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Conceptual volume judgments by squirrel monkeys

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Using a paradigm which precluded criterion performance on the basis of specific (as opposed to conceptualized) cues, monkeys were to choose the largest object when the objects appeared on a white background, the middle-sized on a grey background, and the smallest on a black background among randomized presentations of objects and backgrounds. The monkeys were trained to stringent criteria using only the white background, then the black, then white and black together, then grey, and finally, white, black, and grey together. Only one monkey met criterion with concurrent presentations of the three backgrounds. Two met criterion through the grey condition, and one through the black and white condition. That three monkeys succeeded through the grey condition suggests this species is capable of conceptual size judgments where relative magnitude must be recognized. The implications of these data for quantitative judgments by animals are discussed.

The present study investigated the squirrel monkey's use of volume cues as relative class concepts in a paradigm which also assesses the ability of this animal to make quantitative judgments at the ordinal level of measurement. To explain what is meant by relative class concepts, it will be useful to summarize the general scheme for the assessment of conceptual behaviors in nonhumans proposed by Thomas and Crosby (1977).

Thomas and Crosby distinguished class concepts from relational concepts. Class concepts were defined as those which are structured in terms of the logical operation, affirmation, and its complement, negation. Relational concepts were defined as those which are structured in terms of the *explicitly relational* logical operations of conjunction, disjunction, conditional, biconditional, and their respective complements.

Thomas and Crosby further proposed that class concepts be divided into absolute class concepts and relative class concepts, as distinguished by the logical and operational *necessity* to compare stimulus choices in order to identify an instance of a concept. Specifically, it is necessary to compare stimulus choices in order to identify an instance of a relative class concept but not to identify an instance of an absolute class concept. Examples of absolute class concepts are a color (Weinstein's "redness" or "blueness," 1945), a form (Andrew & Harlow's "triangularity," 1948), and a number (Hicks' "threeness," 1956). Examples of relative class concepts are "oddity" (e.g., Levine & Harlow, 1959) or the more rigorous "dimension-abstracted oddity" (Bernstein, 1961), where relative color, form, or size provided the cues. Tasks which fail to preclude an animal's use of specific stimulus properties or configurations as cues are not considered to provide conclusive evidence for conceptual behavior.

In these terms, the present study was a test of the squirrel monkey's ability to use volume as a relative class concept. Additionally, the monkeys were required to make their volume judgments conditional upon the brightnesses of the backgrounds on which the objects appeared. Specifically, the monkeys were trained to select the largest of three objects when the objects appeared on a white background, the intermediate-sized object when they appeared on a grey background, and the smallest object when they appeared on a black background. Control procedures were used which precluded the attainment of criterion on the basis of learning specific stimulus properties or configurations. Since a given object might be the largest on one trial and that same object the smallest on another trial, etc., relative volume judgments were required. Furthermore, since on some trials the monkeys were required to select the intermediate-sized object based on size cues alone, it is assumed that the monkeys were capable of judging the relative order of the sizes.

METHODS

Subjects

Four wild-born, adult squirrel monkeys (*Saimiri sciureus*), two female (S 11 and S 12) and two male (S 13 and S 14), were used. The females had previously received only the pretraining for a numerosity judgment experiment, and the males were experimentally naive. The monkeys were housed in individual cages in temperature (24°-27°C) and humidity (50%-70%) controlled colony rooms. 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 Monkey Chow (25% protein) which was supplemented regularly with fresh fruits and vegetables. Water was continuously available.

Apparatus, general procedures, and pretraining

The monkeys were trained and tested in a modified Wisconsin General Test Apparatus (WGTA). The stimuli were presented on an apparatus which was basically a box of hexagonal outline (13 cm high × 25 cm sides) with three open compartments which were recessed into every other side of the box. Except for these compartments, the box was enclosed by brown masonite. Each compartment had a floor (13 × 25 cm), sidewalls (13 cm × 13 cm), and a back wall (13 cm × 25 cm). One of the compartments was painted black, one was painted white, and one was painted grey (composed of equal parts of the black and white paints used). Each compartment had three food wells (1.5 cm diameter) which were 8 cm apart but otherwise centrally placed on the compartment floor. This apparatus was mounted on a swivel base to facilitate presenting the stimulus objects on the white, black, or grey backgrounds as a given trial required.

Testing in the WGTA was done only in the illumination provided by a 25-W bulb mounted in the top-center of the apparatus. The monkey was tested in the same 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. On a given trial, after the stimuli had been set and the monkey's door raised, the tray was advanced slightly but not within the monkey's reach. After a 5-sec delay, the tray was advanced within reach. Thirty seconds were allowed for a response, then the door was closed, and a 30-60 sec intertrial interval ensued during which the stimuli for the next trial were set.

The initial pretraining consisted of having a monkey retrieve a total of 15 reinforcers (currants), one at a time, from open foodwells. All pretraining to be described in this and the following paragraph occurred on the white background. On each trial during both pretraining and training, the food well to be baited was selected randomly. Following the retrieval of currants from the open food wells, the monkey retrieved a total of 15 currants placed in front of the food well covered by a yellow toy teacup, and then 15 currants from the food well covered by a yellow teacup.

Following this initial pretraining, five pretraining discrimination problems were administered. For each problem, responses to the largest object were reinforced. The monkeys were required to attain the criteria of 13 correct responses in 15 successive trials and to perform a significant ($p < .01$) "run" of successive correct responses. The discriminanda for these five pretraining problems were (a) two red cylinders, (b) two green hexagonal objects, (c) three orange cylinders with the two smaller ones being the same size, (d) three green rectangular objects with the two smaller ones being the same size, and (e) a large blue cylinder, an intermediatesize orange cylinder, and a small green cylinder.

The goal of training was eventually to have the monkeys select the largest object on the white background, the smallest object on the black background, and the intermediate object on the grey background, where the order of white, black, and grey and the trial-by-trial selection of objects was quasi-random. Training proceeded toward this goal in stages of white background only, black only, white and black only, grey only, and, finally, white, black, and grey.

When black and grey were introduced for the first time, it was decided that certain of the pretraining procedures should be repeated with appropriate adjustments. Thus, some of the pretraining procedures were interspersed among the training procedures. Specifically, when it was appropriate to introduce the black background and its role of signalling that responses to the small object would be reinforced, procedure (d) above was repeated except that there were two larger green rectangular objects the same size and one smaller green rectangular object. Then procedure (e) was repeated except responses to the small green cylinder were reinforced. Similarly, when it was appropriate to introduce the grey background and its role of signalling that responses to the intermediate objects would be reinforced, step (e) was repeated except that responses to the orange cylinder were reinforced.

Training for conceptual volume judgments

A sequence of 10 problems was administered. The stimulus pool for these problems, which did not overlap that of the pretraining problems, consisted of 37 plastic toys. There were six forms which varied as to the number of objects per form. Within a form category, the objects varied in hue, brightness, saturation, and volume. The forms, their numbers, and their internal volumes are shown in Table 1. The volumes were measured by the amount of water held, and the internal volumes should correlate perfectly with the external volumes.

The objects selected for presentation on a given trial had the same form. For problems 1, 3, 5, 7, and 9 described below, the objects within a category were selected randomly except for the restriction that there be at least two size differences between objects chosen for each trial. In other words, it was insured that the volume differences would be more discriminable at these stages of training than an unrestricted random selection might be. For problems 2, 4, 6, 8, and 10, the objects within a form category were selected randomly. The stimuli were changed on each trial, and the positions of the stimulus objects were determined randomly.

(1) In this problem, objects of the same form but differing in color and volume (see the volume restriction described in the preceding paragraph) were presented on the white background. Responses to the largest object were reinforced. Training was continued until the criteria of 13 correct responses in 15 successive trials and a significant run ($p < .01$) of successive correct responses were met in a single 45-trials session. (2) This problem was similar to problem 1 except for the unrestricted random selection of objects within a form category as described in the preceding paragraph. (3) The criteria and selection of the objects for this problem were similar to those described for problem 1. However, the black background was used and responses to the smallest objects were reinforced. (4) This problem was similar to problem 3 except that the objects within a form category were selected randomly, that is, without the volume restriction. (5) This problem consisted of trials such as those described in 1 and 3 being presented concurrently. The order of large-object-correct-on-white (hereafter L/W) and small-object-correct-on-black (hereafter S/B) trials was random except that each occurred an equal number of times in two successive days of training. To attain criteria for this problem, the monkey had to have 13 correct in 15 successive trials and a significant run ($p < .01$) of successive correct responses for each of the L/W and S/B subsets of trials within one session of 45 trials. (6) This problem was similar to problem 5 except that the objects within a form category were selected without volume restriction. (7) This problem was similar to problem 1 except that the grey background and responses to the objects which were intermediate in volume were reinforced. (8) This problem was similar to problem 7 except that the objects within a form category were selected without

Table 1. Internal volume measurements of stimuli (in ml)

Number	Form				
	Cylinder	Half-barrel	Hexagonal	Hemisphere	Cone
1	10	4	17.5	6	8
2	24	10.5	25	14	16
3	33	21	35.5	25	27
4	44	41	45	42.5	46
5	59	72	63	75	77
6	74	121	75	104	121
7	97		117		
8	116		197		
9	141				
10	168				
11	203				

the volume restriction. (9) This problem consisted of trials such as those described in problems 1, 3, and 7 being presented concurrently. The order of L/W, S/B, and intermediate-sized-objects-correct-on-grey (hereafter I/G) trials was random except that there had to be 15 of each type in a single session of 45 trials. The criteria for mastery of this problem were to have 13 correct of 15 successive trials and to have significant runs ($p < .01$) for each of the L/W, S/B, and I/G subsets of trials within a session of 45 tirals. (10) This problem was similar to problem 9 except that the objects within a form category were selected without the volume restriction.

If an animal failed to attain the criteria for a problem within 25 sessions (1,125 trials), training was terminated.

RESULTS

All monkeys met the criteria of 13 correct in 15 successive trials together with significant "runs" of successive correct responses ($p < .01$; see Grant, 1947, for "runs" analysis; see also Note 1 in Thomas & Crosby, 1977) on all pretraining problems. On the training problems, all monkeys met these criteria on problems 1-6 (6 was L/W and S/B presented concurrently with no restriction on volume). Three monkeys (S 12, S 13, and S 14) also met these criteria on problems 7 and 8 (8 was I/G presented with no restriction on volume). Table 2 summarizes these results. One monkey (S 13) met the combined criteria on problem 9 (L/W, S/G, and I/G presented concurrently with the restriction on volume). In the session in which S 13 met criteria on problem 9 in 810 total trials, it had runs of 13 correct in 270 L/W trials ($p < .0002$), 13 correct in 268 S/B trials ($p < .0002$), and 14 correct in 270 I/G trials ($p < .00005$).

Table 2. Trials to criterion for each monkey for each task completed successfully

Tasks[a]	Monkeys				
	S11	S12	S13	S14	Median
L/W 1	155	43	39	43	43
L/W 2	24	90	29	21	26.5
S/B 1	218	77	67	166	121.5
S/B 2	22	26	28	20	24
L/W & S/B 1	389	405	225	180	307
L/W & S/B 2	135	309	90	45	112.5
I/G 1		517	424	559	517
I/G 2		20	37	840	37
L/W, S/B, & I/G I			810		
L/W, S/B, & I/G 2					

[a]L/W = large object correct on white tray; S/B = small object correct on black tray; I/G = intermediate object correct on grey tray; 1 = objects selected randomly except that at least one size was omitted between objects; 2 = objects selected randomly.

Despite the failures of monkeys S 12 and S 14 to meet the criteria necessary on problem 9 to permit them to continue to problem 10, with less stringent criteria it might be argued that they showed considerable achievement on problem 9. Specifically, if one used significant runs of successive correct responses with $p = .05$, and if one did not require that they show significant runs on the separable subsets of trials, S 12 had seven significant runs on problem 9 (2 at $p < .005$, 1 at $p < .01$, and 4 at $p < .03$). During its performance of problem 9, S 14 had 11 significant runs (3 at $p \leqslant .001$, 2 at $p \pm .005$, 2 at $p = .01$, and 4 at $p \leqslant .05$). Similarly, S 13, which met the more stringent criteria on problem 9 but failed to meet them on problem 10 (L/W, S/B, and I/G with no restriction on volume), had 16 significant runs (5 at $p < .001$, 3 at $p < .005$, and 8 at $p < .05$) on problem 10.

The successes of three monkeys on problem 8 (I/G with no restriction on volume) suggest that squirrel monkeys are able to make ordinal judgments conceptually where volume provides the cue. The monkeys could not attain the criteria by learning specific properties, as the intermediate object on one trial might be the largest or the smallest object on another trial. The monkeys could not learn specific configurations, as the selection of objects and their spatial positions were on a random or quasi-random basis from trial to trial.

It is true that the largest object and the smallest object in a form category could not serve as any other size. Therefore, it is possible that the monkeys learned the specific properties of the six largest and the six smallest objects from the pool of 37 objects. However, given the random or quasi-random selection of objects to be presented from trial to trial, it is extremely unlikely that an animal would receive enough trials in succession where one of the six largest or six smallest objects constituted the correct choice to attain the necessary significant runs. In fact, no significant run was achieved on the basis of it involving only correct choices of the 12 objects for which specific properties might have been learned.

Since three of the monkeys achieved criteria on L/W, S/B, and I/G presented separately and on L/W and S/B presented concurrently, it is suggested that the monkeys possessed the necessary perceptual skills to make the required volume judgments. That the same monkeys were less successful in making the L/W, S/B, and I/G judgments concurrently may be attributed to the added difficulty of having to respond to three conceptual conditionals concurrently. The occurrence of the several significant runs of correct responses that each monkey achieved on its final problem (i.e., where the more stringent criteria were not met) suggests that they might have met the criteria had training been extended beyond the 1,125 trials allowed per problem.

DISCUSSION

Although volume was the relevant dimension to the investigators, it is possible that the monkeys responded to the heights or the perceived two-dimensional areas of the stimuli. Regardless of the dimensions to which they responded, the implications and conclusions should be the same. Therefore, subsequent discussion will be in terms of volume or size as a matter of convenience.

Previous work which provides convincing evidence for judgments of size as relative class concepts includes that of Bernstein (1961), who reported that rhesus *(Macaca mulatta)* and pig-tail monkeys *(M. nemestrina)*, orangutans *(Pongo pygmaeus)*, and chimpanzees (species not indicated) responded to relative size on some trials of a "dimension-abstracted oddity" task. In these trials the relatively larger or the relatively smaller object was correct if that determined the odd stimulus. Hayes and Nissen (1971) reported that their five-month old chimpanzee was able to select the relatively larger object on 89% of the trials if the size ratio exceeded 2:1 but on only 55% if the size ratios were less than 2:1.

Klüver's (1933) research using java monkeys *(M. fascicularis)*, which was discussed in terms of the animals responding "relationally" to size, is strongly suggestive of the conceptual use of size cues. However, the evidence is not conclusive on that point, as repeated trials with the same discriminanda were presented. In view of that, it is possible to argue that the monkeys learned the specific size cues on the first few trials and used those cues on subsequent trials. Similar questions might be raised regarding Stone's (1961) claim of conceptual size judgments by rhesus monkeys. It may be noted also that, if conclusive, Stone's data would be described in terms of the theoretical scheme suggested in the introduction as showing the use of size as an absolute class concept.

Spence (1942) investigated the responses of chimpanzees on an "intermediate size problem." However, that study compares minimally to the present one in that his animals received relatively prolonged training with the same three discriminanda. In the transposition test, the previously middle-sized stimulus became the smallest or the largest of three stimuli. Responses to any of the test stimuli were rewarded, and the results indicated a distinct preference for the previously middle-sized stimulus rather than the new middle-sized one. Hence, the animals seemed to respond on the basis of the absolute properties of the stimulus rather than the relative ones. Gonzalez, Gentry, and Bitterman (1954), in an extension of Spence's study, provided a better test of relational responding. They used a series of nine stimuli where each succeeding one was larger than the previous member of the series by a factor of 1.15. After extensive training of their chimpanzees on stimuli 1, 5, 9, followed by extensive training on 3, 5, 7, they tested for transposition by inserting occasional trials with stimuli 2, 4, 6, or 4, 6, 8 among continued presentations of 3, 5, 7. The chimpanzees showed distinct preferences for 4 or 6 when it was the middle-sized member of a set, which suggests a preference for the relative properties in that 4 was sometimes the smallest of a set and 6 was sometimes the largest of a set. However, the repeated test trials with the same discriminanda permit the argument that the specific configurations associated with presentations of 2, 4, 6 and 4, 6, 8 might have been learned and used as cues.

In terms of the theoretical-taxonomic scheme described by Thomas and Crosby (1977) and summarized in the introduction here, work from this laboratory has demonstrated the squirrel monkey's ability to perform absolute class concepts (sameness-difference,[1] Czerny & Thomas, 1975, Thomas & Peay, 1976; greenness/nongreenness, Thomas & Crosby, 1977), relative class concepts (oddity, Noble &

Thomas, 1970, Thomas & Boyd, 1973; oddity/nonoddity, Thomas & Kerr, 1976, Thomas & Crosby, 1977; relative size in the present study), and relational concepts involving conditionals (all the preceding except Noble & Thomas, 1970, and Thomas & Boyd, 1973) and, perhaps, the biconditional. Thomas and Kerr (1976) suggested, perhaps erroneously since the design was not conclusive on the point, that their monkeys' performance might be described as using a biconditional relationship, although they acknowledged that the performances might only reflect the use of two conditionals concurrently. Thomas and Crosby compared the acquisition of the absolute class concepts, greenness/nongreenness, and the relative class concepts, oddity/nonoddity, and found that, with these examples at least, absolute class concepts were easier to learn. The above-mentioned studies which included conditionals actually required the monkeys to use two conditionals concurrently. The present study, on the final two problems, required the monkeys to use three conditionals concurrently.

Although relative class concepts and concurrent conditionals were involved in the present study, its goal was to investigate a nonhuman's ability for quantitative judgments at the ordinal level of measurement. Previously we had demonstrated the monkeys' ability to make quantitative (sameness-difference) judgments where volume (Czerny & Thomas, 1975) or length (Thomas & Peay, 1976) provided the relevant cues. The successes of three monkeys on problems 7 and 8 (relatively intermediate size) suggests their ability to make ordinal judgments. Whether this or any other nonhuman species may show other behaviors indicative of the capacity for ordinal measurement, such as sorting objects according to dimensional categories (e.g., length, area, volume) or rearranging objects along such dimensions in a serial order, remains to be investigated.

It is appropriate to acknowledge certain issues regarding the study of conceptual behavior.[2] For example: (a) What do demonstrations of conceptual behavior as contrived by an experimenter contribute to the general understanding of conceptual behavior? (b) How might demonstrations of specific conceptual behaviors contribute to an understanding of a species' ability to generalize those behaviors across changes in stimuli? (c) How might an animal's existing conceptual system interact with conceptual behaviors elicited under laboratory conditions? To address such questions with the effort they deserve might require a paper longer than the present one. We can only outline some tentative responses to the issues raised here.

Related to questions (a) and (b), our contention is that the basis for "mapping" all conceptual behavior in any species is found in the basic logical operations (Turner's, 1967, account and analysis of logical atomism is fundamental to the view taken here). Affirmation and negation determine the "elements" of conceptual behavior (regarded here as approximation to the "atomic facts" in logical atomism), and the relational operations determine how the elements may be related to form more complex concepts. To go a step further than mere "mapping," we suggest that conceptual behavior, no matter how complex, specific, or general, reduces (neurophysiologically or otherwise) to processes described best in terms of the basic logical operations. As long as the experimental paradigm demands the use of these basic processes (the logical operations), and as long as specific property or pattern cues pertaining to the stimuli have been eliminated, the demonstration will have shown that species' ability to use those basic processes. Questions about the generality of the basic processes with regard to a general understanding of conceptual behavior (question a) or with regard to an animal's ability to generalize the use of its basic abilities (question b) become as much questions about the experimenter's ingenuity in "asking" the animals the right "questions," vis à vis the reinforcement contingencies, as they do about the implication of specific demonstrations for conceptual behavior in general.

The issue of whether existing conceptual systems interact with conceptual behaviors elicited in the laboratory (question c) might be viewed as a special case of a broader issue, namely, whether conceptual behaviors are ever learned in the laboratory or are merely performed. We agree with Hayes and Nissen's (1971) response to the latter. "We cannot imagine any set of operations, applied to any subject, that could detect a concept without at the same time operating to induce its formation" (p. 79). In other words, the acquisition of new concepts and the detection of existing concepts are hopelessly confounded with the subject's acquisition of the reinforcement contingencies, thus the distinction between newly learned and existing conceptual behaviors is scientifically meaningless.

Notes

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1. Sameness-difference as assessed in other paradigms (e.g., Smith, King, Witt, & Rickel, 1975) may be considered a relative class concept.

2. Indeed, a reviewer of the manuscript for this article recommended that we acknowledge these issues even if we could not address them fully at the present time.

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