1993

Counting in Chimpanzees: Nonhuman Principles and Emergent Properties of Number

Sarah T. Boysen

Ohio State University

Recommended Citation

Boysen, S. T. (1993). Counting in chimpanzees: Nonhuman principles and emergent properties of number. The development of numerical competence: Animal and human models, 39-59.

Counting in Chimpanzees: Nonhuman Principles and Emergent Properties of Number

Sarah T. Boysen[1,2]

[1] Ohio State University
[2] Yerkes Regional Primate Research Center – Emory University

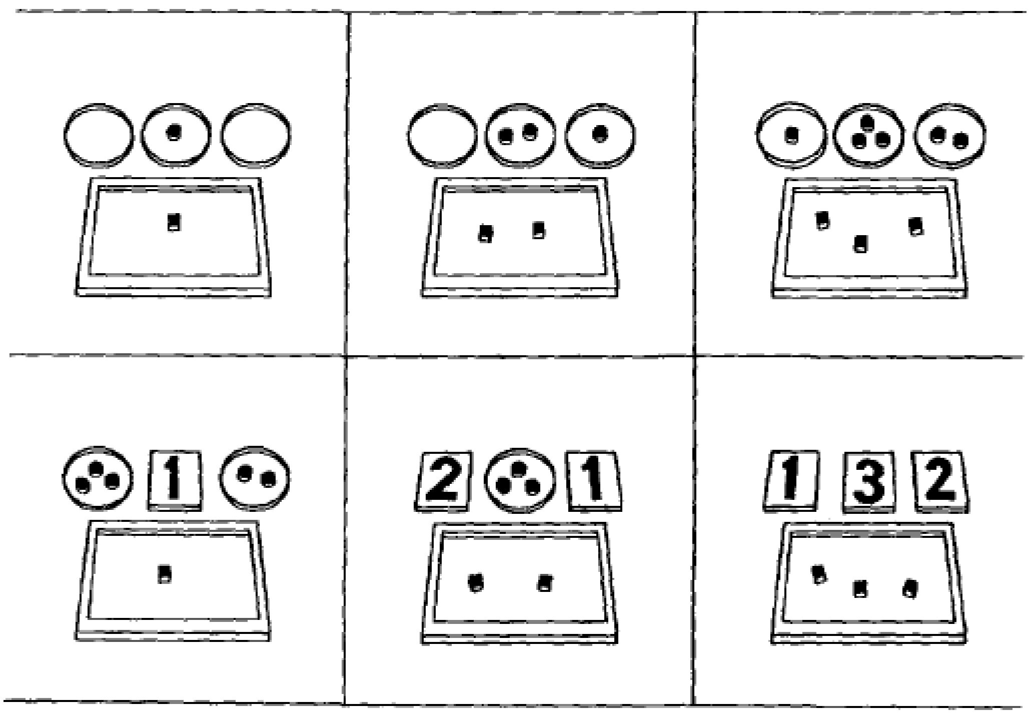
Despite historically bad press, the study of numerical abilities or capacities in nonhuman species is currently provoking renewed interest and controversy among those with interests in animal cognition (Davis & Perusse, 1988; Rilling, chap. 1, this vol.). Indeed, this very volume, devoted to studies of number-related skills among nonhuman and human species, attests to the revitalization of the field. The surrounding chapters highlight the myriad of questions that remain to be addressed from the current data, and suggest new questions that may be explored as pivotal issues related to animal counting come more sharply into focus. Although sensitivity to quantity has been demonstrated among numerous species (Capaldi & Miller, 1988; Davis, 1984; Hicks, 1956; Matsuzawa, 1985; Pepperberg, 1987; Rumbaugh, Savage-Rumbaugh, & Hegel, 1987; Woodruff & Premack, 1981), evidence for counting that is more analogous to the accomplishments of young children may be limited to recent work with chimpanzees (Boysen, 1992a; Boysen & Berntson, 1989; Thomas & Lorden, chap. 6, this vol.).

However, the establishment of such skills in a species even as intelligent as the chimpanzee requires a heroic effort (Boysen, in press), when compared to the seeming ease with which counting skills are acquired by preschoolers. There is little question that such a process is quite complex and unfolds over the course of years in human children (Fuson, 1988; Gelman & Gallistel, 1978). Similarly, our research on the emergence of counting in chimpanzees suggests that the acquisition of counting abilities is a complex process for this species as well, and also unfolds over years, not weeks or months (Boysen, 1992a). As an animal model, the chimpanzee is an apt student for exploring numerical competence for several reasons. First, the chimpanzee is a highly social ape who can be engaged in interactive teaching situations with its human teachers (Boysen, 1992b; Oden & Thompson, 1992). Second, previous work in a variety of laboratories exploring artificial language systems (Fouts, Fouts, & Schoenfeld, 1984; Gardner, Gardner, & van Cantfort, 1989; Matsuzawa, 1985; Premack, 1986; Rumbaugh, 1977; Savage-Rumbaugh, 1986) have clearly established the chimpanzee as a strong candidate for acquiring complex concepts, and it was with this background in mind that we began our studies of counting capacities in the chimpanzee.

Studies of number-related skills in chimpanzees are not unprecedented (Dooley & Gill, 1977; Ferster, 1964; Hayes & Nissen, 1971; Matsuzawa, 1985). In addition, Menzel (1960) reported what appeared to be a natural propensity in the chimpanzee to evaluate food portions, which would seemingly require some level of quantitative judgment of size and/or proportion. Similar tendencies have been observed in other captive chimps during acquired food-sharing, where choices of food shared by the animals appeared often to be a function of size or volume, with the choosing animal reliably selecting the largest portion or the cup containing the larger volume (Boysen, personal observations).

Whereas the task sequence and training on number concepts have been reported in detail elsewhere (Boysen, 1992a; Boysen & Berntson, 1989; Boysen & Berntson, 1990), an overview of the chimps' training would be useful, prior to discussion of more recently completed studies. When we first began exploring numerosity, the three chimpanzees in the lab (Darrell, age 41h; Kermit, age 4; and Sheba, age 3 at the time), spent virtually all day in the company of their human teachers, with brief periods of work on numerous cognitive tasks (sorting or matching colors and shapes; learning to recognize body parts-e.g., pointing to their ear when their teacher pointed to hers; drawing; matching photographs of foods to real foods, etc.). Such tasks were completed in short sessions of approximately 15-20 minutes, interspersed throughout the day, with the balance of the day with teachers spent playing chase games, tickling, taking walks outside the laboratory, and similar activities. In this setting, the first number-related task began as a daily game. The chimps were to place individual pieces of monkey biscuits in each of six compartments of a partitioned tray. The idea was to demonstrate one-to-one correspondence between the number of compartments and the biscuits, because one and only one biscuit was to be placed in each section. We elected to use monkey biscuits because they were readily available, not considered highly palatable by any of the chimps but more important, not really interesting enough to distract them from the task at hand. The animals were tested individually, during which they were given a small bowl containing 8-10 pieces of chow. They quickly learned the game, and were able to accomplish the task within several sessions.

FIG. 2.1. Training stimuli for One-to-One Correspondence Task and introduction of Arabic numerals.



The next numbers task was designed to elaborate on one-to-one correspondence, and provide a conceptual framework onto which Arabic numerals would later be mapped. In this task, the animals learned to match the number of markers affixed to different placards with the corresponding number of gumdrop candies presented to them (Fig. 2.1). All trials initially consisted of the presentation of single gumdrops, until the animals were able to track the various locations of the single marked placard. Next, trials that consisted of presentations of two gumdrops per trial were run, with the animals now required to track the location of the placard with two markers among the three possible locations (see Fig. 2.1). Following criterion, which required 90% correct response on two successive sessions, the animals then completed sessions with trials in which one or two gumdrops were presented. They were now required to make an explicit one-to-one match between the number of candies presented on a given trial, and the corresponding marked placard. After reaching criterion on this phase of training, a third marked placard was introduced, and the animals trained until criterion performance was met with 1, 2, or 3 candies presented on a given trial.

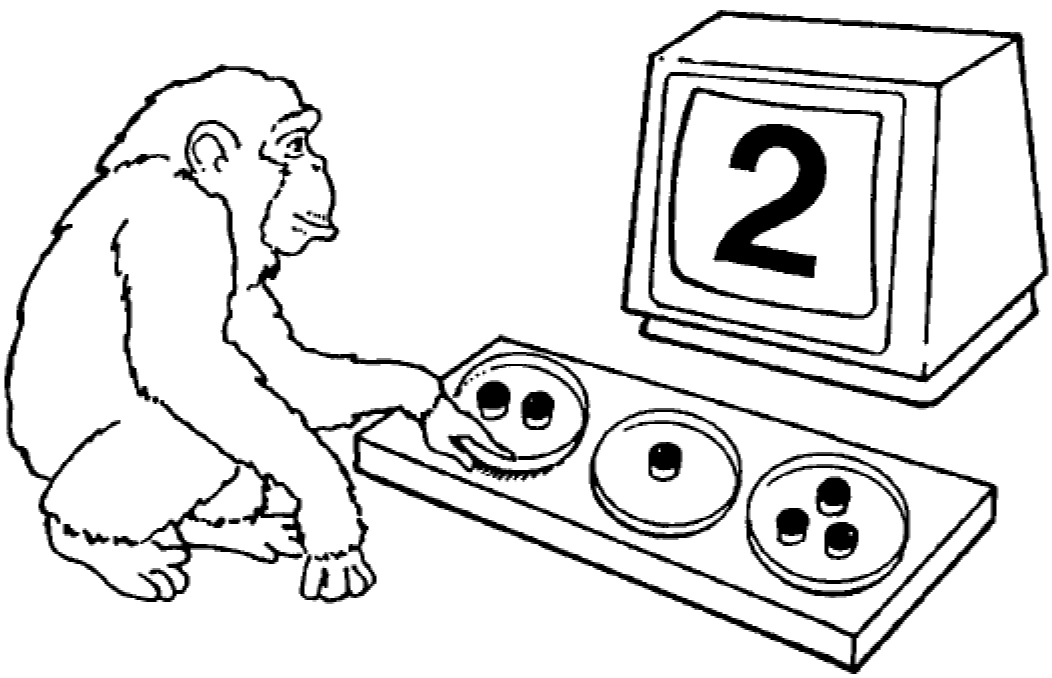
The transition from the one-to-one correspondence task with the marked placards and the association of Arabic numerals with specific quantities was accomplished by systematically substituting each marked placard with its respective numeral. As depicted in Fig. 2.1, the numerals were introduced one at a time, and the animals' performance permitted to stabilize at the 90% criterion level before introducing the next number. The Arabic numerals 1, 2, and 3 were introduced to the chimps in this fashion, whereas all subsequent numerals were introduced directly as Arabic numerals, without the marked placard training phase. This included numerals 0 and 4-8 for Sheba; 0 and 4-7 for Darrell, and 0-5 for Kermit and Sarah.

A number comprehension task was the next phase of training for the chimps, although procedural changes in the task had to be made almost immediately. We were interested in providing the animals with a task analogous to a receptive language task, reasoning that like other symbol systems, numbers would need to be manipulated in both productive and receptive modes in order to achieve representational status (Savage-Rumbaugh, 1986). Thus, although the animals were able to produce a label for different-sized arrays by pointing to the correct Arabic numeral, similar to naming an object as we do with spoken language, the chimps also needed to demonstrate that they understood the *meaning* of a number if it was used by someone else. This would be analogous to a person being able to label an object (i.e., "cup") when it was presented for naming (productive mode), and then being able to select the correct object (i.e., select the cup from among several objects) when asked, "Show me the cup" (receptive mode). Both modes of symbol use are necessary for any type of dialogue to unfold around a particular representational system, and thus numbers, as a symbolic, representational system, seemed to warrant establishment of both receptive and productive symbol use. Other studies with chimpanzees trained on an artificial, visual language system demonstrated that the animals could not automatically translate their productive labeling skills to the receptive mode, but rather, both types of symbol use had to be trained separately (Savage-Rumbaugh, Rumbaugh, & Boysen, 1980).

To train the animals on the receptive number comprehension task, we initially planned to present two different-sized arrays per trial, as the chimps viewed a videomonitor displaying a single numeral 1, 2, or 3. Thus, for example, if the number 3 was shown, the chimp was to point to the array consisting of three gumdrops, and ignore the array with one gumdrop. As in all number-related tasks, the animal always got to eat the "stimuli" after each correct response. In the receptive task, they were permitted to eat the array they chose, with the idea being they would learn to pick the array that matched the number presented on the monitor. The chimps did not necessarily see the task in the same way we did, as they appeared to completely ignore the number being presented, and began to consistently choose the larger array of the two being offered. After several sessions of bleak performance, with no indication that they could inhibit this response pattern, we elected to substitute the arrays of gumdrops with the original one-to-one correspondence placards (see Fig. 2.1). Now the chimps were to view the number on the monitor during each trial, and select from among the three placards which had one, two, or three markers (Fig. 2.2). This procedural change made a significant difference in their performance almost immediately. The animals were quickly able to learn to attend to the videomonitor, which they had previously ignored, and select the placard with the corresponding number of markers. Darrell's performance was slightly better than Kermit's or Sheba's in reaching criterion, but overall, all three chimps' receptive performance was quite similar (Darrell, 201 trials to criterion, 70% CR; Kermit, 315 trials to criterion, 72% CR; Sheba, 282 trials to criterion, 69% correct response [CR]).

These four structured numbers tasks-one-to-one correspondence, matching arrays to marked placards, the transition to matching arrays with the appropriate Arabic numeral, and the number comprehension task-evolved one from the other over two years of training. In an effort to broaden the chimps' use of number concepts, additional number tasks were devised for the youngest animal, Sheba. Sheba, by now age 6, was still quite tractable, and was able to move unrestrained throughout the laboratory during the day. Kermit and Darrell, however, had entered into the tumultuous period of chimpanzee male adolescence, and were not able to move about freely because of their large size. Today, at age 10, Sheba continues to work interactively with her teacher in the same manner throughout the day, and has shown no aggressive or noncompliant behavior. Although some of the difficulties of working with male chimps into adulthood are gender-related, some may be dispositional with respect to the individual animals' personalities and other early experiential influences. Kermit and Darrell continue to readily engage in tasks with their teacher through the front of their home cages on a daily basis, as they did throughout the 3- to 5-year period associated with adolescent changes in their physical size and demeanor. However, at the time the new number tasks were designed for Sheba that required free movement in the lab, we elected to focus our efforts on these tasks with this single female subject.

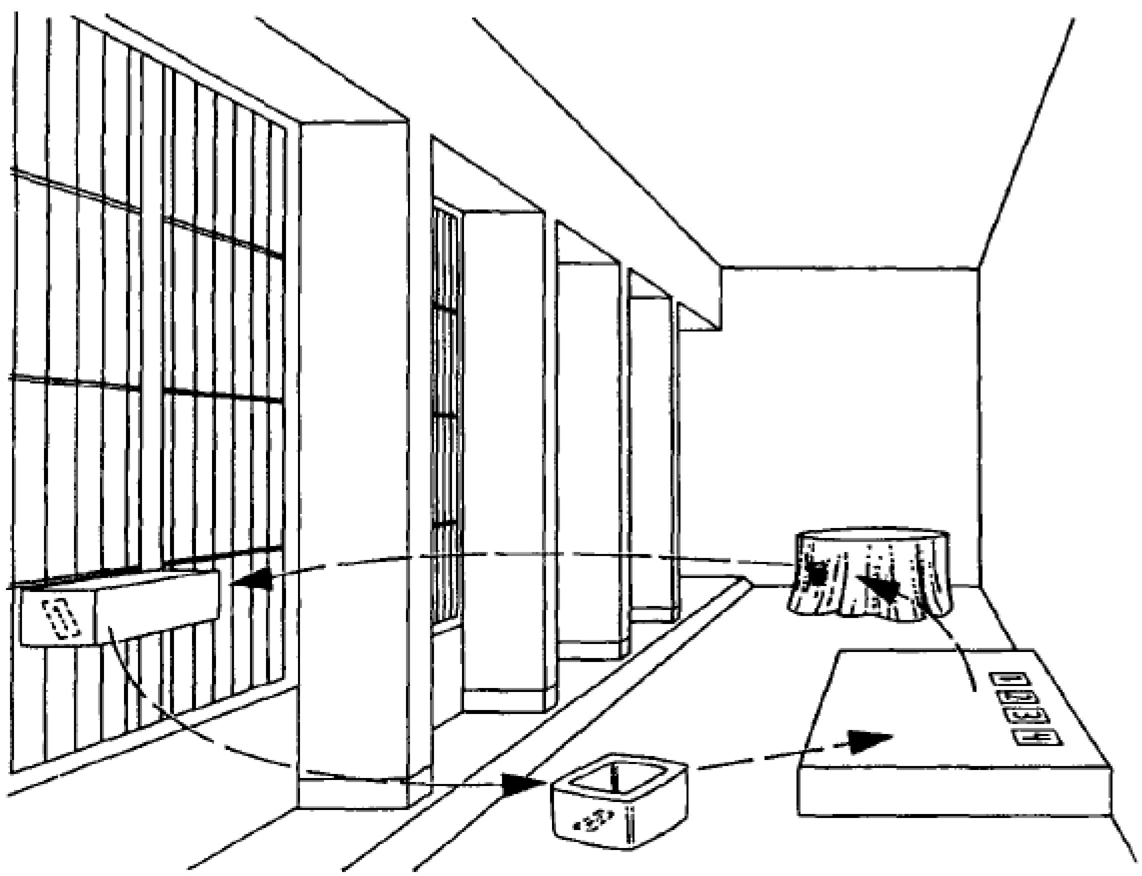
FIG. 2.2. Task format and training stimuli for Receptive Number Task.



Interests centered around whether or not a chimpanzee, trained on the structured numbers tasks described earlier, could learn to "sum" arrays presented to her in a somewhat more naturalistic encounter. That is, if Sheba were to come upon an array of size *X* in the lab, and next locate a second array of size *Y,* could she come to learn to combine the two arrays, and report a total number representing the two arrays? This is precisely the situation we presented to her, and the results were surprising for several reasons. Three food sites were selected for use in the first task, called the *functional counting task:* (a) a tree stump formerly used as a tool site by the animals, located at the far end of the lab; (b) a stainless steel food bin attached to the front of an unused cage, located approximately 10 feet from the stump; and (c) a plastic dishpan, positioned on the floor, approximately 20 feet from the stump, such that the three sites formed a rough triangle (see Fig. 2.3). Sheba's Arabic numerals 0-4 were positioned in ordinal sequence on a wooden platform (work station) located between Site 1 (stump) and Site 3 (dishpan). Sheba was accustomed to working on most tasks while sitting on this low platform with her teacher (Fig. 2.3). With the three sites available, the teacher (or a second experimenter, as during testing) placed from

0-4 oranges in two of the three sites, such that the arrays of oranges were not directly visible by Sheba as she sat at the work station. Sheba's task was to move among the three sites, return to the work station, and select the Arabic numeral that represented the total number of oranges hidden among the three sites. It was startling that Sheba was able to demonstrate the ability to complete this task from the very first session, moreover, from the very first trial. Rather than having to spend months training her on the many novel parameters of the functional counting task, she was able to readily grasp the rule structure of the testing arrangement immediately, and provide the correct total number during session one and maintain comparable performance throughout the 2-week testing period (Boysen & Berntson, 1989).

FIG. 2.3. Functional and Symbolic Counting Task: Physical setting, three sites for object and symbol stimuli, and numerical choices.



To challenge her further, given her ability to successfully complete the functional task, we next substituted the arrays of oranges with replicas of the Arabic numeral placards that Sheba used as response stimuli. Now, instead of finding three oranges at Site 2, and one orange at Site 3, for example, Sheba came on the numeral 3 and the numeral 1 at the sites. Nonetheless, Sheba readily generalized her very limited experience in the functional counting task to this new paradigm, which we called the *symbolic counting task.* Her performance from Session 1, using symbols instead of object arrays, was significantly above chance, and she continued with similar performance levels for the balance of the study (Boysen & Berntson, 1989). One of the most remarkable things about Sheba's performance on both the functional and symbolic counting tasks was the fact that these novel tasks involved individual task components entirely new to her. Nonetheless, she was able to spontaneously move beyond the structured counting tasks described earlier, and readily solve both novel tasks, which required summation and/ or maintaining a running tally of two separate arrays.

Although initial assessment of Sheba's performance on these tasks seemed somewhat inexplicable, an examination of the literature on early addition with human children offered some interesting insights (Groen & Parkman, 1972). Children as young as 3 are able to utilize spontaneous addition algorithms to solve simple problems, long before they receive any formal training in arithmetic (Starkey & Gelman, 1982), with such abilities growing out of their early counting experience and emerging concept of number. Sheba's performance on the functional and symbolic counting tasks suggested that she, too, was using a spontaneous addition algorithm, although the specific process by which she was solving the task remains unknown. She may have been counting both arrays sequentially, maintaining a running count, until she got to the last item, or she may have tallied the first array, and begun the count of the second array with that cardinal number. Both strategies are used by children as addition strategies, and are known respectively as "counting-on" and "counting-all" (Fuson, 1982, 1988; Groen & Resnick, 1977). Whatever strategies she was using, it is clear that Sheba had more skills with numbers than could be accounted for by the individual tasks for which she had been trained. Some emergent properties associated with the counting process became available to her for application with sequential arrays the first time they were presented to her. In addition, Sheba's performance on the symbolic counting task, in particular, suggested that number symbols served as representations for her-objects and numerals were interchangeable in their use. Number symbols were thus abstract representations of real-world referents, and could be readily manipulated in a novel context by Sheba, to characterize quantities represented by object arrays or other Arabic symbols. Her ability to perform both new tasks at the first opportunity also suggested that some emergent properties of numbers that were readily available for these novel complex tasks may have been the by-products of more directed training on counting. Sheba's abilities were highly reminiscent of similar transitions in counting skills and number concepts in preschoolers, and the process whereby such skills are acquired in children is also currently not well understood.

MOTOR TAGGING DURING COUNTING

In addition to the emergence of counting principles that seemed to be "beyond the information given," Sheba also began to exhibit tagging behavior and other indicating acts (Fuson, 1988; Gelman & Gallistel, 1978) during counting. Such behaviors first began with the introduction of the number 4, which was the first Arabic symbol introduced directly as a number symbol. Recall that the chimps had learned the numbers 1-3 by first learning to match the number of items in an array with placards bearing one, two, or three markers (see Fig. 2.1). When the number 4 was introduced directly as an Arabic numeral, Sheba began to move the items to be counted to new locations, push them apart, touch them, tap them, or simply point to them, prior to making her choice of the corresponding Arabic numeral (Fig. 2.4). Although such behaviors were noted by her teachers at the time, and comments added to her daily records, regrettably, no filmed record of the emergence of these tagging behaviors was made. As the behavior became more refined and consistent, we hypothesized that motor tagging could be functioning in a similar capacity as it did for children in the early stages of learning to count. That is, tagging may have helped Sheba keep track of the items in an array that she had already counted, and those that remained to be counted (Fuson, 1988; Gelman & Gallistel, 1978). To evaluate her tagging performance, all counting sessions over a 3-month period were videotaped, and Sheba's tagging behaviors were tallied. Two naive observers evaluated the videotaped sessions on a trial-by-trial basis, recording the number of tagging behaviors exhibited by Sheba, the number of repeat tags she made per trial, the correct number of items in the array, and the Arabic numeral Sheba chose on each trial. Inter-rater reliability between the two observers was .97, and disputed trials were resolved by a third observer. The high intercorrelations among the four measures revealed a close relationship between the number of items, Sheba's tagging responses, and her ultimate number choices. This is consistent with the proposition that Sheba used tagging of items in an array to help keep track of items she had counted, which may have permitted her to make a more accurate count (Table 2.1). It has been suggested by other investigators interested in animal counting that some covert process that permitted the animal to keep track of the items might be operating. For example, Koehler (1950) noted that the birds in his study might have employed some type of “inner marks,” and used these to “think unnamed numbers,” and such a process allowed the animal to keep track of items already counted. However, Sheba’s tagging behavior may provide the first definitive evidence that such marking behavior is closely linked with both the number of stimulus items and the response.

FIG. 2.4. Tagging behavior sequence (from videotaped counting sessions) with array of six items.

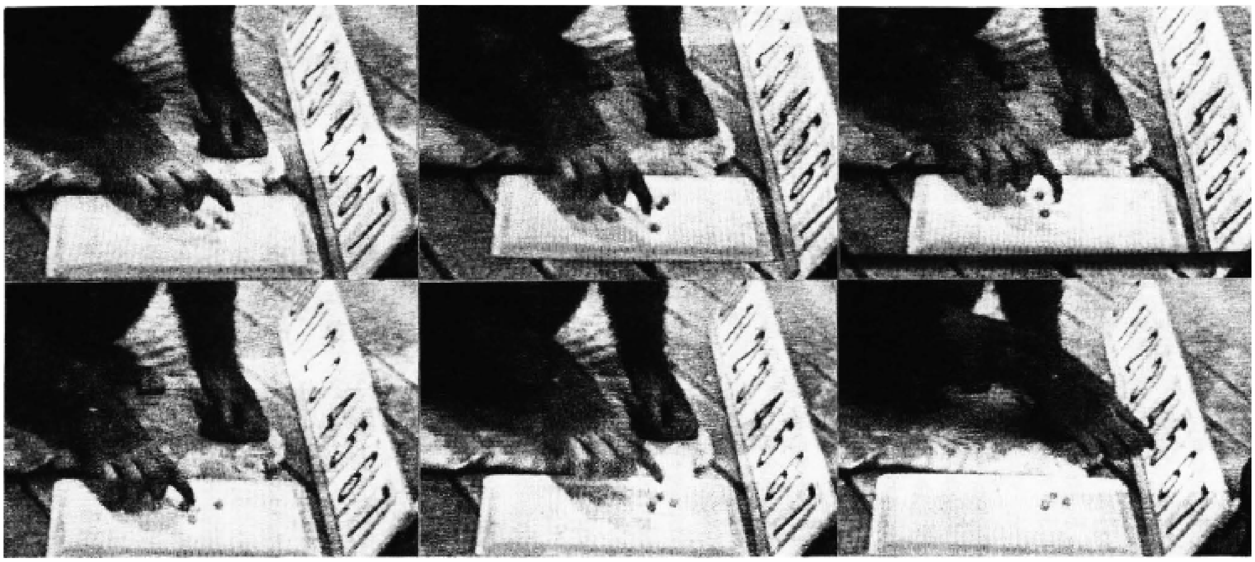


TABLE 2.1. Intercorrelation Matrix Among Variables During Motor Tagging Task

	Sheba’s Choice	No. of tags by Sheba	Items
Number of items	.73*	.77**	1.0
Number of tags by Sheba	.63***	1.0	
Sheba’s choice	1.0		

**t* = 22.09, *p* < .0001
***t* = 25.06. *p* < .0001
****t* = 16.56, *p* < .0001

Another significant issue in the counting debate centers around the principle of ordinality. In order to be considered as a candidate for “true counting,” Davis and Perusse (1988) suggested that an organism must demonstrate an appreciation for the ordered relations among and between numbers. That is, to say that one is counting is to assume they understand (and can demonstrate) that 2 is larger than 1, 5 is more than 3, 6 is greater than 4, and so forth-that the set of numbers used to label arrays of size *N* has a stable sequence, and represents an ascending series of increasing size. With human adults and children, we can simply pose the question verbally (e.g., “Is 4 more than 3?”). With nonhuman species, the evaluation of ordinality becomes more challenging.

To explore ordinality in the chimpanzee, we first sought to replicate Gillan’s (1981) study of transitive inference in chimps. Transitive inference is an inferential judgment of the ordinal relationship between two elements, derived from premises that specify the relationship of each of the two elements to a third (Halford, 1984; Kingma & Zumbo, 1987). Typical test procedures with children consist of presenting a series of object pairs ABCDE (e.g., sticks of different colors and lengths), with each pair serving as a premise such that A > B > C > D > E. Under test conditions, the child is asked to identify the correct object of a nonadjacent pair, such as BD, which has not been explicitly trained. The assumption is that the child must derive the relationship between the two nonadjacent sticks, based on their relative position within the ordered series. The development of such tasks for use with young children, with minimal linguistic demands, led to models for testing of nonhuman primates, as in the Gillan (1981) study with chimpanzees and McGonigle and Chalmers (1977) with squirrel monkeys.

In a series of experiments similar to the earlier study of McGonigle and Chalmers (1977), Gillan (1981) used a series of colored boxes containing relative amount of foods, presented to young nonlanguage-trained chimpanzees. The boxes were presented serially in pairs, in the following sequence and respective contingencies: A - B +, B - C +, C - D +, D - E + . Following criterion performance on all nonadjacent pairs, the chimps were tested on the novel BD comparison. Two of the three animals tested eventually demonstrated consistent choice of D. From these and other tasks in the study, Gillan concluded that integration theories, suggesting that subjects integrate information about separate stimuli or pairs of stimuli into an ordered series, provided stronger support for his animals' data, and language training was not necessary to subserve use of transitive inference in the chimpanzee.

We viewed the Gillan (1981) procedure as a viable task for examining ordinality in our chimpanzees that had been previously trained in counting. Each of the chimps, however, evidenced considerable performance differences in their numerical abilities. At the beginning of the ordinality study, Sheba had the most breadth of experience with counting tasks, and also had the largest counting repertoire, from 0-6. Kermit and Darrell had begun training with numbers in identical fashion. However, early in his training, Kermit showed great difficulty in the transition to Arabic numerals, and continued to demonstrate confusion as each new number was added. Darrell, however, was able to perform consistently on numbers tasks with his Arabic numeral repertoire of 0-4, and was receiving concurrent training with the number 5 at the beginning of the ordinality study. Thus, despite their demonstrated individual differences in numerical abilities, all three chimps served as subjects in the ordinality study modeled directly after Gillan (1981).

The first phase of the training entailed an explicit replication of Gillan (1981), with the chimps trained with five pairs of colored boxes that formed an ascending, ordered series ABCDE. Boxes were always presented as adjacent pairs during training, with only one box of the pair baited. For instance, when Pair A - B + was presented, A never contained a food item, and B always did; for pair B - C +, B never contained food, and C always did, and so on. Thus, Box A was never baited, and Box E, when presented, always contained food, with these boxes representing the low and high endpoints of the box series. Pairs were trained in order, to a criterion of 90% or better for two consecutive, 16-trial sessions. Eventually, mixed-pair sessions were conducted, such that the animals had to reach criterion on each pair within a session. Following overall criterion performance, blind tests were completed in which probe trials with boxes BD were presented. All three chimpanzees selected Box D from the nonadjacent pair BD during novel testing, thus supporting the findings of Gillan (1981), that chimpanzees may be capable of employing transitive inference to determine the correct choice between two nonadjacent items in an ordered series (Boysen, 1988; Boysen, 1992a).

In a second experiment, in an effort to demonstrate an appreciation for ordinality in chimpanzees with experience in numerical tasks, Arabic numerals served as the training stimuli. Similar to the first task, adjacent number pairs between 1 and 5 were presented serially, and the chimps were to select the "larger" of the two symbols. If correct, the animals were reinforced with yogurt or juice, both nondiscrete edibles that would help avoid any task-specific association of the numerals with absolute numbers of reinforcers. The same 90% criterion was used, including mixed-pair sessions during which the animals had to reach criterion on all pairs in a given session. Novel tests were then conducted in which the nonadjacent, nontrained number pair 2,4 was presented as probe trials among randomly ordered training trials. Both Kermit and Darrell failed the first novel test, whereas Sheba consistently selected the number 4 when the novel 2,4 pair was presented. These results suggested that Sheba recognized the ordinal relationships among the number series 1-5, and thus was able to report the larger number when a novel pair of numbers was presented. Although all three chimps had met the criterion performance demands of the training phase, both Kermit and Darrell were just as likely to select the number 2 as the number 4, when the novel 2,4 pair was presented. As seen in Table 2.2, both Kermit and Darrell had required a significantly greater number of trials to reach criterion in the final phases of training than were necessary for Sheba. Poor performance by Kermit was quite predictable, given his paltry performance with number concepts. Darrell's failure to pass the novel tests, however, was somewhat surprising, as he demonstrated a consistent ability to utilize Arabic numerals in both productive and receptive comprehension tasks, using numbers 0 through 4.

Sheba had both a larger counting repertoire than either Kermit or Darrell, as well as considerably more varied experiences with other number-related tasks, so this raised the question as to whether Sheba's success with both novel ordinality tests could be attributed to these training history differences. Perhaps the larger repertoire was a significant factor, and once Darrell (and presumably not Kermit, who still was not consistent in his use of 1-5) had expanded his counting ability to include additional numbers, he might be able to more readily represent the numbers as an ordered series. Sheba had also completed the reversal task, with training on number pairs in which she was now required to select the smaller number, and was successful during novel tests with the nonadjacent pair 2,4, so similar training was completed over several months with Kermit and Darrell. We reasoned that training with the descending pairs might help them further in organizing the numbers into a coherent series.

TABLE 2.2. Trials to Criterion for Number Pair Discriminations

Stimulus Pair	Sheba	Darrell	Kermit
Phase I: 1 vs. 2	111	12	27
Phase II: 2 vs. 3	71	56	226
Phase III: 3 vs. 4	36	104	155
Phase IV: 4 vs. 5	36	72	208
Phase V: 1 vs. 2, 2 vs. 3	72	44	158
Phase VI: 1 vs. 2, 2 vs. 3, 3 vs. 4	64	191	159
Phase VII: 1 vs. 2, 2 vs. 3, 3 vs. 4, 4 vs. 5	160	2,426	1,854

Following the descending series training ("smaller than") with Kermit and Darrell, all three animals were given a refresher series of training sessions with ascending number pairs ("larger than"), approximately a year after initial testing. During the ensuing year, Darrell had received additional training with productive numbers, and had a fairly stable repertoire of 0 through 6. He also acquired facility with two fractions, 1/2 and 1/4, and had learned to create arrays of sizes 1, 2, 3, or 4 with wooden spools when Arabic numerals between 1 and 4 were presented. The latter task, known as Perceived Numbers, represented a high-level receptive skill that had emerged slowly by Darrell and Sheba over many months of training. However, different from most other number-related tasks completed in recent years, Darrell's performance on perceived numbers had exceeded that of Sheba's, whose progress was still painfully slow. Whether Darrell's conceptual breakthrough on the perceived numbers task reflected some new level of awareness relative to his sense of number remained to be seen.

The refresher sessions followed the same procedures as the original task, in which pairs of numbers were presented, and the chimps were to select the larger of the two. Following criterion performance on all four possible pairs (1,2; 2,3; 3,4; 4,5), probe trials in which the nonadjacent pair 2,4 were re-presented to the animals. Additional probe trials designated as "novel/novel," consisting of nonadjacent pairs of numbers that, with the exception of 1, were not part of the training stimuli, were also presented during novel testing. Sheba correctly selected the larger number of each probe pair, including all 12 trials of novel/novel stimuli. These novel/novel pairs included two trials each of 0,1; 4,6; 5,6; 5,7; 6,7; and 0,7. A total of 34 test trials were completed, including 20 training trials. Sheba's performance was 100% on the 2,4 trials, 100% on the novel/novel trials, and 90% on the training trials.

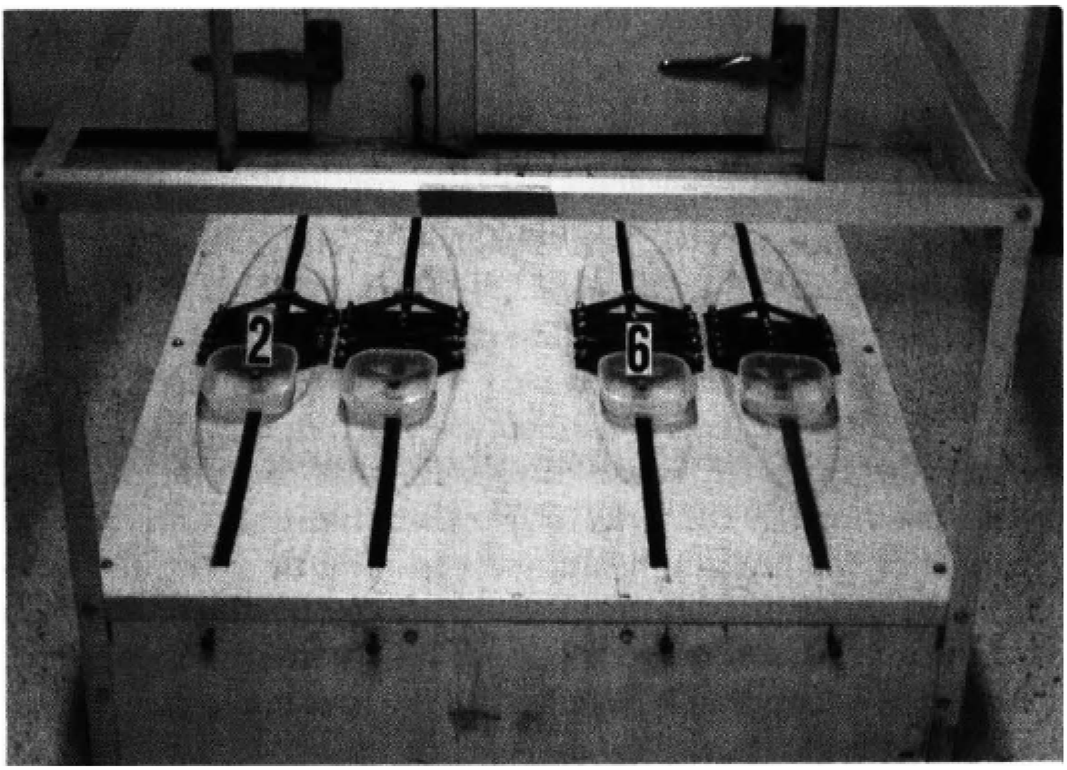
Both Kermit and Darrell also successfully completed the second novel tests, supporting the hypothesis that they had an appreciation for the ordinal features of the number series. Whereas Kermit's performance on the novel/novel probe trials did not reach significance, it should be emphasized that most of these numbers were completely unknown to him. All animals, however, were able to represent the numbers 1-5 in an ordered sequence, and both Sheba and Darrell were able to correctly select the larger number among pairs of nonadjacent, nontrained numbers. Darrell's data also suggests that familiarity with a greater number of Arabic representations, with which the animals had a working knowledge relative to their individual quantitative referents, contributed significantly toward organizing numbers into a coherent series.

CONSTRAINTS ON COUNTING CAPABILITIES?

Although some have required varying degrees of persistence in training, most number tasks that have been attempted with Darrell and Sheba had been learned by the animals. More recently, a study that involved a numerosity comparison task was designed to be conducted with two chimpanzees. Successful outcome of the task was dependent on the cooperation of both animals. The first phase of the study involved teaching the chimps a simple task in which they were required to compare two separate dishes of candies, each containing different numbers of food jtems. One chimp was supposed to select a dish, and the experimenter then would provide the contents of that dish to the second chimpanzee. The contents of the remaining dish would then be given to the chimp who had made the initial selection. Given the not-so-altruistic nature of chimpanzees when it comes to food, we had predicted that the chimps would eventually learn that if they picked the dish containing the smaller number of candies first, they would reap the larger amount from the second dish for themselves. Once the chimps learned this task, we proposed, we would introduce a cover for the dishes so that only one chimp would be able to see which dish had the larger amount. The chimpanzee who had visual access to the food dishes, however, would not have physical access to handles that operated a connecting mechanism between the two food dishes. If the chimp who knew where the food was located pointed to the correct dish, the other chimp, who had access to the rods, could pull on the correct rod, and bring the food dishes to within reach of each chimp. The chimps already knew how to operate the apparatus from an earlier study on perspective-taking (Povinelli, Nelson, & Boysen, 1990). For the comparison study described here, the goal was to see if the pointing chimp would attempt to deceive the other animal by indicating the dish with the smaller amount first. What began as a study of possible intentional deception between chimpanzees ended up as a very intriguing picture of possible perceptual preparedness, constraints on learning, and a glimpse at the power of symbols.

Sheba and Sarah were selected as subjects for the study, and Sheba was chosen to be the first selector chimp. The apparatus (Fig. 2.5) had originally had four pairs of food dishes, although only one dish from each pair was ultimately used in the present study. Two of the four dishes were baited with candies on each trial, with one dish containing one candy, and the other containing two pieces on a given trial. The selector chimp, Sheba, was free to choose either dish, with the rule that whatever dish was chosen first, its contents were given to Sarah. Eight sessions were completed with the 1:2 ratio, with Sheba failing to perform above chance. The ratio of candies was then increased to 1 versus 4, to make the difference between the two arrays more discriminable, and perhaps increase Sheba's motivation to learn the task. Chance performance was maintained for the next eight sessions, as well as during eight additional sessions with ratios of 1 versus 6 candies per trial. When the animals switched social roles, so that now Sarah was the selector, she fared no better than Sheba in learning the task. Here were two of the most highly trained chimpanzees in the world, unable to acquire what we had perceived as a simple discrimination problem.

FIG. 2.5. Apparatus used in Numerosity Comparison Task.



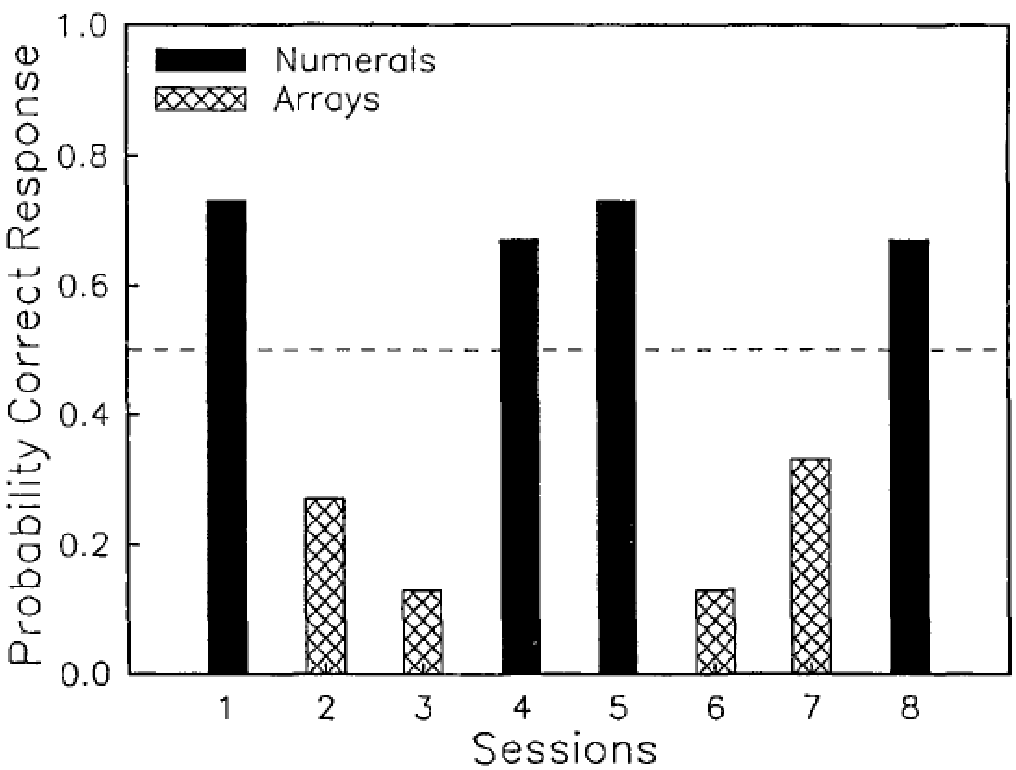
Although Sarah was still in the early stages of learning Arabic numerals, recall that Sheba had an extensive counting repertoire that now included use of number symbols from zero to eight. Neither animal seemed to be able to learn to pick the smaller array of candies, so we abandoned hopes of studying deception, and instead sought to understand why the animals were unable to learn the comparison task. Both chimps seemed unable to inhibit selecting the larger of the two arrays, regardless of the ratio of candies (1 vs. 2; 1 vs. 4; 1 vs. 6). We hypothesized that the immediate presence of the reinforcers may be interfering with their ability to either acquire the underlying rule structure of the task, or the presence of the food was interfering with their ability to invoke the rule that would net them the greater reinforcement. To explore these issues, the food arrays were replaced with number placards 1 versus 2, 1 versus 4, and 1 versus 6. Sheba's performance from Trial 1, Session 1 was correct, and her overall performance for that session and the next two was significant. Thus, her performance on the comparison task when number symbols were used to represent the food arrays suggested that, in fact, she had learned the rules of the task. However, this latent knowledge was being expressed only when number symbols, and not the actual food arrays, were used as stimuli. On Day 4, arrays of edibles were reintroduced, and Sheba's performance plummeted to 17%. Her performance over the entire nine sessions of this testing phase is shown in Table 2.3. Without question, Sheba was able to demonstrate recognition of the rule structure of the task that would permit her to garner the larger number of candies. Yet, she appeared to only be able to express this knowledge if representational symbols were employed (Boysen & Raskin, 1990). Any time that actual food items were used, her performance deteriorated to well below chance. These results now provided an additional, new question: Why was Sheba able to solve the task when number symbols were used?

TABLE 2.3. Numerosity Comparison Task: Alternating Sessions of Numerical Comparisons and Food Arrays*

Test Stimuli	Correct Trials / Total	% CR
Day 1 Numbers 1 vs. 2, 1 vs. 4, 1 vs. 6	8/12	67
Day 2 Numbers	9/12	75
Day 3 Numbers	10/12	83
Day 4 Foods	2/12	17
Day 5 Numbers	9/12	75
Day 6 Numbers	8/12	67
Day 7 Foods	2/12	17
Day 8 Foods	2/12	17
Day 9 Numbers	9/12	75

*Sheba as selector

FIG. 2.6. Numerosity Comparison Task: Performance comparisons between novel number pairs and food arrays.



Recall that the ratios of the arrays always consisted of 1 versus 2, 4, or 6 candies, and thus the numbers used in the symbol sessions were 1 versus 2, 4, or 6. This raised the possibility that Sheba had fortuitously learned to select the numeral “1,” and was continuing a “win-stay’’ strategy without necessarily recognizing the actual strategy for solving the problem (i.e., select smaller amount first; one receives larger remainder). To test this hypothesis, we ran eight test sessions in an ABBA design, during which edible arrays were used as stimuli for four sessions, and number combinations comprised of all possible numbers in Sheba's counting repertoire were used as stimuli in the other four sessions. Sheba's performance over the eight sessions was virtually identical to the first test (Fig. 2.6). She was able to readily complete each novel symbol trial, reliably selecting the smaller number of the pairs. Thus, she consistently received the larger number of reinforcements on each trial, and Sarah got the smaller amount. These tests eliminated the hypothesis that Sheba had simply learned to pick the numeral ''I'' in the first test, when the symbolic comparison trials used only I compared with 2, 4, or 6. Rather, she was operating from a more general conceptual rule" pick the smaller number first." These findings also suggested that Sheba had learned the task, even though she continued to be unable to express her knowledge of the conceptual rule if physical arrays were used. The use of numerical representations, however, permitted her to accurately and consistently decide between each symbolic comparison (Boysen & Raskin, I990). In a very dramatic way, replacing the physical arrays with an abstract, arbitrary symbol freed Sheba from the limitations and constraints imposed by the immediate presence of the food items. If, however, her tendency to choose the larger food source is viewed as part of an innately endowed, adaptive mechanism that permits the rapid evaluation and/or estimation of quantity, it is not difficult to see how such a processing system would be advantageous for a foraging, visually oriented species like the chimpanzee. It is only within a cultural context such as a primate learning study, when the task at hand imposes a conceptual rule that, in principle, runs counter to a more adaptive response, that we were able to view the chimpanzee's inability to acquire the "correct" response. A myriad of questions remain with respect to the demonstrated performance differences with physical arrays and numerical representations, and the level of response preparedness for quantity judgments in the chimpanzee. Additional studies are currently underway in an effort to further clarify the relative perceptual and cognitive contributions to the animals' performance.

CONCLUSIONS

Studies of numerical competence in the chimpanzee continue to provide new insights into the range and capacity for quantitatively based information processing in this species. In general, the rebirth of studies of animal counting currently suggests that this area remains a rich and fruitful source of contributions to our understanding of animal cognition and behavior. And for a truly comparative perspective, it will be important for researchers to challenge their creativity, by continuing to devise new methods for tapping capacities toward counting in a variety of species, including nonhuman primates, rats, birds, and additional new species for whom no data currently exists.

REFERENCES

Boysen, S. T. (1992a). Counting as the chimpanzee views it. In G. Fetterman & W. K. Honig (Eds.), *Cognitive aspects of stimulus control* (pp. 367-383). Hillsdale, NJ: Lawrence Erlbaum Associates.

Boysen, S. T. (1992b). Pongid pedagogy: The contribution of human/chimpanzee interaction to the study of ape cognition. In H. Davis & D. Balfour (Eds.), *The inevitable bond: Examining scientist-animal interaction* (pp. 205-217). New York: Cambridge University Press.

Boysen, S. T. (1988, May). *Pour is more: Evidence for an understanding of ordinality in chimpanzees* (Pan troglodytes). Paper presented at the annual meeting of the Midwestern Psychological Association, Chicago, IL.

Boysen, S. T., & Berntson, G. G. (1989). The development of numerical competence in the chimpanzee *(Pan troglodytes). Journal of Comparative Psychology, 103,* 23-31.

Boysen, S. T., & Berntson, G. G. (1990). The development of numerical skills in chimpanzees *(Pan troglodytes).* In S. T. Parker & K. R. Gibson (Eds.), *"Language" and intelligence in nonhuman primates* (pp. 435-450). New York: Cambridge University Press.

Boysen, S. T., & Raskin, L. S. (1990, November). *Symbolically-facilitated discrimination of quantities by chimpanzees.* Paper presented at the annual meetings of the Psychonomic Society, New Orleans, LA.

Capaldi, E. J., & Miller, D. J. (1988). Counting in rats: Its functional significance and the independent cognitive processes that constitute it. *Journal of Experimental Psychology: Animal Behavior Processes, 14,* 3-17.

Davis, H. (1984). Discrimination of the number "three" by a raccoon *(Procyon lotor). Animal Learning and Behavior, 12,* 409-413.

Davis, H., & Perusse, R. (1988). Numerical competence in animals: Definitional issues, current evidence, and a new research agenda. *The Behavioral and Brain Sciences, 11,* 561-579.

Dooley, G. B., & Gill, T. (1977). Acquisition and use of mathematical skills by a linguistic chimpanzee. In D. M. Rumbaugh (Ed.), *Language learning by a chimpanzee: The Lana project* (pp. 247-260). New York: Academic Press.

Ferster, C. B. (1964). Arithmetic behavior in chimpanzees. *Scientific American, 210,* 98-106.

Fouts, R. S., Fouts, D. H., & Schoenfeld, D. (1984). Sign language conversational interactions between chimpanzees. *Sign Language Studies, 34,* 1-12.

Fuson, K. C. (1982). An analysis of the counting-on solution procedure in addition. In T. C. Carpenter, J. M. Moser, & T. A. Romberg (Eds.), *Addition and subtraction: A cognitive perspective* (pp. 67-81). Hillsdale, NJ: Lawrence Erlbaum Associates.

Fuson, K. C. (1988). *Children's counting and concepts of number.* New York: Springer-Verlag.

Gardner, R. A., Gardner, B. T., & van Cantfort, T. (1989). *Teaching sign language to chimpanzees.* Albany: State University of New York Press.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number.* Cambridge, MA: Harvard University Press.

Gillan, D. J. (1981). Reasoning in the chimpanzee: II. Transitive inference. *Journal of Experimental Psychology: Animal Behavior Processes,* 7, 150-164.

Groen, G. J., & Parkman,]. M. (1972). A chronometric analysis of simple addition. *Psychological Review, 79,* 329-342.

Groen, G. J., & Resnick, L. B. (1977). Can preschool children invent addition algorithms? *Journal of Educational Psychology, 69,* 645-652.

Halford, G. S. (1984). Can young children integrate premises in transitivity and serial order tasks? *Cognitive Psychology, 16,* 65-93.

Hayes, K. J., & Nissen, C. H. (1971). Higher mental functions of a home-raised chimpanzee. In A.M. Schrier & F. Stollnitz (Eds.), *Behavior of nonhuman primates* (Vol. 4, pp. 59-115). New York: Academic Press.

Hicks, L. H. (1956). An analysis of number-concept formation in the rhesus monkey. *Journal of Comparative and Physiological Psychology, 49,* 212-218.

Kingma, J., & Zumbo, B. (1987). Relationship between seriation, transitivity, and explicit ordinal number comprehension. *Perceptual and Motor Skills, 65,* 559-569.

Koehler, O. (1950). The ability of birds to "count." *Bulletin of Animal Behavior, 9,* 41-45.

Matsuzawa, T. (1985). Use of numbers by a chimpanzee. *Nature, 315,* 57-59.

McGonigle, B., & Chalmers, M. (1977). Are monkeys logical? *Nature, 267,* 694-696.

Menzel, E. (1960). Selection of food by size in the chimpanzee, and comparison with human judgments. *Science, 131,* 1527-1528.

Oden, D., & Thompson, R. (1992). The role of social bonds in motivating chimpanzee cognition. In H. Davis & D. Balfour (Eds.), *The inevitable bond: Examining scientist-animal interaction.* New York: Cambridge University Press.

Pepperberg, I. M. (1987). Evidence for conceptual quantitative abilities in the African Grey Parrot: Labelling of cardinal sets. *Ethology, 75,* 37-61.

Povinelli, D.J., Nelson, K. E., & Boysen, S. T. (1990). Inferences about guessing and knowing by chimpanzees *(Pan troglodytes). Journal of Comparative Psychology, 104,* 203-210.

Premack, D. (1986). *Gavagai.* London: Cambridge University Press.

Rumbaugh, D. M. (1977). *Language learning in a chimpanzee: The Lana project.* New York: Academic Press.

Rumbaugh, D. M., Savage-Rumbaugh, E. S., & Hegel, M. (1987). Summation in the chim*panzee. Journal of Experimental Psychology: Animal Behavior Processes, 13,* 107-115.

Savage-Rumbaugh, E. S. (1986). Ape language: From conditioned response to symbol. New York: Columbia University Press.

Savage-Rumbaugh, E. S., Rumbaugh, D. M., & Boysen, S. (1980). Do apes use language? American Scientist, 68, 49-61.

Starkey, P., & Gelman, R. (1982). The development of addition and subtraction abilities prior to formal schooling in arithmetic. In T. P. Carpenter, J. M. Moser, & T. A. Romberg (Eds.), Addition and subtraction: A cognitive perspective (pp. 99-116). Hillsdale, NJ: Lawrence Erlbaum Associates.

Woodruff, G., & Premack, D. (1981). Primitive mathematical concepts in the chimpanzee: Proportionality and numerosity. Nature, 293. 568-570.