TOPICS IN PRIMATOLOGY

Volume 1

Human Origins

Edited by
Toshisada Nishida, William C. McGrew, Peter Marler,
Martin Pickford, and Frans B. M. de Waal

1992

UNIVERSITY OF TOKYO PRESS

Primates' Conceptual Use of Number: Ecological Perspectives and Psychological Processes

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INTRODUCTION

Evidence from our laboratory has shown that squirrel monkeys (most likely *Saimiri sciureus sciureus* and *Saimiri boliviensus boliviensus*; Hershkovitz, 1984) can discriminate reliably and accurately seven from eight entities, whether the entities are discrete, such as dots (Thomas *et al.*, 1980) or connected, such as the sides of randomly constructed polygons (Terrell and Thomas, 1990). I suspect that most primates can discriminate seven from eight entities, although as far as I know, only squirrel monkeys and humans (Thomas *et al.*, 1990) have been shown to be able to do so under appropriately controlled experimental conditions.

I believe that these seven versus eight discriminations (hereafter, the form 7:8 is used) are done without counting. In the case of the monkeys, they lacked the prerequisite experience and skills to count. With the humans, procedures were used to preclude counting.

Later, I will discuss what I think are the likely numerical processes that the monkeys and humans used, but for now I will note that the evidence we have obtained may be instances of Miller's (1956) "magical number seven, plus or minus two" in reference to unidimensional information-processing channel capacity. Miller cited data to show that with a variety of physical continua, subjects could reliably process approximately seven items of information. Although there are too few data to say, I suspect that this capacity is pervasive in the order Primates and, possibly, other mammals and birds (e.g., Emmerton, 1989). Assuming for present purposes that the capacity is widespread, two questions of interest should be: 1) Why might animals have this capacity? 2) If they have this capacity, what is its underlying basis?

SOME EMPIRICAL EVIDENCE

Before addressing these questions, I will summarize the evidence for 7:8 discriminations obtained in our laboratory. Thomas *et al.* (1980) used squirrel monkeys as subjects and black-filled circles of different sizes as discriminanda (hereafter, I refer to such discriminanda as "dots"). The different sizes were used to preclude the monkeys' use of cumulative area or differential brightness cues. We used a large number of quasirandomly constructed patterns of dots to preclude pattern memorization. We also used programmatic training (e.g., 2:7, then 2:6, 2:5, etc., 3:7, 3:6, etc.) and both monkeys in the study were able eventually to discriminate reliably between a card that had seven dots and a card that had eight dots (one of the monkeys succeeded on 8:9 dots). Terrell and I (1990) used squirrel monkeys and similar controls for area, brightness, and specific polygon memorization and showed that two of four squirrel monkeys discriminated randomly constructed heptagons from octagons. The third monkey met criterion on 6:7, and the fourth met criterion on 5:7.

In another study, we presented humans with both dots and polygons similar to those used in the studies with the monkeys (Thomas *et al.*, 1990). We presented the discriminanda for 200 msec with poststimulus masking intended to preclude counting based on afterimages. Each subject was "pretrained" on three versus four, using both dots and polygons in separate procedures; half the subjects were tested on dots first and half were tested on polygons first. Note that unlike the monkeys' discrimination task, the humans' task was to identify whether a single, briefly presented discriminandum had n or $n+1$ entities.

Following pretraining on the 3:4 task, a given human subject was trained separately on dots and polygons from one set only of two successive numbers (*viz.*, 4:5, 5:6, 6:7, or 7:8). While the higher-number problems were more difficult, eight subjects met our 90% correct-response criterion on 7:8 dots and three met criterion on 7:8 polygons (criterion was 18 of 20 correct with 10 exemplars of each number in 20 successive trials). However, only one subject of the 20 tested on the 7:8 task met criterion on both dots and polygons in the 200 trials allowed; this subject reported that he had considerable experience estimating quantities of trees and bushes for his father's landscaping business. Although most subjects did not reach criterion on 7:8, several showed near-criterion performances, and we expect that more human subjects would reach criterion if more than 200 trials were given.

I attribute nothing significant to the monkeys' apparently greater success, because the monkeys' discrimination task with both the seven and eight discriminanda present is likely to be easier than the humans' identification task. Further, the monkeys had as much as 30-sec viewing time (although they typically responded very quickly) while the humans had only a 200-msec viewing time followed by a masking stimulus.

POSSIBLE ECOLOGICAL BASES FOR NUMEROUSNESS JUDGMENTS

Having shown that the evidence indicated that squirrel monkeys and possibly other nonhuman animals are able to discriminate as many as seven from eight entities, I return to one of the questions raised earlier: Why might animals have such ability? The answer at this time is necessarily speculative, but I believe it is to be found in the salience of numerousness in animals' natural environments. Consistent with Gibson's (1986) theoretical views on perception, I suggest that numerousness is a directly perceptible attribute of spatially contiguous sets of entities for animals with the requisite visual (or other sensory) systems. If it is granted that an animal can perceive directly the numerousness of such sets of objects, then it is reasonable to ask why it might be adaptable for animals to discriminate among two or more concurrently present sets.

A primary example in which numerousness occurs as a relevant attribute is in conjunction with foraging. Food items often appear as discriminable entities. Surely, most mammals and birds experience opportunities to choose between sets of food items. Clusters of fruit constitute a ready example. With other things being equal, it is adaptable for an animal to go first to the set of food items which represents the most food, whether this occurs in competitive or noncompetitive feeding. Although what comprises the perception of "most food" usually confounds cumulative volume and number, experientially number should be as salient if not more so than volume. For example, squirrel monkeys that are insect and fruit eaters in the wild are reported in the laboratory to "...rapidly approach and take *several pieces* of food..." (Fragaszy, 1985, p. 90; emphasis added). Furthermore, the salience of number should be enhanced, because most food items are consumed one or a few at a time.

Predation is another example of a behavioral category in which numerousness *per se* should be salient and in which responsiveness based on numerousness can be adaptable. If presented with a choice, it is reasonable to suggest that predators (such as lions) of animal groups that use escape as their principal defense (such as wildebeest) would choose a group having more potential prey, because the odds of finding a young, weak, or injured victim will be greater. On the other hand, predators (such as leopards) of potential prey which use aggressive forms of group defense against them (such as baboons) should learn that it is best to attack such prey when they occur alone or in small numbers.

Others more knowledgeable of animal ecology than I should be able to suggest even better examples. Among some other possibilities that I will mention, one thinks of the salience of the number of eggs in a nest, the number of offspring in a multiparous birth, and the fact that many species of animals aggregate. The salience to humans and, presumably, to many nonhuman animals of animal aggregations is suggested by the many terms humans use to characterize such aggregations (e.g., gaggle of geese, flock of sheep, pride of lions, etc.; Lipton, 1968, has compiled an extensive list of both serious and humorous examples).

I return now to the finding that squirrel monkeys can discriminate seven from eight entities and to our (Terrell and Thomas, 1990; Thomas and Lorden, in press) interpretation that they do this without counting. I suspect that squirrel monkeys in their natural habitats rarely, if ever, need to make discriminations as fine as seven versus eight. Nevertheless, precise numerousness discrimination within these limits appears to be an inherent capacity acquired during evolution. That the limit may be seven, plus or minus two, may be coincidental to some more general process that underlies the hypothetical limit of unidimensional information-processing channel capacity described by Miller's (1956) magical number seven. Miller cited examples across sensory modalities that supported seven, plus or minus two, as the range of recurring numbers representing this basic capacity.

Since I am invoking Miller's (1956) hypothesis, I am compelled to report that he doubted whether the famous "breakpoint" in accuracy around seven for humans' numerousness judgments based on identifying the number of briefly (200 msec) presented dots (Kaufman *et al.*, 1949) was an instance of the magical number seven in terms of information-processing channel capacity. Miller's (1956) doubts were based on his supposition that the magical number seven applies to unidimensional information sources and that dot judgments as studied by Kaufman *et al.* (1949) may be based on two dimensions, area and density. Since we controlled for area in our studies, area was not informative, and my understanding of density suggests that it would also provide ambiguous information when area is controlled. Thus, I suggest that in our studies the single dimension, numerousness, was the source of information for the judgments required.

PROCESSES FOR NUMEROUSNESS IDENTIFICATION AND DISCRIMINATION

Counting

It is my view that there is very little evidence that nonhuman animals can count, although I should note that there are those who believe that animals, including rats, have been shown to count (see Davis and Perusse, 1988a,b). Most of the basis for disagreement depends on the evidence that one requires to show counting. Agreeing with Davis and Perusse, I base my opinion on the requirement that one must show evidence for at least the first three of the five principles of counting listed and discussed by Gelman and Gallistel (1978). The principles are: 1) the one-to-one principle according to which each item to be counted is tagged uniquely; 2) the stable-order principle according to which the tags must be applied in a consistent order; 3) the cardinal principle by which the last tag applied to the last item describes the number of items in the set; 4) the abstraction principle, which means that one can count any set of items; and 5) the order-irrelevance principle which means the items can be counted in any order.

I deem the abstraction principal to be nonessential, because, for example, an animal might learn to count random arrays of black-filled circles without necessarily transferring, immediately at least, its counting ability to squares. I deem the order-irrelevance principle to be nonessential, because an animal might learn to count items reliably in one order, say from left to right, without necessarily showing immediately that it can count items in other orders. Of course, evidence for both the abstraction and the order-irrelevance principles is necessary to show a general ability to count. Davis and Perusse's (1988a) reasons for minimalizing the necessity of the abstraction and order-irrelevance principles may be found on page 565 of their article.

My disagreement with those who are more liberal in terms of what they will accept as evidence for counting primarily involves the first principle (which is not to say independently of the second and third principles). Tagging implies that the animal has acquired and can use a symbol substitution system where the symbols are substituted systematically in a one-to-one correspondence with the items to be counted. Some appear willing merely to infer this evidence from the end result that an animal can discriminate or respond appropriately to the total numerousness property of a set of items or events. My view is that such end results can be had by other means (such as the prototype matching hypothesis summarized below) and that a demonstration of counting will require evidence both for the acquisition of the symbol system *per se* and its use in stable order and one-to-one correspondence with the items to be counted.

With the possible exceptions of the reports of chimpanzees by Boysen and Berntson (1989), Rumbaugh, Hopkins, Washburn, and Savage-Rumbaugh (1989), and Rumbaugh (1990), I am unaware of any research that provides sufficient evidence that an animal had acquired a symbol system and had used it in stable-order and one-to-one correspondence with items to be counted. However, even these data must be viewed with caution, because Boysen and Berntson's chimpanzee, Sheba, did not exceed four, and Rumbaugh *et al.*'s chimpanzee, Lana, did not exceed three. Numbers up to four are reported to be used precisely in human cultures that lack a developed counting system (Ifrah, 1985); therefore, such use might be associated with behavior that gives the appearance of counting. While I have these reservations in terms of the conclusiveness of the evidence for counting, I hasten to say that I would not be surprised that the aforementioned chimpanzees were counting and that some monkeys and, perhaps, other animals will be able to count, given the appropriate training.

Whether animals can count does not matter with respect to the monkey's and humans' performances reported here for the seven versus eight numerousness discriminations, because a noncounting process can explain these performances. Furthermore, in terms of ecological validity and animals' abilities to make numerousness discriminations in their natural habitats, a noncounting process seems more likely.

Prototype Matching

Terrell and Thomas (1990) and Thomas and Lorden (in press) have suggested that numerousness judgments may be based on a process that is directly analogous to if not commensurate with a prototype matching process such as Rosch (e.g., 1975) and others have applied to other kinds of concept acquisition and use. For example, with conceptual categories such as "tree" or "bird," humans respond to exemplars with varying degrees of confidence, presumably, according to how well a given exemplar matches their average memorial representation of a tree or a bird.

Human subjects who are inhabitants of the United States, for example, seem to use passerine birds, in general, and the American robin (*Turdus migratorius*) in particular, as "best" memorial representations of a bird. Subjects respond less quickly and less confidently to exemplars of birds as a function of how much the exemplar departs from the passerine/robin prototype. In Rosch's (1975) study, for example, the penguin was viewed as representing a considerable departure from the

prototype. Presumably prototypes, as in the case of bird, are acquired in a human subject's lifetime of experience with birds in storybooks, photographs, other pictures, and everyday experiences with real birds.

Our college student subjects showed little difficulty judging the numerousness of three versus four dots. The average subject met criterion in 29 trials, only nine trials more than the minimum required, but an average of 48 trials was required to meet criterion on four versus five dots, 75 trials for five versus six dots, 114 for six versus seven dots, and 130 for seven versus eight dots. It may be noted also that fewer subjects met criterion on the higher numbers in the 200 trials allowed. Specifically, while all 10 subjects tested met criterion on four versus five dots, 13 of 20 met criterion on five versus six dots, 17 of 20 met criterion on six versus seven dots, and eight of 20 met criterion on seven versus eight dots.

From such data I speculate that prototypes were probably well developed for three, four, and, perhaps, five dots, but it was necessary for the subjects to experience the discriminanda and acquire the prototypes for the higher numbers. It is further speculated that in cultures with well-developed number systems and in which counting skills are acquired at relatively young ages, there is little need to develop numerousness prototypes. It is easy enough and certainly more reliable, especially when five or more entities are involved, to just count when one needs to know the number of items in an array.

Our college student subjects presumably had well-developed number concepts and vocabulary, and their task was primarily one of applying the appropriate number-names reliably to the discriminanda. Matsuzawa, Asano, Kubota, and Murofushi's (1986) elegant research with the chimpanzee, "Ai," shows that this primate can acquire number labels up to six and apply those labels reliably and appropriately according to the number of objects in a set.

With animals generally, and especially those in laboratories where investigations of numerousness prototype acquisition and use must be done, the acquisition of numerousness prototypes will be confounded with acquisition of the reinforcement contingencies. Therefore, performance measures such as trials to criterion will confound acquisition of prototypes with acquisition of the reinforcement contingencies. This confounding will prevent us from knowing whether they might have acquired prototypes prior to their laboratory experiences. Therefore, whether or to what extent experience in the natural habitat leads to prototype acquisition will likely remain unknown.

Absolute and Relative Prototype Matching

Thomas and Lorden (in press) proposed that numerousness prototype matching is of two basic kinds, absolute and relative. We suggested that absolute prototype matching (e.g., "threeness," and "sevenness") is a prerequisite for relative prototype matching (e.g., "fewer," "more"). That is, before a subject can judge which of two (or more) collections of objects has the fewer or the more objects, the subject must have acquired the ability to affirm the numerousness of independent sets of objects.

The affirmation of absolute numerousness may be imprecise, such as the collection represents "many" or "few" objects. Alternatively, the affirmation of absolute numerousness may be precise, such as, affirming the "threeness" or the "sevenness," etc. of sets of objects. Relative numerousness judgments may also be precise, such as, selecting the "fewer" objects when two sets differ by only one number (e.g., six versus seven objects). Alternatively, they may be imprecise such as selecting the set with "fewer" objects when the two sets differ by more than one (e.g., 25 versus 50 objects).

SUMMARY

For animals with the requisite sensory capacities, the ability to perceive the numerousness of a collection of objects may be as fundamental as the ability to perceive the color, shape, and size of objects. If so, the development of the ability to perceive numerousness *per se* is likely due to natural selection during the evolution of the species.

The affirmation of the cardinal number of a set of objects does not require the ability to count. It may be based on the acquisition of prototypes for different numerousness sets. Numerousness judgments may be absolute or relative, and both types may be done precisely or imprecisely. It is suggested that absolute numerousness judgments are prerequisites for relative numerousness judgments.

That the limit of absolute, precise numerousness judgments may be found to be close to seven (e.g., Miller's, 1956, "magical number seven, plus or minus two") may reflect a limit on basic information-processing channel capapcity. Such a capacity may not be limited to or defined by numerousness but may represent some more fundamental limit on information processing that applies to a variety of physical continua. However, whether the limit is seven, plus or minus two, and whether it represents some basic physical limit on information processing will require confirmation through further research.

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