

WellBeing International
WBI Studies Repository

1992

Counting as the Chimpanzee Views It

Sarah T. Boysen
The Ohio State University

Follow this and additional works at: <https://www.wellbeingintludiesrepository.org/numera>

 Part of the [Animal Studies Commons](#), [Comparative Psychology Commons](#), and the [Other Animal Sciences Commons](#)

Recommended Citation

Boysen, S. T. (1992). Counting as the chimpanzee views it. Cognitive aspects of stimulus control. Erlbaum, Hillsdale, 367-383.

This material is brought to you for free and open access by WellBeing International. It has been accepted for inclusion by an authorized administrator of the WBI Studies Repository. For more information, please contact wbisr-info@wellbeingintl.org.



Counting as the Chimpanzee Views It

Sarah T. Boysen^{1,2}

¹ The Ohio State University

² Yerkes Regional Primate Research Center

INTRODUCTION

The study of numerical competence in animals has a long and colorful history (Rilling, in press), and studies that require judgments of quantity continue to be actively explored in a variety of nonhuman species, including rats (Capaldi & Miller, 1989), pigeons (Honig & Stewart, 1989), the African grey parrot (Pepperberg, 1987), squirrel monkeys (Thomas & Chase, 1980), and chimpanzees (Boysen & Berntson, 1989; Matsuzawa, 1985). Despite differences in methods and interpretations, the evidence seems compelling that species other than *Homo sapiens* are capable of representing relative and/or absolute numerosities (Davis & Perusse, 1988).

For the past several years, we have been exploring the acquisition of number concepts in chimpanzees (*Pan troglodytes*), a species with considerable biological and perhaps cognitive overlap with humans (Goldman, Giri, & O'Brien, 1987; Goodman, Braunitzer, Stangl, & Shrank, 1983). Chimpanzees have demonstrated capabilities for utilizing symbolic information in cross-fostering contexts (Gardner, Gardner, & van Cantfort, 1989) and more structured laboratory settings (Premack, 1976; Savage-Rumbaugh, 1986). One question of particular interest is the extent to which a chimpanzee might demonstrate numerical competence without such prior language-like training (i.e., symbol manipulation).

Premack (1983, 1986) has suggested that language training imbues a tutored chimpanzee with problem-solving capacities that are not demonstrable in animals that have not been so trained. Such differences are most apparent in analogy tests during which a language-trained animal (Sarah), using plastic symbols that represented words (Premack, 1971), was able to solve analogy problems that required an understanding of relational features among relations (Gillan, Premack, & Woodruff, 1981). For example, other chimpanzees that had not received comparable training were unable to solve the relational analogy task (Premack, 1983), although they were able to solve same/different tasks that required them to recognize and match physical similarities between a sample and two possible alternatives. However, Sarah was capable of judging whether the relationship between two *pairs* of sample stimuli were the "same" or "different," by selecting symbols that represented similarity or differences in the relational features of the stimulus pairs. Premack (1983) proposed that two different representational codes subserved performance on the two versions of same/different tasks. A match-to-sample task based on nonrelational physical similarity could be solved by animals relying upon an imaginal code, whereas solution of the relational analogy task required the use of an abstract code. Cautioning that language training could not instill an abstract code, Premack suggested that, for those species that have access to such a code, language training may enhance their ability to utilize it (Premack, 1983).

Premack's ideas on the contribution of language training to complex problem solving have been challenged (e.g., Haber, 1983; Roberts, 1983; Roitblat, 1983), and it still needs to be determined what cognitive abilities might be tapped in chimpanzees not trained in the use of an artificial symbol system. In the area of numerical competence, we have studied the acquisition of counting skills in chimpanzees who were already immersed in an interactional learning context but did not have language training (Berntson & Boysen, 1990; Boysen & Berntson, 1986; Boysen, Berntson, & Prentice, 1987). Number-related tasks

were one of many cognitive tasks designed to engage the chimps daily with their human teachers. Although the animals were intentionally tutored in number skills, the task setting was highly social. The actual teaching periods were quite brief, typically 15-20 minute sessions on a given number task, consisting of 15-20 trials per animal per day. Thus, the chimps did not depend on a computer or mechanical apparatus for daily rations, stimulation, or instruction. Instead, the setting was more reminiscent of an open preschool in which children are engaged in a variety of activities throughout the day, some of which are more structured than others.

Preliminary Training on Number Concepts

Training began with two young male chimpanzees, Kermit and Darrell (4.5 and 5 yrs. old, respectively, at the start of the study), approximately 1 year after their arrival at Ohio State. The third chimpanzee, Sheba (4 yrs. old at the beginning of the study and previously home reared from age 4 mos. to 2.5 yrs.), had been with the project for 6 months. Initial training consisted of a simple task designed to encourage the mapping of one-to-one correspondence. The animals were required to place objects one at a time into a tray that was partitioned into six compartments until all the bins were filled. They received social praise and candy after each successful turn, and all three animals acquired facility with the task within two sessions.

One-to-One Correspondence. The next task was an elaboration of the one-to-one correspondence paradigm that was intended to expand the animals' representation of quantity from arrays consisting of a single item to arrays of three. In this task, the chimps were required to select a round placard that had one, two, or three markers affixed (Fig. 18.1), equal to the number of candies presented on a given trial. As the experimenter presented each array of candies, she always counted aloud and tagged each item with her index finger. On completion of the count, she repeated the last number of the count series verbally. In this phase of training, as in all subsequent number-related tasks, the chimps were permitted to eat the items following a correct response. In the first phase of training on the task, three placards were presented, with one marker fixed on a single placard, and the other two left blank (see Fig. 18.1A). Only one-item arrays were presented, with the position of the placard bearing the single marker being counterbalanced across trials. Once the animals were reliably selecting the singly marked placard, one of the blank placards was replaced with one bearing two markers (Fig. 18.1B). Each trial now consisted of the presentation of two-item arrays, with the chimps choosing from among placards bearing 1, 2, or 0 markers. As before, locations of all choice alternatives were counterbalanced. Following criterion (90% performance for two successive sessions) on two-item arrays, training consisted of trials in which one or two items were presented, to be matched with the correct placard bearing one or two markers (Fig. 18.1C). In contrast to the earlier phases, however, the chimps were now required to attend to the specific number of items in the array. In the earlier training phase, only a single array (consisting of one and later two items) was presented within a session. In this phase, with array size varying between one and two items, a specific one-to-one correspondence was necessary for the animals to be correct on a given trial. Considerable training was necessary for the animals to move beyond this phase, and following criterion, the final blank placard was replaced with one bearing three markers. The animals were now required to select the corresponding marked placard when confronted with 1-, 2-, or 3-item arrays on a given trial (Fig. 18.1D).

The Transition from Static Arrays to Arabic Symbols. The introduction of Arabic numerals was accomplished by systematically replacing the marked placards (with their fixed arrays) with a corresponding numeral (Fig. 18.2). Initially, only the placard with one marker was replaced by the numeral! (Fig. 18.2A). The two remaining placards and the Arabic numeral 1 now served as the response alternatives for trials in which arrays of one to three candies were presented. Each successive numeral

was added by replacing the corresponding placard, and the animals' performances were always required to return to criterion before the next number was added (see Fig. 18.2B and Fig. 18.2C).

FIG. 18.1. Stimuli presented for training phases of one-to-one correspondence.

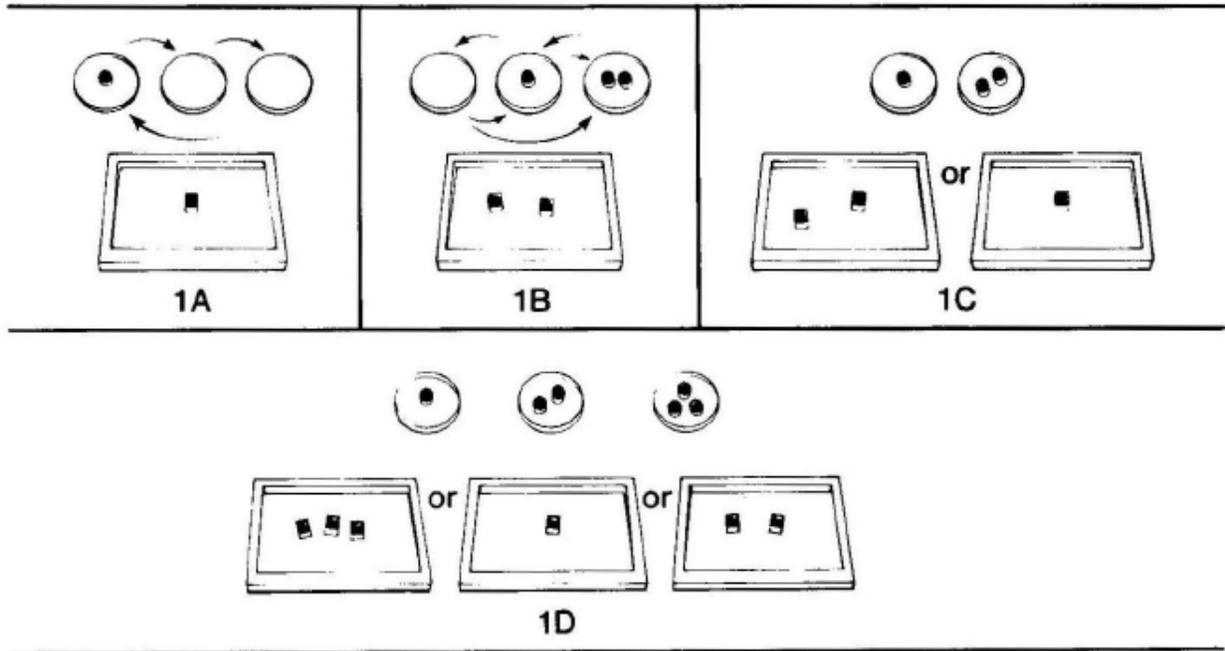
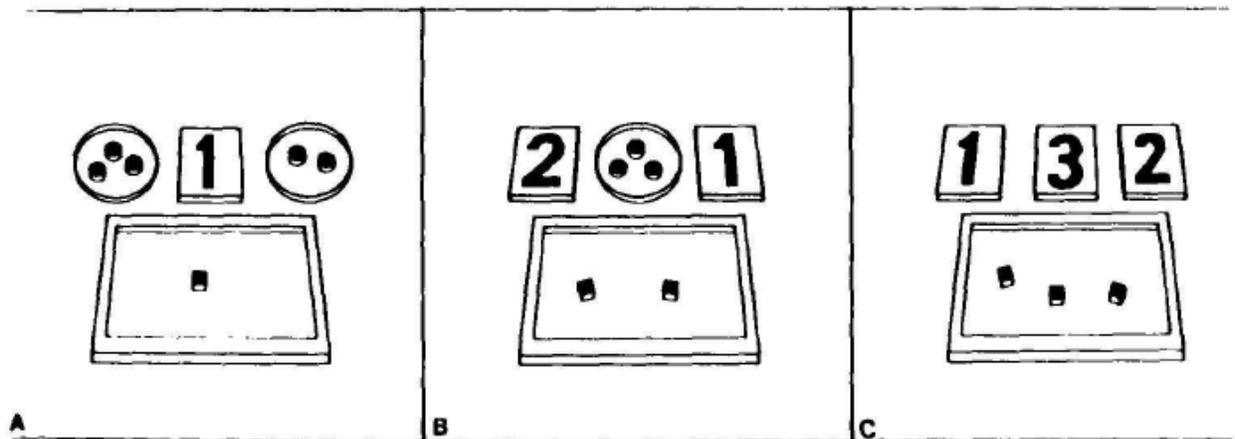


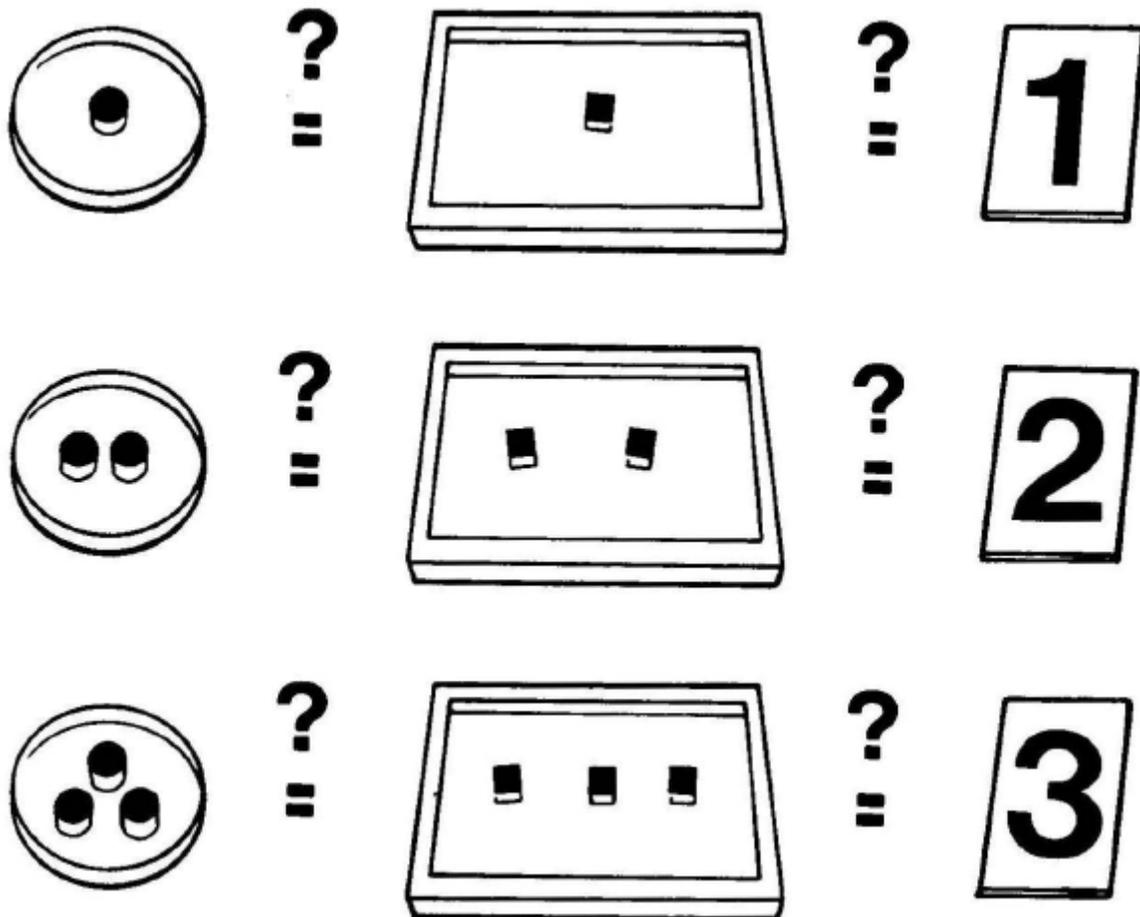
FIG. 18.2. Transitional stimulus arrays employed during the introduction of Arabic numeral symbols.



The initial training phase just described, consisting of the elaborated one-to-one correspondence task using static arrays (shown in Fig. 18.1), had been designed to address a pivotal principle found in every model of counting, known as the one-one principle (Gelman & Gallistel, 1978). This principle is included in Gelman and Gallistel's (1978) "how-to-count" principles and describes the process whereby a child must tag items in an array in such a way that one and only one tag is used for each item. Children accomplish this process either mentally or physically by transferring items one at a time from a category of items that remain to be tagged, to those that have already been tagged. If our chimpanzees were to

employ tagging as described for counting in young children (Fuson, 1988; Gelman & Gallistel, 1978), it would ultimately be essential for them to recognize the one-to-one relationship between representative symbols (in this case, Arabic numerals) and the corresponding number of items in an array.

FIG. 18.3. Potential stimulus equivalence relationships among and between different stimuli used by the chimpanzees during number-related tasks.



Although the chimps' performance suggested they were able to coordinate such a one-one correspondence between the markers on the stimulus placards and the number of candies presented on each trial, other alternative hypotheses could account for, or contribute to, their observed behavior. For example, because the marked placards were fixed static arrays, it could be possible for the animals to associate a particular stimulus pattern with a specific number of items, rather than to recognize a strict one-to-one relationship. They could also have associated differing stimulus densities with a particular placard pattern. Although the specific configuration of the arrays of gumdrops differed between trials, arrays consisting of one item were less dense than arrays of two or three items. Differences among arrays that were associated with the marked placards could have been based on such numerosity as opposed to enumeration, and not necessarily on numerical cues alone. It is also conceivable that some combination of spatial and numerical cues contributed to an overall configuration that was then associated with a specific placard pattern. Although it is not clear what type of strategy the chimps applied in the task, their behavioral performances nonetheless met our criteria for moving onto the next stage of numbers training.

When Arabic numerals were introduced, they were intended to serve as equivalent stimuli for the marked placards (Devany, Hayes, & Nelson, 1986; Sidman & Tailby, 1982), so that numerals would now symbolically represent and replace the fixed arrays on the placards. However, our perspectives of the new stimuli may not have been shared by the chimps, who were now required to respond to novel orthographic configurations. Their task was to associate a specific numeral with a particular array of edibles. The chimps continued to be permitted to eat the "stimuli" following a correct response. This facet of our training procedure (obtaining and ingesting the counted items) appears to have been a significant procedural contribution to the animals' overall success with number concepts. Immediate access to the food items was highly motivating. Earlier attempts at training chimpanzees on numerical concepts, such as the extensive training on binary numbers by Ferster (1964), or the efforts by Hayes and Nissen (1971) to teach Viki to match numbers of dots on cards, met with little success in providing the animals with enumerative skills. Getting to eat what you count appears to have more ecological validity for the chimpanzee.

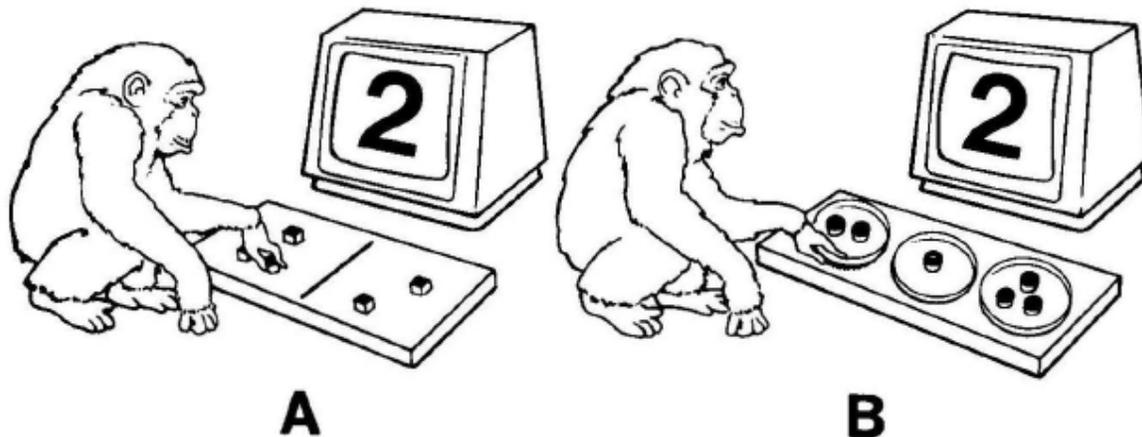
Alternative strategies, other than numerical cues, may also have facilitated performance on the Arabic numeral task. The Arabic numerals could have been seen in some sense as equivalent to, or associated with, the corresponding marked placards, and thus served as substitutes in the relationship between the different arrays (1, 2, or 3 items) and the respective placards (Fig. 18.3). As already noted, the associations between Arabic numerals and array size could also have been based on stimulus density and/or other perceptual cues related to the stimulus configurations. Numerical cues may not have been involved in the task solution. Nonetheless, the animals' behavior, in terms of solving the problems as presented, met our performance criterion of two successive sessions of 90% correct response, regardless of the strategies they were employing at the time.

Receptive Number Training. The next phase of number training was modeled after procedures previously employed by Savage-Rumbaugh (1986), with chimpanzees trained on a visual symbol system. It was apparent that chimpanzees with productive skills using graphic symbols did not spontaneously transfer such abilities in the receptive mode; that is, the ability to use a symbol to label a referent did not automatically mean that the animal was able to comprehend the use of that same symbol by someone else. Thus, the chimps in Rumbaugh's lab were able to name foods (e.g., "orange") and other objects, but could not initially respond when an experimenter used their keyboard to ask them to, for example, "Show me the orange," when a collection of foods and objects was presented. Rather, comprehension (the receptive use of symbols) had to be taught as a separate skill. Similarly, in the present studies, we assumed that, if number symbols were to represent quantities at an abstract level, it would be necessary for the chimps to have both productive *and* receptive abilities with Arabic numerals. Thus, if selection of an Arabic numeral allowed a chimp to "produce" a label for an array, a comparable receptive task was necessary for the animals to demonstrate number comprehension.

After one false start, the chimps readily acquired receptive skills with number symbols. The task was originally designed such that two different-sized arrays of candies were presented simultaneously, while the chimp viewed a single Arabic numeral displayed on a video monitor (Fig. 18.4A). The chimp was required to point to an array that was composed of the same number of items represented by the number on the screen. However, we quickly discovered that the animals would not inhibit pointing to the larger of the two arrays and thus ignored the displayed number completely. They appeared to interpret the task as an opportunity to pick between two collections of gumdrops, and, given a choice, they invariably selected the larger array. This difficulty in attending to the displayed numeral, which we had intended to be the relevant dimension of the task, was overcome by employing the marked placards from the one-to-one correspondence task, in place of arrays of edibles (see Fig. 18.4B). Now the animals viewed an Arabic numeral on the television screen and pointed to the placard that had the corresponding number of

markers as a fixed array (see Fig. 18.4B). This required that the chimps be able to decode a specific number and match that representation with a placard having the equivalent number of markers. The receptive task was, in a sense, the reverse of the initial one-to-one correspondence task, except that arrays of edibles were not used as choice stimuli. Instead, the animals had to treat the Arabic numeral symbols as equivalent to arrays of items and then match the numerals with the respective marked placard. All three animals required a comparable number of trials to reach criterion on the receptive task.

FIG. 18.4. Initial training task (A) for receptive numbers (number comprehension), which was abandoned; successful format (B) of receptive task that led to number comprehension by the animals.



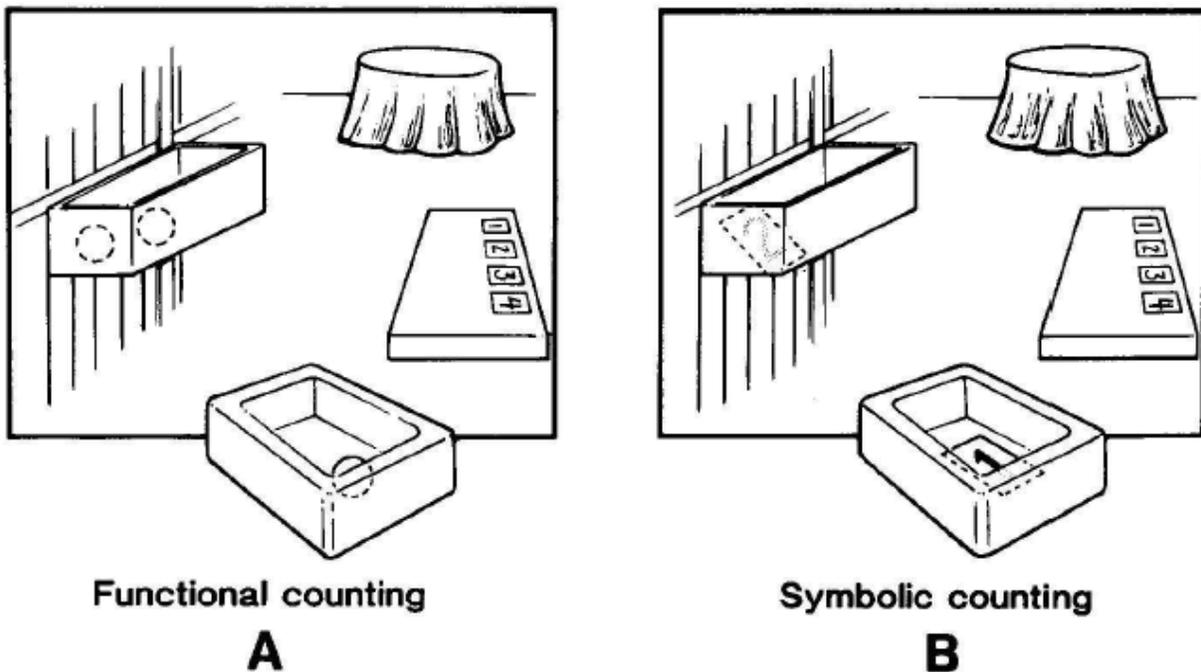
These three tasks, one-to-one correspondence, productive labeling of arrays using Arabic numerals, and comprehension of Arabic numerals, represented the only structured training situations within which the chimpanzees were tutored in number concepts. A permanent record of every trial for each task was maintained, so that a complete acquisition history is available for all three chimpanzees. Individual differences were quite apparent across all three animals, similar to differences we have observed on other conceptual tasks (Boysen, in press). Kermit, for example, grew increasingly confused with Arabic numbers as we attempted to increase his repertoire beyond 4. In other testing situations, such as vigilance tasks, Kermit's performance was remarkably similar to children with Attention Deficit Disorder (O'Dougherty, Berntson, Boysen, Wright, & Teske, 1988); that is, any manipulation of the stimuli, such as perceptual degradation or decreased viewing time, resulted in a significant decrement in Kermit's performance, mirroring precisely the type of deterioration in performance on the same vigilance task we had used to test ADD children (O'Dougherty et al., 1988). Ultimately, his formal numbers training was temporarily curtailed, and more time was devoted to Sheba, a younger and more tractable animal than the emotionally labile adolescent Kermit.

Functional and Symbolic Counting: The Emergence of a "Sense of Number"

As we continued to expand Sheba's counting repertoire, we recognized that what she could *do* with numbers was of much more interest to us than how large her counting repertoire might become. To address the use of numbers in a more functional sense, a counting task requiring summation that we called functional counting was devised. This task combined several novel features that were not previously included in the chimps' structured numbers training (Boysen & Berntson, 1989). Three sites were designated in the laboratory where food items could be hidden from view (oranges were chosen for their perceptual salience). On a given trial, the experimenter placed between one and four oranges in two of the three sites. Sheba's task was to move from site to site and return to a starting point where her

number placards were displayed in ordinal sequence (Fig. 18.5A). There she was to indicate (by pointing to one of the Arabic numerals) the number that represented the total number of food items she encountered on her foray among the three sites. Although we had assumed that Sheba might eventually come to acquire proficiency with the functional counting task, we were quite surprised when she performed at a significant level during the very first session. Clearly more questions were raised than were answered by her performance. How did Sheba learn to sum arrays? What facet of her previous training may have facilitated the integration of so many novel components of the functional counting task? The functional counting task required Sheba to locate an array, encode its quantity, move to another location, encode a second quantity, and then move to yet a third location. She had to maintain these representations in memory, or perhaps maintain a single running total, move back to her original starting location, and produce a label (by selecting the correct Arabic numeral) that represented the *total* number of items encountered across all three food sites. At that point in her training, the only subcomponent of the functional task for which she had specific training was labeling individual arrays of zero to five items (following receptive training, the numbers "0," "4," and "5" had been introduced directly as Arabic symbols). She was also well versed in receptive number comprehension and one-to-one correspondence. None of these individual tasks, however, appeared adequate in preparing her to deal with the complexities of the functional task. Yet, Sheba's performance, significantly above chance from Session 1, suggested that she could manipulate numbers in ways that could not be explicitly traced to any of her prior structured training tasks. Rather, some generative process appeared to be operating that permitted her to integrate features of that training into cognitive number skills that transcended the specific training paradigms.

FIG. 18.5. Physical setting within the laboratory for the functional and symbolic counting tasks, including three possible sites for hiding stimuli, and an available series of Arabic numeral response placards from 0-4.



The functional counting task was immediately extended to include sessions in which the arrays of oranges were replaced by Arabic symbols between 1 and 4, termed the symbolic counting task (Fig.

18.5B) (Boysen & Berntson, 1989). Now Sheba might encounter the numeral "2" at one site, and the numeral "1" at another, and was required to select the correct Arabic label "3" from among her number alternatives. Once again, during her first opportunity to do so, Sheba's performance was significantly above chance (Day 1: 10/12 correct trials; 83 percent CR; $X^2 = 21.77$, $p = 0$), and she maintained similar performance during subsequent blind test sessions (17/20 correct trials; 85% CR; $X^2 = 35.27$, $p < .001$).

Developmental Studies of Addition in Children

The literature on emergent counting principles observed in very young children's addition and subtraction performance may provide theoretical support for Sheba's performance on the functional and symbolic counting tasks. Groen and Parkman (1972) have described the use of spontaneous addition algorithms in young children (mean age = 4 yrs 8 mos) and the application of such algorithms despite intentional training by experimenters to employ another explicit strategy. By a process not yet clearly understood, young children acquire some understanding of increasing and decreasing numerosity that appears to grow out of their early counting experience, prior to any formal training in arithmetic. A variety of hypotheses have been proposed to account for the appearance of such rudimentary summation and addition (Groen & Parkman, 1972; Groen & Resnick, 1977; Starkey & Gelman, 1982). A growing body of evidence indicates that children are able to use several counting strategies for solving addition or subtraction problems prior to formal instruction, and that these same strategies can be used successfully to solve even simple word problems (Carpenter & Moser, 1982). More recently, Starkey and Gelman (1982) noted that preschool children possess a counting scheme and are therefore capable of much more than rote counting (also see Fuson, 1988; Gelman & Gallistel, 1978). They suggest that young children's use of algorithms reveals more about their understanding of counting than simply their ability to apply algorithms to solve addition and subtraction problems, because children who use counting algorithms must also be able to recognize and select the appropriate type of counting to solve a specific type of problem (Starkey & Gelman, 1982). Thus, pre-school children appear to have an understanding of the directional effects of numerosity of adding and subtracting elements from an array and are able to infer the occurrence of either operation by establishing directional effects on numerosity (Starkey & Gelman, 1982). These authors suggest that current data support the view that number forms a natural cognitive domain, and that cultural transmission is not necessary for children to separate number from domains of space, time, or causality.

CONCLUSIONS

We would also argue that, for the chimpanzee, and for a number of other nonhuman species, sensitivity to quantity and/or number also forms a natural cognitive domain (also see Capaldi & Miller, 1989). An important premise to understanding the results from the functional and symbolic tasks is that Sheba is able to count (Boysen & Berntson, 1989) and that she may be using strategies similar to those used by young children (Fuson, 1988; Gelman & Gallistel, 1978). With respect to Sheba's sense of number, we have provided her with an overt symbol system that has been intentionally mapped onto and/or associated with specific quantities. This symbol system, which currently consists of Arabic numerals from 0-8, has come to serve as representations for various equivalent sets of numerically based stimuli. This background may have set the cognitive stage for Sheba to apply counting algorithms for summing arrays in both the functional and symbolic counting tasks. For Sheba, two apples share a functional dimension of equivalence to the symbol "2," to a placard with two markers on it, two gumdrops (or any two foods), two balloons (or any two objects), or two of anything else. In light of Sheba's extensive training on counting, it seems reasonable to suggest that she was able to employ a counting algorithm such as counting-on (Fuson, 1988), when first confronted with different arrays placed in two spatial locations. And, because the various types of numerical stimuli may be all functionally equivalent to her, substituting Arabic

numerals for actual objects did not disrupt the application of a counting algorithm in the symbolic counting task.

It is difficult to conceive of how Sheba would have been able to solve either the functional or symbolic tasks from the outset if she were unable to count. The arrays were not physically visible to her when she made her choice among the number alternatives (see Fig. 18.5), and thus no direct comparisons of the arrays based on physical and/or perceptual cues were possible. Any comparisons Sheba made had to be at an abstract, representational level, and this applies particularly to the case where the hidden stimuli consisted of Arabic numerals. Regardless of the original strategies Sheba may have used to acquire the relationships among the number-related stimuli, which included marked placards, arrays of edibles, Arabic numerals, and probably spoken English number words, performance on the functional and symbolic tasks suggested that some emergent principles that had not been explicitly taught were responsible for her behavior. She was able to integrate completely novel task parameters into a meaningful problem-solving context, permitting rapid solution of the problem at hand. In hindsight, both the experimental structure of these tasks, and her ability to grasp the fundamental features of the problem without specific training in summation, are tantalizingly similar to those situations in which very young children utilize counting algorithms of their own invention (Groen & Resnick, 1972; Ilg & Ames, 1951; Starkey & Gelman, 1982).

As noted, several features of our training procedures for the establishment of numerical skills in the chimps share some of what appear to be critical cross-modal features for establishing stimulus-equivalence (Sidman & Cresson, 1973; Sidman, Rauzin, Lazar, Cunningham, Tailby, & Carrigan, 1982). It has been noted by Sidman et al. (1982) that stimulus equivalence has not been clearly demonstrated in any nonhuman species, although Vaughan (1988), using pigeons, may represent an exception. With the chimps, efforts to train productive and receptive use of number symbols may have established an equivalence relationship among the various forms of numerical stimuli employed. These include the static arrays originally used to teach one-to-one correspondence, arrays of edibles and objects composed of zero-to-eight objects, Arabic numerals used to "label" arrays, and may also include comprehension of spoken English number words (used by experimenters during all number-related tasks). (Note: The chimps' ability to understand spoken English other than number words has been evaluated in a separate study [Boysen, Raskin & Berntson, 1991], and testing for the comprehension of number words is planned for the near future.)

Three properties are necessary to define equivalence relations among stimuli (Sidman & Tailby, 1982; Sidman et al., 1982). The first property is Reflexivity, which is demonstrated through identity matching. A subject who has acquired an arbitrary sample-comparison relation (A-B) must be able, without additional explicit training, to match A to itself, and B to itself. A second property of equivalence relations is Symmetry, demonstrated when a subject who has learned to match a sample A to comparison B is able, without explicit training, to match B as a sample to A as a comparison (Sidman & Tailby, 1982). The third property of equivalence is Transitivity. To demonstrate transitivity, a subject must be taught a second sample-comparison set B-C. If the relations A-B and B-C are transitive, the subject should be able to match sample A to comparison C, and thus a third relation, A-C, will be generated. These properties have been evaluated in numerous human populations, including retarded children with, and without, language (Devany, Hayes, & Nelson, 1986; Sidman & Cresson, 1973). Sidman and Tail by (1982) reported that most children, when challenged in such a conditional discrimination study, could form equivalence sets, and Devany et al. (1986) found equivalence formation in formal and retarded children who had language. However, they did not observe the development of equivalence relations in retarded children who did not possess language. These authors suggested that language and symbol use could therefore be pivotal to such abilities.

These findings raise possible explanations for the few instances of such demonstrated relations in nonhuman animals. For example, Sidman et al. (1982) found that children were able to demonstrate equivalence relations, but similar testing with baboons and rhesus macaques failed to show comparable performance. Similarly, D'Amato, Salmon, Loukas, and Tomie (1985) were able to demonstrate associative transitivity (but not symmetry) in monkeys but not in pigeons. More recently, Vaughan (1988) taught pigeons arbitrary stimulus equivalences by reinforcing responding to slides of trees that formed two separate arbitrary sets. After several training sessions, reinforcement contingencies were reversed again. Using the measure ρ , which represents the probability of ranking a positive over a negative, values above .5 indicated that the pigeons were responding correctly to most slides of a reversal session after correct responses to the initial slides. Vaughan proposed that the birds had learned arbitrary stimulus equivalences, with the reinforcement contingencies for slides at the beginning of a reversal session predicting reversed contingencies for the remaining slides in the different sets. It is important to note that Sidman et al. (1982) suggested that their failure to demonstrate equivalence formation in the animals they tested could have been due to methodological differences, and Vaughan acknowledges that his procedures differ significantly from those used by others to establish equivalence relations. Nonetheless, his data appear to establish the capacity for pigeons to acquire equivalence, whereas the behavioral process supporting how this phenomenon occurs remains unclear (Vaughan, 1988). What Vaughan's (1988) data also appear to indicate is the need to rethink some theoretical ideas about relations between language and equivalence set.

Evaluation of the chimps' numerical competence and possible equivalence formation among the various stimuli employed indicates that the animals have already demonstrated identity-matching capabilities throughout the testing with one-to-one correspondence, labeling with Arabic numbers and the receptive task, in support of the reflexivity property of equivalence. Similarly, they have demonstrated symmetry through the number comprehension or receptive task. Such testing will be expanded to additional testing of symmetry using Arabic numerals and photographs of object arrays. The chimps have demonstrated the capability of labeling arrays of foods and objects using Arabic symbols, and photographs should be readily substituted in the labeling task. If, without explicit training, the animals are able to select the appropriate photograph of an array when presented with an Arabic numeral, these results would provide additional support for the property of symmetry between number symbols and photographic representations of arrays (if A-B, then B-A).

In addition to expanded testing of symmetry, a second new relationship, transitivity, should be readily testable. Spoken English is used continuously in the laboratory, and during numbers training the experimenter always counted aloud as stimuli were presented. As previously noted, although the chimps' understanding of spoken English has been verified using familiar objects from the laboratory, no explicit tests have been completed for number words. The animals appear to understand number words, however, as verbal prompts typically yield positive results (e.g., "Find the two. Where the two?"). To explore transitivity, the B-C relation (B = Arabic numerals and C = spoken English number words) will be examined. As Sidman et al. (1982) has specified, from the conditional A-B, then B-C relationships, an emergent A-C relationship may be generated, demonstrating the formation of equivalence among the various relations. To explicitly test for transitivity with the chimps, it would be possible to present photographs of object arrays as comparison stimuli (used in tests of symmetry described earlier), with dictated English words as samples. If the animals were able to respond correctly, the property of transitivity (A-C) would be demonstrated, as the relationship between the photographs and spoken English count words would not have been explicitly taught. These tests for reflexivity, symmetry, and transitivity may provide the first experimental evidence for all three properties of equivalence set formation in a nonhuman species and provide additional insights into the boundaries of chimpanzee cognitive ability. We will continue to explore the capacity of the chimpanzee for numerical competence, as

such studies promise further glimpses into the Darwinian continuum that draws two similar, yet distinctly different, species closer toward understanding our shared cognitive heritage.

REFERENCES

Berntson, G. G., & Boysen, S. T. (1990). Cardiac correlates of cognition in chimpanzees and children. In L. Lipsett and C. Rovee-Collier (Eds.), *Advances in infancy* (pp. 187-220). New York: Ablex.

Boysen, S. T. (in press). Pongid pedagogy: The contribution of human/chimpanzee interaction to the study of ape cognition. In H. Davis & D. Balfour (Eds.), *The inevitable bond*. MA: Cambridge University Press.

Boysen, S. T., & Berntson, G. G. (1986). Cardiac correlates of individual recognition in the chimpanzee (*Pan troglodytes*). *Journal of Comparative Psychology*, 100, 321-324.

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

Boysen, S. T., Berntson, G. G., & Prentice, J. (1987). Simian scribbles: A reappraisal of drawing by chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology*, 101, 82-89.

Boysen, S. T., Raskin, L.A., & Berntson, G. G. (1991). *Comprehension of spoken English by common chimpanzees (Pan troglodytes)*. Paper presented at the annual meetings of the American Society of Primatologists, Vera Cruz, Mexico.

Capaldi, E. J., & Miller, D. J. (1989). A conditional numerical discrimination based on qualitatively different reinforcers. *Learning and Motivation*, 20, 48-59.

Carpenter, T. P., & Moser, J. M. (1982). The development of addition and subtraction problem-solving skills. In T. P. Carpenter, J. M. Moser, & T. A. Romberg (Eds.), *Addition and subtraction: A cognitive perspective* (pp. 9-24). Hillsdale, NJ: Lawrence Erlbaum Associates.

D'Amato, M. R., Salmon, D. P., Loukas, E., & Tomie, A. (1985). Symmetry and transitivity of conditional relations in monkeys (*Cebus apella*) and pigeons. *Journal of the Experimental Analysis of Behavior*, 44, 35-47.

Davis, H., & Perusse, R. (1988). Numerical competence in animals: Definitional issues, current evidence, and a new research agenda. *Behavioral and Brain Sciences*, 11, 561-615.

Devany, J. M., Hayes, S.C., & Nelson, R. O. (1986). Equivalence class formation in language-able and language-disabled children. *Journal of the Experimental Analysis of Behavior*, 46, 243-257.

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

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

Gardner, R. A., Gardner, B. T., & van Cantfort, T. E. (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., Premack, D., & Woodruff, G. (1981). Reasoning in the chimpanzee: I. Analogical reasoning. *Journal of Experimental Psychology: Animal Behavior Processes*, 7, 1-17.
- Goldman, D., Giri, P.R., & O'Brien, S. J. (1987). A molecular phylogeny of the hominoid primates as indicated by two-dimensional protein electrophoresis. *Proceedings of the National Academy of Sciences of the United States of America*, 84, 3307-3311.
- Goodman, M., Braunitzer, G., Stangl, A., & Shrank, B. (1983). Evidence on human origins from haemoglobins of African apes. *Nature*, 303, 546-548.
- Groen, G. J., & Parkman, J. M. (1972). A chronometric analysis of simple addition. *Psychological Review*, 70, 329-343.
- Groen, G. J., & Resnick, L. B. (1977). Can preschool children invent addition algorithms? *Journal of Educational Psychology*, 69, 645-652.
- Haber, L. (1983). Language training vs. training in relations. *Behavioral and Brain Sciences*, 6, 146-147.
- Hayes, K. J., & Nissen, C. H. (1971). Higher mental functions in a home-reared chimpanzee. In A. M. Schrier & F. Stollnitz (Eds.), *Behavior of non-human primates* (Vol. 4, pp. 70-115). New York: Academic Press.
- Honig, W. K. , & Stewart, K. (1989). Discrimination of relative numerosity by pigeons. *Animal Learning and Behavior*, 17, 134-146.
- Ilg, F., & Ames, L. B. (1951). Developmental trends in arithmetic. *Journal of Genetic Psychology*, 79, 3-28.
- Matsuzawa, T. (1985). Use of numbers by a chimpanzee. *Nature*, 315, 57-59.
- O'Dougherty, M., Berntson, G. G., Boysen, S. T., Wright, F. S., & Teske, D. (1988). Psychophysiological predictors of attentional dysfunction in children with congenital heart defects. *Psychophysiology*, 25, 305-315.
- Pepperberg, I. M. (1987). Evidence for conceptual quantitative abilities in the African Grey Parrot: Labelling of cardinal sets. *Ethology*, 75, 37-61.
- Premack, D. (1971). Language in the chimpanzee? *Science*, 172, 808-822.
- Premack, D. (1976). *Intelligence in ape and man*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Premack, D. (1983). The codes of man and beasts. *Behavioral and Brain Sciences*, 6, 125-167.
- Premack, D. (1986). *Gavagai*. London: Cambridge University Press.
- Rilling, M. (in press). Invisible counting animals: A history of contributions from comparative psychology, ethology and learning theory. In S. T. Boysen & E. J. Capaldi (Eds.), *The development of numerical competence: Animal and human models*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Roberts, W.A. (1983). Doubts about the importance of language training and the abstract code. *Behavioral and Brain Sciences*, 6, 154-155.

Roitblat, H. L. (1983). Does language training affect the code used by chimpanzee?: Some cautions and reservations. *Behavioral and Brain Sciences*, 6, 155-156.

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

Sidman, M., & Cresson, O. (1973). Reading and cross-modal transfer of stimulus equivalences in severe retardation. *American journal of Mental Deficiency*, 77, 515-523.

Sidman, M., Rauzin, R., Lazar, R., Cunningham, S., Tailby, W., & Carrigan, P. (1982). A search for symmetry in the conditional discriminations of rhesus monkeys, baboons and children. *Journal of the Experimental Analysis of Behavior*, 37, 23--44.

Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior*, 37, 5-22.

Starkey, P., & Gelman, R. (1982). The development of addition and subtraction abilities prior to formal school 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.

Thomas, R. K., & Chase, L. (1980). Relative numerosness judgments by squirrel monkeys. *Bulletin of the Psychonomic Society*, 16, 79-82.

Vaughan, W. (1988). Formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 14, 36--42.