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# Conceptual numerousness judgments by squirrel monkeys

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Two monkeys were reinforced for responding to the card which displayed fewer number of entities (three randomly selected sizes of filled circles) than the other card in any given pair. Area and brightness cues were controlled (at least for the successive numerousness discriminations), as were specific-pattern learning cues. Training proceeded in the order 2 versus 7 (2:7), 2:6, 2:5 . . . 2:3, 3:7, 3:6 . . . 3:4, etc., until it was judged that the monkeys were unlikely to attain the stringent criteria for discrimination. Both monkeys met criteria on the 7:8 discrimination, and one monkey met criteria on the 8:9 discrimination. It was concluded that the monkeys' numerousness judgments were made on a conceptual basis and that, among nonhuman animals, the evidence for such judgments appears to be limited to apes and monkeys.

Most of the nonhuman animal research to which the present study relates has been presented in terms such as "number concept" (e.g., Wesley, 1961), "arithmetic behavior" (Ferster & Hammar, 1966), or "mathematical skills" (Dooley & Gill, 1977). The task requirements typically have been to have the animal estimate the cardinality attribute of a collection of stimuli (objects or two-dimensional entities such as dots or filled circles on a card). Stevens (1951) distinguished between the "numerosity" and "numerousness" attributes of such collections, regarding the former to be determined by counting and the latter to be "the 'subjective' aspect or attibute that we observe when we look at, but do not count, a collection of objects" (p. 22). It is assumed here that none of the animal studies have involved counting, although the kinds of estimations intended appear to go beyond being "subjective." In any event, the present study adopts Stevens's term, numerousness, as most appropriate to describe the kinds of judgments to which the majority of the animal studies have been directed.

Despite extensive investigation of animals' abilities to judge numerousness, findings are inconclusive or unclear. For example, in their reviews, Salman (1943), Wesley (1961), and Swenson (1970) unequivocably accept only Hicks's (1956) study, which demonstrated rhesus monkeys' ability to judge "threeness." The most frequent objections to the earlier studies were concerned with the failure to control against the animals' use of cues from the other stimulus properties (e.g., cumulative area of the numerousness entities) or from specific pattern cues.

Recent studies not considered by Salman, Wesley, or Swenson include those of Ferster and Hammer (1966), Ferster (1964), Hayes and Nissen (1971), and Dooley and Gill (1977). Ferster, in his study, which was an extension of that by Ferster and Hammer, concluded that two chimpanzees "learned to identify from one through seven objects by writing the appropriate binary number" (p. 105). "Writing" meant that the chimpanzees had learned to operate switches to light the appropriate lamps in a row of three and thereby indicate the binary number for the particular set of objects shown. Hayes and Nissen reported that their chimpanzee was able to discriminate between cards bearing arrays of 3 versus 4 filled circles of various sizes, but she was unable to discriminate 4 versus 5 in the number of trials given (162). Dooley and Gill used washers of various sizes as their numerousness entities. Using conditional cues to indicate "more" or "less," their chimpanzee was said to be able to discriminate 3 versus 4 on these bases as well as some presumably easier discriminations, but not 3 versus 5 or 4 versus 5.

In our studies, we planned a training schedule that would progress generally from presumably 'easy' to 'difficult' discriminations, until we decided that it was unlikely that the monkeys would meet the stringent criteria for a successful discrimination. We controlled for non-number cues, at least for successive discriminations. The order of the discriminations was to be 2 versus 7 (hereafter the form 2:7 will be used to designate numerousness pairs placed in opposition), 2:6, 2:5, 2:4, 2:3, 3:7, 3:6, 3:5, 3:4, 4:7, 4:6, 4:5, 5:7, 5:6, and 6:7. In the event that the monkeys should meet the criteria (45/50 correct in one session and a significant "run" of successive correct responses, with $p < .05$) for 6:7, the plan was to continue with 7:8, 8:9, etc. until it was judged that the monkey was unlikely to reach the joint criterion.

It might be useful to note that we modified some procedures that were used in a study preliminary to the present one. In that study, two horizontally placed platforms were used, with black wooden discs of various diameters displayed on them as the objects for numerousness. With a total of 1,950 trials, one monkey met criterion on 2:7, 2:6, 2:5, and 2:4. It had completed an additional 1,050 trials on 2:3 without achieving criterion when this initial study was terminated, although it had achieved 88% correct in three of the sessions and a significant run

($p < .007$) in one of those. A second monkey met criterion in succession on the 2:7 through the 3:5 discriminations in a total of 1,650 trials. It had completed a total of 1,500 trials on the 3:4 discrimination without reaching criterion when this study was terminated. We had begun by using three-dimensional stimuli owing to literature which suggested that monkeys might perform better with such stimuli than with two-dimensional ones. However, our particular situation may have had two disadvantages that offset any gain to be had with three-dimensional objects. (a) The monkey's angle of regard may have been such that numerousness was obscured as a cue. (b) The apparatus separated the cues to reinforcement, the numerousness displays on the white platforms, from the sites of reinforcement, covered food wells in front of the platforms. The literature suggests that separation of cue and reinforcement may be detrimental to performance (Meyer, Treichler, & Meyer, 1965; Mendoza & Thomas, 1975). Both disadvantages were overcome in the present work.

## METHOD

### Subjects

Two wild born, adult male squirrel monkeys (*Saimiri sciureus*) designated 78-I-1 and 78-I-2 were used. They were obtained in an exchange with a colleague (Walter Isaac). Their previous experience as subjects in research was limited to measures of their general activity (measured via photocell beam interruptions). The monkeys were housed in individual cages in a colony room with controlled temperature (24°-27°C) and humidity (50-70%). Timers controlled light onset at 8:00 a.m. and light offset at 8:00 p.m. local time; all testing was done in the light phase. The monkeys received a diet of Purina or Wayne monkey food (25% and 24% protein, respectively) which was supplemented regularly with fresh fruits. Water was continuously available.

### Apparatus, general procedures, and pretaining

The monkeys were trained and tested in a modified Wisconsin General Test Apparatus (WGTA). The WGTA had a wooden stimulus tray which was painted grey and which had area dimensions of 27 cm × 35 cm. Two transparent acrylic, vertically oriented card holders (9 cm × 9 cm) with a 4.5cm × 9 cm base were used. Each holder was mounted flush with the front (35cm) and one of the sides of the tray. A food well (1.5 cm diameter) was centered beneath the base of each card holder. The bases of the holders were rendered opaque to prevent the monkey from seeing the food wells until the holder had been displaced. Testing was done in the illumination provided by a 25-W bulb mounted in the top-center of the WGTA. The monkey was tested in the room in which it was housed by moving its home cage to an empty slot on the cage rack, which was adjacent to the WGTA. Screens prevented the other monkeys in the room from observing the ongoing testing. With the door between the monkey and the WGTA closed, the stimuli were set. The experimenter's door was then closed, the monkey's door was raised, and the stimulus tray was advanced slightly but not within the monkey's reach. After a 5-sec delay, the tray was advanced within reach, and the monkey was allowed 30-sec in which to respond. Following a response, the monkey's door was closed, the experimenter's door was raised, and a 30-60 sec intertrial interval ensued during which the stimuli for the next trial were set. In the event of an erroneous choice, the trial was repeated as though it were a new trial, until a correct choice was made. Only the initial error was recorded.

The following procedures were used to familiarize the monkey with the testing situation:

1. We fed currants, the reinforcers, to the monkey by hand each day for several days. Later, the monkey was introduced to the WGTA initially by having it retrieve 30 currants, one at a time, from one of the uncovered food wells. Here and hereafter, the positions of the baited food wells from trial to trial was determined according to the Fellows series (1967).

2. In the next session, the monkey was required to displace one of the empty card holders in order to obtain 30 currants, one at a time, that were presented beneath it; the nonbaited card holder was adjacent to the empty food well but displaced to expose the well's emptiness.

3. In the next session, a card bearing a black, filled isosceles triangle (6.5 cm base and 6.5 cm height) and a blank card were used in the holders. The food well beneath the triangle was baited, and 30 trials were administered. Monkey 78-I-1 had two errors, and 78-I-2 had three errors.

4. Beginning in the next session, a form discrimination problem was administered at a rate of 50 trials/session until a joint criterion of 45/50 correct and a significant "run" of successive correct responses in one session was seen; see Grant (1947) and Thomas and Crosby (1977) for information regarding the "runs" analysis. The discriminanda were a black filled circle (6.5 cm diameter) and a black filled symmetrical cross (7.5 cm lengths and 3 cm widths). Responses to the circle were reinforced. At the end of the fourth session, monkey 78-I-1 had 45/50 correct and a run of 16 successive correct responses ($p < .002$). At the end of the fifth session, monkey 78-I-2 had 46/50 correct and a run of 20 successive correct responses ($p < .0002$).

## Numerousness judgment training

**Stimuli.** The stimulus cards were plain white index cards trimmed (8.5 cm × 8.5 cm) to fit the card holders. Three sizes of black filled circles were used, with radii of 2.5 mm, 5.0 mm, and 10 mm, and areas of 19.6 $mm^2$, 78.5 $mm^2$, and 314.1 $mm^2$, respectively. A 16 point (4 × 4) grid was used to determine the loci of the circles on the cards. The sizes of the circles to be used on a card were determined randomly. The loci of the circles on the cards were determined randomly except that each circle had to be located adjacent to at least one other circle; the latter restriction was used to prevent clusters of numbers from appearing on a single card (e.g., two in one corner and three in the diagonally opposite corner). Twenty-five cards were constructed for each number, and all four orientations were used; thus, each number was represented by 100 distinguishable patterns. The variations in the sizes of the filled circles were used to control against the use of area or brightness cues. The number of patterns used was intended to control against a monkey's reaching criterion merely by learning the specific patterns involved.

**Procedure.** Training, which proceeded at a rate of 50 trials per session, began with the 2:7 discrimination. The cards for this and the succeeding discrimination problems were selected randomly from the 100 patterns available for each number. The positions of the correct card were determined by the Fellows series. In all numerousness discriminations, responses to the lower number were reinforced. The joint criterion to be met was to achieve a minimum of 45/50 correct in a single session and a significant run of successive correct responses ($p < .05$).

The planned order of problems to be administered, contingent on criterion having been met on each preceding problem, was 2:7, 2:6, 2:5, 2:4, 2:3, 3:7, 3:6, 3:5, 3:4, 4:7, 4:6, 4:5, 5:7, 5:6, and 6:7. It was also planned that if criterion was met on 6:7, training would proceed in the order 7:8, 8:9, etc. until the experimenter decided that an animal was unlikely to reach criterion.

After a few observations of the monkeys' performance, we decided that failure to equal or exceed a mean of 75% correct in 500 trials on a given problem would be the basis for terminating a monkey's training. We avoided using a lower standard, such as chance performance, as we anticipated using these animals in further studies involving numerousness relationships. We did not want to risk the induction of experimental neurosis by means of unsolvable numerousness discriminations (e.g., see Thomas and DeWald, 1977, for a general discussion of experimental neurosis).

## RESULTS

Both monkeys met criterion on all discriminations through 7:8. Monkey 78-I-1 also met criterion on 8:9. The numbers of trials to criterion and the probability values associated with runs of successive correct responses in the criterion session for all the numerousness discriminations may be seen in Table 1. Figure 1 shows the performances in each session of training involving the successive number discriminations. Figure 1 also shows the performances in each session for the problem on which the monkey failed to attain criterion. The figure suggests that the performances on the discriminations on which the monkeys eventually met criterion were sustained at a generally higher level throughout than those on the final problem. On the 8:9 discrimination for which criterion was not met, monkey 78-I-2 had a mean of 71% correct responses for the 500 trials. On the 9:10 discrimination, for which criterion was not met, monkey 78-I-1 also had a mean of 71% correct on its 500 trials.

Although three sizes of filled circles were used and were assigned randomly to the cards, the area or brightness differences resulting from the cumulative area of the black circles on the white card were possible cues for criterion performances on some of the numerousness discriminations. For example, the mean cumulative area of black on the "2" cards was 3.4% versus 12.3% for the "7" cards, and in fact, only one of the "7" cards

Table 1. Trials to criterion and probabilities associated with chance "runs" of successive correct responses for the numerousness discriminations

| | Monkeys | | | Monkeys | |
|---|---|---|---|---|---|
| Discriminations | 78-I-1 | 78-I-2 | Discriminations | 78-I-1 | 78-I-2 |
| 2:7 | | | 4:7 | | |
| Trials | 300 | 350 | Trials | 250 | 50 |
| p< | .00001 | .03 | p< | .00001 | .00001 |
| 2:6 | | | 4:6 | | |
| Trials | 350 | 250 | Trials | 250 | 100 |
| p< | .001 | .03 | p< | .05 | .00002 |
| 2:5 | | | 4:5 | | |
| Trials | 400 | 400 | Trials | 400 | 300 |
| p< | .01 | .002 | p< | .002 | .00006 |
| 2:4 | | | 5:7 | | |
| Trials | 250 | 250 | Trials | 100 | 500 |
| p< | .001 | .001 | p< | .00001 | .00001 |
| 2:3 | | | 5:6 | | |
| Trials | 200 | 200 | Trials | 150 | 50 |
| p< | .00001 | .01 | p< | .00001 | .00001 |
| 3:7 | | | 6:7 | | |
| Trials | 50 | 50 | Trials | 650 | 50 |
| p< | .00001 | .00001 | p< | .0003 | .00001 |
| 3:6 | | | 7:8 | | |
| Trials | 50 | 50 | Trials | 200 | 550 |
| p< | .00001 | .0001 | p< | .00001 | .0001 |
| 3:5 | | | 8:9 | | |
| Trials | 100 | 100 | Trials | 200 | |
| p< | .00001 | .00001 | p< | .0003 | |
| 3:4 | | | | | |
| Trials | 150 | 150 | | | |
| p< | .0006 | .003 | | | |

was exceeded in black area by five of the "2" cards. However, criterion could not be met on the successive numerousness discriminations by using area or brightness cues. Table 2 shows the percentages of correct responses during the criterion sessions involving the successive numerousness discriminations for the trials when the lower number had the greater black area. It may be noted also that errors during the criterion sessions were about evenly distributed with regard to the lower number having the greater or lesser amount of black area.

## DISCUSSION

Despite the use of 100 distinguishable patterns per number, it might be argued in some cases that the monkey may have had the opportunity to learn specific patterns. For example, monkey 78-I-1 received a total

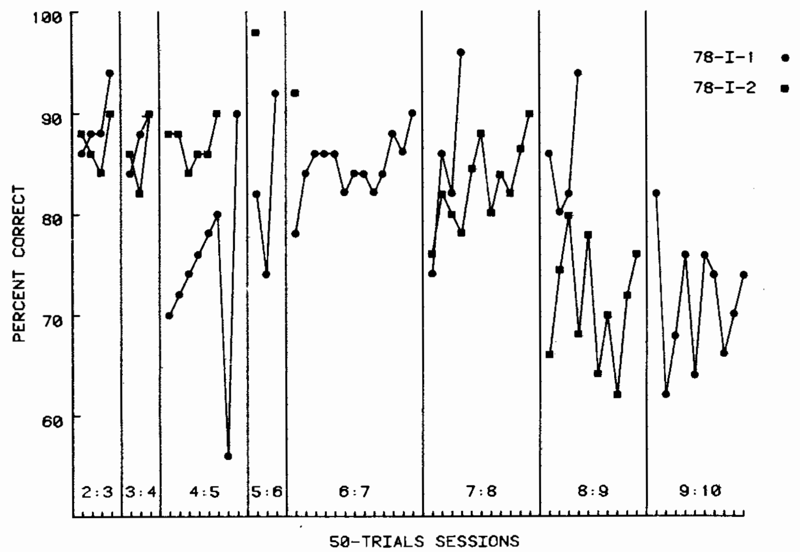


**Figure 1.** Percent correct responses during acquisition of the successive numerousness discriminations: 2:3, 3:4, 4:5, 5:6, 6:7, 7:8, 8:9, and 9:10

of 1,500 trials on which "2" was correct. A specific-pattern learning interpretation would be much harder to sustain for numbers above 2 as those numbers were sometimes associated with reinforcement and other times they were not (except for the higher numbers in the last discrimination which are not considered here, as criterion was not met in those cases). A specific pattern-learning interpretation requires that each pattern be learned in terms of its relationship to reinforcement. Thus, for each number greater than 2 there would be 200 specific pattern-reinforcement relationships to be learned. Additionally, correct performances on the basis of having learned the 200 patterns

Table 2. Percentages of correct responses when the correct stimulus (the smaller number) had the greater total black area during the criterion session of successive numerousness discrimination

| | Monkeys | |
|---|---|---|
| Discriminations | 78-I-1 | 78-I-2 |
| 2:3 | 92 | 92 |
| 3:4 | 92 | 92 |
| 4:5 | 82 | 94 |
| 5:6 | 94 | 100 |
| 6:7 | 94 | 100 |
| 7:8 | 93 | 77 |
| 8:9 | 95 | |

associated with a given number would be conditional upon having learned the specific patterns of the numbers placed in opposition to that number. For example, to learn the specific pattern which associated "3" with nonreinforcement would require learning those patterns together with their specific relationships to the specific patterns associated with "2" and reinforcement.

Even with the "2" cards for which only 100 specific patterns had to be associated with reinforcement, a specific-pattern learning interpretation might be difficult to sustain. Nissen (1951), perhaps in view of the 15,796 trials to criterion required by his chimpanzee to learn 16 conditional discriminations presented concurrently, suggested that the chimpanzee may have learned the 16 specific configurations associated with the conditional discriminations rather than their conceptual relationships. A direct comparison of the difficulty of learning the specific patterns in Nissen's study versus those involved with the "2" cards is impossible. It is reasonable to suggest, however, that owing to competing elements with respect to the reinforcement contingencies among Nissen's patterns, his patterns may have been more difficult to learn. Nevertheless, the difference between learning those 16 patterns in 15,796 trials by a chimpanzee and learning the 100 patterns for "2" in something less than 1,500 trials by a squirrel monkey seems to be too great to account for the monkey's performances in terms of specific pattern learning.

Thus, in view of the impossibility for area/brightness cues to account for the criterion performances seen with the successive numerousness discriminations and in view of the arguments against specific pattern learning, we suggest that the monkeys' numerousness judgments were performed on a conceptual basis. Our study was intended merely (a) to determine whether squirrel monkeys are capable of conceptual numerousness judgments and, if so, (b) to gain some indication of the degree of their capability. We used a research design which we believed to be likely to maximize the probability of determining these two things.

Unfortunately, the design did not permit us to distinguish between two possible types of conceptual solutions. (a) The monkeys might have learned each of the numerousness sets as it was reinforced, that is, learned the concepts "twoness," then "threeness," and so forth through "sevenness" (for 78-I-1) and "eightness" (for 78-I-2). (b) Alternatively, since the correct numerousness set in this study was also always the one having the fewer stimuli, the monkeys might have learned to respond on this relative numerousness basis. The immediate transfer by monkey 78-I-2 from "4" correct on 4:5 to "5" correct in 5:6, then "6" correct in 6:7 suggests that it may have responded on a relative basis. Using terms suggested by Thomas and Crosby (1977), solution (a) indicates the use of absolute class concepts and solution (b) indicates the use of relative class concepts. Further research is needed to determine clearly whether squirrel monkeys are capable of both absolute and relative class conceptual judgments when numerousness provides the relevant cue.

The results here may be surprising in comparison to the results of previous studies. For example, Hicks's (1956) rhesus monkeys only judged "threeness" at a "moderately proficient level" (p. 218). It should be noted, however, that Hicks reinforced responses only to threeness, that is, the results of reinforcing responses to other numbers were not determined. As for the moderately proficient level of performance, it should be noted that Hicks used geometric shapes (cut from construction paper and also varying in color) mounted on a gray posterboard which filled from 18.75 to 62.5 percent of the background area; probably numerousness as a cue was obscured.

Perhaps the study most comparable to the present one was that of Hayes and Nissen (1971) using the chimpanzee, Viki. They too used as stimuli filled circles of various sizes drawn on index cards. Viki was able to discriminate 3:4 as well as, presumably, easier discriminations (including 4:6), but training was terminated after 162 trials of 4:5 "because of Viki's emotional distress and failure to improve" (p. 75). It may only be speculated whether she might have improved eventually and performed even more difficult discriminations.

Based on the description provided in Ferster's study (1964), it cannot be determined whether area cues were controlled adequately; chimpanzees learned to identify with binary numbers "the number of objects (triangles, squares or whatever) presented in the sample window" (p. 105). Judging from the later report (Ferster & Hammer, 1966), it appears that the forms were identical on a given trial. If, for example, only a few forms were used, the chimpanzees might have learned to respond to the relative cumulative areas of a given form rather than to the number of forms; certainly the reported 170,000 trials for this phase of the study would have been sufficient for such learning. Admittedly, it seems more reasonable to accept the view that the chimpanzees learned to respond to the numerousness cues rather than to their relative areas, but at present it seems to be necessary to say that Ferster's study is inconclusive on the point raised and, therefore, can not be evaluated in terms of the present study.

Dooley and Gill (1977) used washers of various sizes as their number entities and reinforced their chimpanzee, Lana, for responding to the side of the stimulus board which held either "more" or "less" washers. The required response for a given trial was indicated to Lana by a conditional cue (the presentation of a lexigram for "more" or "less"). Following extensive training, Lana was given 100 test trials involving 10 number ratios of which 4:5 presumably represented the most difficult discrimination. Overall Lana was 89% correct in her responses but only 60% correct each in her responses to 3:5 and 4:5. She was either 90% or 100% correct on the other number ratios, of which the most difficult presumably was 3:4. In a subsequent "control test" the 45 ratios which result from pairing every number between 1 and 10 with each of the other numbers one time were presented in three ways: line versus line (washers presented in a line), cluster versus cluster (washers presented in either oval or circular configurations), and line versus cluster. Lana had a mean of 84% correct in these tests, but the ratios associated with her errors were not reported.

Considering the literature reviewed by Salman (1943), Wesley (1961), and Swenson (1970) together with more recent research cited here, it appears that conclusive evidence for conceptual numerousness judgments may be limited to the order *Primates*. Among the nonhuman primates, apes (chimpanzee: Hayes & Nissen, 1971; Dooley & Gill, 1977), old world monkeys (rhesus: Hicks, 1956), and new world monkeys (squirrel monkey: the present study) are capable of conceptual numerousness judgments. It would be premature, however, to suggest that this ability is limited to primates until acceptably controlled studies have been done with nonprimates.

Finally, we must consider the problem of odor cues; since the correct card well was baited with currants, perhaps monkeys chose this card because they smelled the food behind it. Although there were usually other methodological objections for the same studies, Wesley criticized some of the early studies for their failures to control against the use of odor cues. That criticism might be raised about the present study as well as Hicks's study, which Wesley cited favorably. Regarding the present work, odor is not believed to have been a cue, since the monkeys failed to attain criterion on the last and most difficult numerousness discrimination with which they were presented. If odor cues were controlling performance, no discrimination failure should occur. Additionally, among the problems for which the monkeys met criterion, there was considerable variation in performance. That variation appeared to be a function of problem difficulty or increasing experience. Such variation should not have occurred if odor cues were controlling the performances.

## Note

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