only applied to collections of individuable entities, not to substances. These properties could inform children that they pertain to the quantification of *discrete items*. This does not yet distinguish the number words from determiners such as "many" and " a few," which also apply only to the quantity of discrete items. Here, context may be critical. Imagine a case where a child takes some cookies off a plate. A parent says "No, you can't have *three* cookies, you're only allowed to have *two*," while taking one cookie away. Here the child has seen one number word applied to a set of discrete entities, and has then seen a (very salient) operation performed on the set effecting the smallest possible change in the numerosity, followed by the application of a *different* number word. Contrastive situations such as this might help the child infer that, for even the smallest change in numerosity, a new number word must apply, and therefore that the number words do not apply to indeterminate amounts as do words such as "many," "a few," and "some." Learning this for a few of the number words would likely allow the child to infer this about all the number words in general; there is independent evidence that 2½ year olds know that the counting words all belong to a single semantic class. For example, when asked "how many" of something there are, they will almost always respond with a number word or words rather than with other words (e.g., Gelman & Gallistel, 1978; Fuson, 1988; Wynn, 1990). Furthermore, they know the list of number words for counting (up to some limit); the number words occur together in this list so children might reasonably be expected to infer that general properties of some of the number words might apply to the rest as well.

2. Time Span of Acquisition and Representation of Number

The findings of this study suggest that children do have difficulty learning the counting system. It appears to take them about a year, after knowing that the number words refer to numerosities, to learn how the counting system represents numerosity. This indicates that children may have difficulty in mapping their own representation of numerosity onto the counting activity, and suggests that young children's concept of number may take quite a different form than the way number is represented in the counting system. This finding goes against the "counting-principles" theory of representation of number, which predicts that children will learn the cardinal meaning of each number word relatively easily, as soon as they have determined that word's place in the number word list.

The findings are, however, consistent with theories that posit an initial representation of number quite different in form from the counting system, such as the accumulator theory (Wynn, in press). In linguistic counting, it is the ordinal position of each of the number words in the list that is the key to the system of their representation of number. They represent cardinalities with a system that does not directly reproduce, but is analogous to, the inherent relationships among the numerosities—the linguistic symbols for the numbers bear relationships to each other in their ordinality that are exactly analogous to the relationships the numerosities themselves bear to each other in their cardinality. The linguistic symbol for *seven* occurs three positions later in the number word list than the linguistic symbol for *four;* the numerosity *seven* is three units larger than the numerosity *four*. The linguistic symbol "ten" occurs five times later in the number word list than does the symbol "two"; the numerosity *ten* is five times larger than the numerosity *two*. In contrast, on the accumulator representation of number, the representations for the numerosities bear exactly the *same* relationship to each other as do the numbers themselves; the representation for *seven* is itself three units larger than the representation for *four* (has three more increments or terms), the representation for *ten* is five times larger than the representation for *two* (has five times as many increments or terms). On this theory, in order to learn the counting system, children must implicitly make the analogy between the magnitudinal relationships of their own representations of numerosities, and the positional relationships of the number words. Discovering an analogical relationship between two symbol systems is surely not a trivial process, and could be expected to take children a long time to accomplish.

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