Paper 2

Learning and Color Discrimination in the American Black Bear

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INTRODUCTION

The black bear (*Ursus americanus*) has been thought to possess limited visual ability, especially compared to its good hearing and smell (Bray and Barnes 1967; Seton 1909; Skinner 1925; Wormser 1966). This view is not based on experimentation or controlled observation. In fact, the perceptual abilities of the black bear are virtually unknown aside from gross generalizations. Little more is known about the perceptual abilities of other species of Ursidae; however, Couturier (1954) states that brown bears are capable of discriminating bright colors (his source was unidentified) and Kuckuk (1937) demonstrates that young brown bears are capable of recognizing their keeper moving toward them at a distance of 110 m.

There is a general lack of information pertaining to the sensory abilities of bears and other carnivores. Hue perception in mammals, aside from primates, has been considered rudimentary or non-existent (Gregory 1966). Such conclusions too often have been based on poorly controlled experiments on relatively few species. For example, Walls (1942) in his compendium on the eye mentions research on color vision, much of which yielded questionable or conflicting results, for only ten non-primates. The primates are the only mammals in which both behavioral and physiological data convincingly establish widespread hue perception (Grether 1940; Walls 1942; Dücker 1965; Rosengren 1969; Hess 1973). However, behavioral research since 1950 indicates that several non-primates, including swine (Klopfer 1966) and horses, squirrels and prairie dogs (see review in Hess 1973), can readily discriminate between hues.

In carnivores color vision research has been limited to a relatively few species (Dücker 1965; Rosengren 1969): domestic dog and cat, raccoon (*Procyon*), red fox (*Vulpes*), civet (*Viverra*), mongoose (Herpestinae) and weasels (*Mustela*). This study was designed both to assess the ability of black bears to discriminate visually on the basis of hue and to develop a training method generally applicable to the study of discrimination in this species. Additional details of the methods described below, as well as comparable experiments on form discrimination, are found in Bacon (1973) and Burghardt (1975).

METHODS

Subjects

The two bears were named Kit and Kate; Kate was 19-31 months of age during testing and Kit 28-31 months. Both were hand-reared since 10 weeks of age

(Burghardt and Burghardt 1972) and were the same animals used in Bacon and Burghardt (Paper 1 this volume).

Apparatus

Stimulus Items. These consisted of 8 oz. (0.24 l) translucent polyethylene cups painted with a semi-gloss latex paint. Each cup was painted at least twice to insure a homogeneous appearance. Varying shades of each hue (or color) were produced by adding differing amounts of pigment to either a latex paint base or white latex paint. The shades, or saturations, ranged from dark to light for each hue. There were 5 hues with the following number of shades: blue—7, green—5, red—5, yellow—5, and gray—18.

Spectrographic Analysis. The intensity of transmission within the visible spectra was obtained for each hue and shade. Using a Bausch and Lomb 505 spectrometer, light transmission relative to a barium carbonate standard was obtained at every two nanometers between 400 and 700 nanometers. The shades of blue, green, red and yellow hues remained remarkably stable. The transmission spectra for the shades of each hue varied primarily in saturation (expressed as relative transmission) and did not show significant shifts up or down the visible spectrum. The shades of gray also exhibited an excellent homogeneity in that the relative transmission was almost constant along the visible spectrum.

Olfactory Control Boards. Olfactory cues were controlled by olfactory control boards upon which stimulus items were placed (Figure 3). Each board consisted of two 30 × 30 × 63 cm plywood squares bolted together. A hole the size of the stimulus item was cut in the top board, and a shallow well was hollowed out in the bottom board. Two squares of copper window screen were placed between the boards. During testing raisins were placed in the small hollow

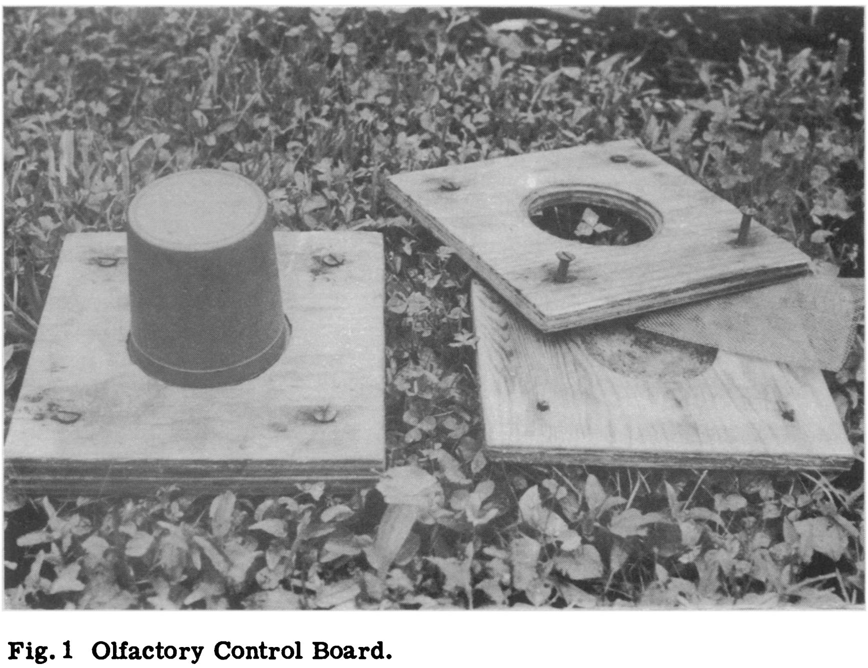

Fig. 1 Olfactory Control Board.

under the copper screen where the bear could not reach them. Stimulus items were placed on the control boards covering the copper screen, and two additional raisins were placed under the positive stimulus. In this way raisins were directly beneath each stimulus item but available only under the positive stimulus.

Procedure

Stimulus Arrays. Seven combinations of the five hues described previously were presented as two-choice discriminations during the testing. The two

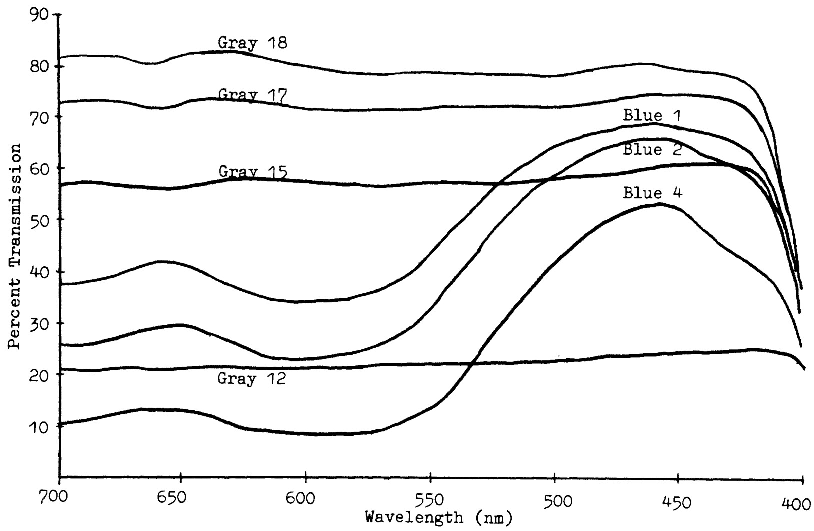

Fig. 2 Transmission spectra for selected blue and gray.

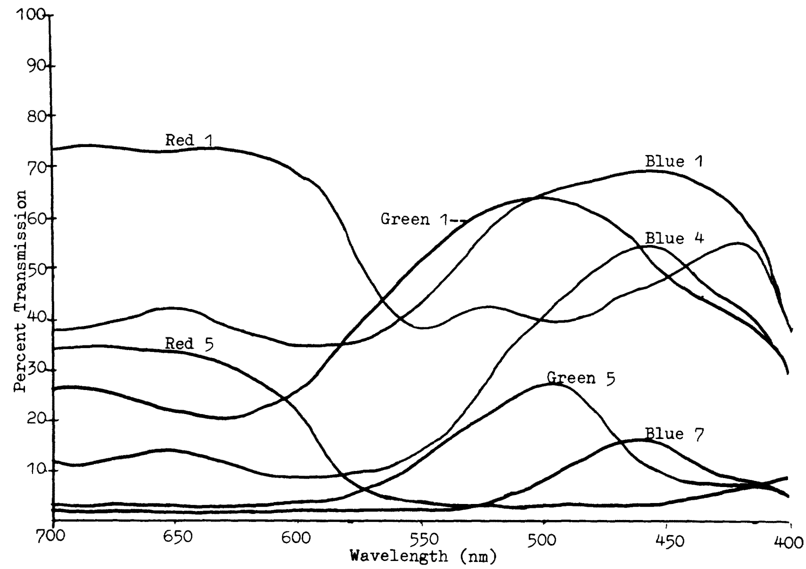

Fig. 3 Selected transmission spectra for blue, green and red.

stimuli were placed one to four m apart, and when possible, equidistant on either side of the line of approach of the subject.

Kate was trained positively to blue and was tested with four color pairs: blue-gray, blue-green, blue-red and blue-yellow. Kit was trained positively to green and was tested with three color combinations: green-gray, green-blue and green-red. The four remaining possible color pairs (red-gray, yellow-gray, green-yellow and yellow-red) were not tested.

Side preferences and hypothesis testing, such as perseverance and alternation, were corrected by the use of chance stimulus sequences (Fellows 1967).

Testing Routine. Testing was done in the animals' home enclosure. This enclosure was 18.3 m square divided by a center fence having a gate at each end. Before each trial the subject was manoeuvered to the end of the enclosure away from the apparatus. Two control boards and stimulus items were placed on the ground near the center of the testing side of the enclosure. The experimenter would leave the enclosure, obtain two stimulus items, and on return place each stimulus on the proper control board. The stimulus item to the left of the bear's path of approach was always positioned first. Attempts were made to equate the motions during placement of the two stimuli on the control boards. A clipboard oriented between the control board and bear prevented the latter from seeing the stimuli being placed. After this one of the center gates was opened allowing the subject to enter. The experimenter walked along the center fence while the bear approached the stimuli. Care was taken to remain behind the subject and not to present extraneous cues as to correct choice. After the bear obtained the reinforcement, she was given another raisin for a correct discrimination and was again placed on the side opposite the stimulus items. The entire trial formed a circular pattern of movement to which both bears became accustomed. As each subject was tested in a different half of the enclosure, both bears became well adjusted as to which side of the cage they would be allowed to enter during any particular test.

The average testing time for the 16-19 trials in a session was 37 minutes. This represents the time from the start of trial one to the end of the session. Approximately one-third of the time was devoted to preparing the stimulus arrays.

Criteria. A discrimination was considered correct when the subject turned over the positive stimulus item before touching or turning over the other (incorrect) stimulus. The bear was allowed to correct her response to obtain the reward (i.e. after the initial incorrect response, the animal could turn over the correct stimulus item for the reward). The bear was considered to be discriminating at a significant level when she responded correctly in nine of ten consecutive trials.

Control of Brightness Cues—Stimulus Bracketing. Since the testing occurred outdoors, precise control of brightness was impossible. Such precision, however, was rendered less critical by bracketing the positive stimulus. From the transmission spectra of the paints one could predict which colors would appear lighter or darker, under constant lighting, to a monochromatic animal. Figure 2 illustrates the spectral transmissions of several of the blues and grays used in the testing. Regardless of the spectral sensitivity of the retina of a monochromatic animal, under constant lighting blue 1 and blue 2 would always appear brighter than gray 12. For points within the visible spectrum the two blues reflect more light than the gray. Conversely, gray 15 and 17 will always appear lighter than blue 4. The shades with intersecting curves could appear lighter or darker depending on the spectral sensitivity of the visual system of the monochromatic animal.

Selected spectral transmission curves for blue, red and green appear in Figure 3. The principle of bracketing the positive stimulus is again illustrated. Since certain colors will always appear lighter or darker to a monochromatic animal, it cannot consistently discriminate correctly using brightness cues when the colors are presented randomly.

Control of Brightness Cues—Variable Illumination. Stimulus bracketing of the positive stimulus depends on constant illumination of both stimuli. Because of the shifting light patterns in the partially shaded outdoor enclosure, an attempt was made to vary systematically the illumination of the stimulus items. Three lighting conditions were used: both stimuli in the sun, both stimuli in the shade, and one stimulus in the sun and the other in the shade. Two controls were introduced by varying the illumination. First, the relative brightness of the positive stimuli was further compounded, making it more difficult for the subject to respond to brightness cues. Secondly, with one stimulus item in the sun and the other in the shade, the relative brightness according to the spectral curves may be reversed. A slightly darker cup resting in the sun will transmit more light than the lighter cup resting in the shade. Varying the illumination made consistent discrimination using brightness cues still less likely.

Training the Subjects. The above procedures evolved during the 12 months prior to the final testing presented in this report. Kate was used for all of the preliminary testing, a total of 31 sessions. Kit was trained over 12 sessions with no procedural modifications made during her training. Kit had previously been trained in a form discrimination task using similar procedures which facilitated her acquisition of the new task.

RESULTS

The results of the seven discriminations are illustrated in Tables 1 through 3. The blue-gray, blue-green, blue-red, blue-yellow, green-gray and green-blue discriminations were all consistently positive. Only in the green-red discrimination by Kit did a subject fail to reach criterion consistently. With this color combination Kit reached criterion in only eight out of 17 sessions. However, her cumulative correct response was 225 of 312 total presentations. The cumulative probability of this response is less than .0001. This indicates the bear was making a correct, but not consistent, choice.

DISCUSSION

The results indicate that the bears could discriminate between hues. The blue-gray and green-gray discriminations by themselves illustrate the presence of more than a monochromatic system. Unfortunately, the exact type of chromatic mechanisms cannot be postulated from the available data. Muntz and Cronly-Dillon (1966) trained goldfish (*Carrasius auratus*) to discriminate successfully red-green, green-red, blue-green, green-blue, blue-red and red-blue color pairs. They concluded the fish were trichromatic since at least three types of photoreceptors with different spectral sensitivities were required to successfully discriminate the six color pairs. Yager and Jameson (1968), however, argue that with Muntz's data, a deuteranope could make similar discrimination. The success of the discriminations did not necessarily require a trichromatic

TABLE 1 RESULTS OF THE BLUE-GRAY, TWO-CHOICE DISCRIMINATION FOR KATE MADE IN 1972

	Shades of Stimulus Items		Illumination[a]			
Date	Blue	Gray	Left	Right	Number of Correct Responses	Criterion Reached
5 May	1, 2	10-18	Shade	Shade	12 of 18	no
11 May	1-5	12-15, 17	Shade	Shade	24 of 25	yes
12 May	1, 3-6	11, 12, 14-16	Sun	Sun	25 of 27	yes
15 May	3-5, 7	11, 13, 14, 16	Shade	Shade	16 of 17	yes
24 May	2-5	9, 13, 15, 18	Shade	Shade	10 of 16	yes
25 May	2-5	9, 13, 15, 18	Sun	Shade	16 of 18	yes
26 May	1, 3, 4, 5	12, 14, 15, 17	Sun	Sun	16 of 19	yes
27 May	1, 3, 5, 6	10, 13, 15, 18	Shade	Sun	17 of 18	yes
30 May	2, 4, 6, 7	5, 11, 13, 17	Sun	Shade	17 of 18	yes

[a] Illumination of the stimuli is relative to the path of approach of the subject.

TABLE 2 RESULTS OF THE BLUE-GREEN, TWO-CHOICE DISCRIMINATION FOR KATE MADE IN 1972

Date	Shades of Stimulus Items		Illumination[a]		Number of Correct Responses	Criterion Reached
	Blue	Green	Left	Right		
14 May	1, 3, 4-6	1-5	Shade	Shade	25 of 27	yes
16 May	1, 3, 4-6	1-5	Shade	Shade	25 of 25	yes
17 May	1, 3, 5, 7	2-5	Sun	Sun	16 of 18	yes
26 May	1, 2, 5, 7	1-4	Sun	Sun	16 of 16	yes
1 June	1, 3, 5, 6	2-5	Sun	Shade	17 of 18	yes
1 June	2, 4, 5, 6	2-5	Shade	Sun	16 of 16	yes
2 June	1, 2, 5, 7	1-4	Sun	Sun	17 of 18	yes

[a] Illumination of the stimuli is relative to the path of approach of the subject.

TABLE 3 RESULTS OF THE GREEN-RED, TWO-CHOICE DISCRIMINATION FOR KIT MADE IN 1972

Date	Shades of Stimulus Items		Illumination[a]		Number of Correct Responses	Criterion Reached
	Green	Red	Left	Right		
5 August	1-4	1-4	Shade	Shade	10 of 16	no
5 August	1-4	1-4	Shade	Shade	12 of 22	no
16 August	1-4	1-4	Sun	Sun	9 of 16	no
21 August	2-5	1, 2, 4, 5	Shade	Shade	15 of 20	yes
22 August	1, 2, 4, 5	1-4	Shade	Shade	15 of 24	no
23 August	1, 2, 4, 5	1-4	Shade	Shade	14 of 16	yes
24 August	1-3, 5	1, 2, 4, 5	Shade	Shade	10 of 16	no
25 August	1-3, 5	1, 2, 4, 5	Sun	Shade	15 of 20	yes
26 August	1-3, 5	1-4	Sun	Sun	10 of 16	no
26 August	1-3, 5	1-4	Shade	Shade	16 of 20	yes
27 August	1-3, 5	1-4	Shade	Shade	15 of 20	yes
29 August	2-5	1, 3-5	Sun	Shade	10 of 16	no
30 August	1-3, 5	1-4	Varied	Varied	18 of 21	yes
1 September	1-3, 5	2-5	Varied	Varied	7 of 12	no
2 September	1-3, 5	2-5	Shade	Shade	15 of 18	yes
2 September	1-4	1-4	Varied	Varied	17 of 19	yes
3 September	2-5	1-4	Varied	Varied	15 of 20	no

[a] Illumination of the stimuli is relative to the path of approach of the subject.

system. This critique appears to apply to our study; therefore, no assumptions are made concerning trichromaticity in the black bear.

Nevertheless, hue discrimination was clear and, contrary to Courtier (1954), did not depend on 'bright' colors. The task acquisition was very rapid and the discriminations were consistently correct. The bears learned more rapidly than Grether's (1940) chimpanzees, and as fast as the dogs used by Rosengren (1969). This positive performance by the bears indicates that hue discrimination is most likely a strong and widely used component of the bear's visual perception.

The existence of color vision in the black bear belies some generalizations in recent literature concerning mammalian visual capacities, as does our work on form discrimination in black bears (Bacon 1973; see also Burghardt 1975). The foraging behavior of black bears supports our findings on their color vision. Black bears appear to use their eyesight during ingestive behaviors much more than previously supposed. The food items consumed indicate that the bear simply does not just smell these objects out. Consumption of small insects, berries, and scattered ground foods such as acorns, may require good visual acuity. A highly developed color sense would also aid in such discriminations.

The black bear has been assumed to be primarily nocturnal. Anatomical evidence for this lies in the well developed tapetum lucidum of the eye. However, the observed feeding behaviors indicate that the bear, in natural situations, may feed during the light or crepuscular hours of the day, and relies greatly on sight to locate and obtain food. A monochromatic retina would appear insufficient to cope with the needs of an animal that feeds by day on often small and scattered objects. In summary, the results show that black bears can be easily and quickly trained to perform learned hue discriminations.

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