

*COLOR-NAMING FUNCTIONS FOR THE PIGEON*¹ANTHONY A. WRIGHT *and* WILLIAM W. CUMMING²

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Six pigeons were trained to match wavelengths in a three-key matching-to-sample paradigm. Test trials were occasionally presented, where probe wavelengths appeared on the center key and choices were made to the training stimuli presented on the side keys. Color naming functions were obtained by plotting the percentage of test trials that each training stimulus wavelength was chosen for each center key probe wavelength. The wavelength where the functions intersected was interpreted as a transition point between pigeon hues. Three experiments employed different wavelengths as training stimuli. The first two experiments demonstrated that the intersection of the color-naming functions occurred in all cases at 540 nm and 595 nm. The third experiment employed 540 nm and 595 nm as two of the three training stimuli, and the relatively slow acquisition, together with the resulting color-naming functions, supported the proposition that 540 nm and 595 nm may be transition point wavelengths between pigeon hues.

These experiments were conducted to determine if the visible spectrum can be divided into several sets of wavelengths, each set representing a hue. Probe wavelengths were presented on the center key during a matching-to-sample session, and color-naming gradients were derived from the side-key choices.

Cumming, Berryman, and Cohen (1965) proposed that pigeons in a matching-to-sample experiment coded the center-key stimulus and chose a side-key stimulus on the basis of this code. Pigeons were trained on a procedure in which a response to the center-key stimulus turned off the center-key stimulus and simultaneously turned on two side-key stimuli. A response to the side-key stimulus that matched the center-key stimulus produced reinforcement, whereas a response to the side-key stimulus that did not match the center-key stimulus produced blackout. After prolonged training with red, green, and blue Christmas-tree bulbs

as stimuli, a transfer test was conducted; yellow Christmas-tree bulbs were substituted in the place of the blue bulbs. Performance on trials with combinations of yellow and green stimuli, and red and green stimuli was maintained at a high level of accuracy, but on trials where the novel yellow stimulus appeared on the center key in conjunction with the familiar red stimulus on a side key, the birds' performance was 19% correct. Performance on these trials gradually improved over 11 sessions, and with this acquisition there was a complementary deterioration in performance on trials where the familiar red stimulus appeared on the center key and the novel yellow stimulus on a side key. It seemed possible that what most humans identify as two distinct hues (yellow and red) might appear to the pigeon as a single hue, a unitary set of wavelengths. In order to determine the range of wavelengths comprising each set, monochromatic stimuli were used in these experiments.

EXPERIMENT I

METHOD

Subjects

Six experimentally naive White Carneaux pigeons from the Palmetto Pigeon Plant, Sumter, South Carolina, were used. They were between 5 and 8 yr old at the beginning of the

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²William W. Cumming died shortly after this paper was completed.

experiment. Experimental sessions were conducted seven days a week if the subjects weighed $80\% \pm 15$ g of their free-feeding weight.

Apparatus

The experimental chamber consisted of a double compartmental box that could be separated at the stimulus panel to facilitate calibration of stimulus wavelength and intensity. The subject's portion was rectangular, 24 in. long, 15 in. wide, and 14 in. high (609 by 381 by 487 mm). The stimulus panel was covered with matte black plastic, with three horizontally aligned pigeon keys (Lehigh Valley #1348), and a grain hopper centrally located 5 in. (127 mm) below the center key. The ground-glass keys, which were spaced 2 in. (51 mm) apart and 10 in. (254 mm) from the chamber floor, required a force of 20 g (0.20 N) through a distance of 1 mm for actuation. The experiment was controlled by a system of relays, timers, and counters in a separate room.

Monochromatic stimuli were produced by passing collimated light through series #46 Bausch and Lomb interference filters. Filters were automatically placed in the light beam by actuating a solenoid (Johnson, 1966). Each filter was placed in the apparatus and calibrated with a Edgerton, Germeshausen, and Grier #580-585 Spectroradiometer. Filters having a peak wavelength equal to or greater than 480 nanometers (nm) were attenuated according to the pigeon's spectral luminosity coefficients (Blough, 1957) to give equal brightness for the pigeon. Kodak Wratten blocking filters (either #2A, #4, or #15) were used to eliminate undesired lower harmonics of energy.

Intensities from the three sources (Sylvania quartz iodine #75Q/cl) were adjusted with neutral density filters to give an irradiance of 1.40×10^{-7} watts/cm² at 560 nm, with the radiometer input diffuser placed 3.5 in. (88.9 mm) from the ground-glass key. This intensity is just within the human photopic region (27.4 cd/m² with an Ilford SEI photometer at 560 nm), and is assumed to be within the pigeon's as well. A low level of intensity in the chamber was provided by two General Electric #1829 bulbs in a dome houselight. This chamber light was on at all times except during blackout periods early in training. Illuminance from the chamber walls was 6.4

cd/m² as calibrated with an Ilford SEI photometer.

Procedure

During the first five sessions, the pigeons' key peck was shaped. Initially, key pecks were shaped to a tungsten white light on the center key. Following this initial shaping, key pecks were reinforced to the training wavelengths (512 nm, 572 nm, 655 nm) alternately appearing on the three keys.

During the sixth session, the pigeons were introduced to the matching-to-sample procedure. On each trial one training stimulus appeared on the center key. A center-key peck resulted in stimuli appearing on the side keys. A peck on either side key activated shutters that removed the stimuli from the three keys. In addition, if the side key that matched the stimulus on the center key was pecked, then 3-sec access to grain resulted, whereas if the side key that did not match the stimulus on the center key was pecked, then 3 sec of blackout (houselight and keylights turned off) resulted. Access to grain or blackout was followed by a 15-sec intertrial interval (houselight turned on and keylights turned off). During the intertrial interval, key pecks were ineffective.

Each 120-trial session was composed of 10 randomized blocks of 12 different types of trials, which were distinguished by their stimulus displays. The side-key stimulus that was identical in wavelength to the center-key stimulus appeared as frequently on the right side key as on the left side key. The side-key stimulus that was different in wavelength from the center-key stimulus was one of the two remaining training stimuli. For each training stimulus there were thus four different types of trials, and hence a total of 12 with three training stimuli.

Matching-to-sample training continued until accuracy was 90% or more for seven consecutive daily sessions. For the six subjects this criterion was met in 30 to 50 sessions. The procedure was then changed to one of intermittent reinforcement.

Reinforcement was available on 60 predetermined trials out of a 360-trial session. (30 randomized blocks of the 12 different types of trials). Selection of particular trials where a reinforcer could be obtained was accomplished by a computer program that randomly selected

trials with the restriction that reinforcement would be available five times on each of the 12 different types of trials and that the number of trials between reinforcement availability would be geometrically distributed. Four equivalent sequences were available and the particular sequence used to schedule the session varied from day to day for each subject.

Unreinforced side-key pecks (correct or incorrect) were followed immediately by a 1.5-sec intertrial interval. A 1.5-sec intertrial interval also followed reinforcement.

After performance stabilized to an accuracy of about 90%, 60 test trials were intermixed with 300 regular training trials. During a test session, three probe stimuli, of different wavelength than the training stimuli, were each presented 20 times. Reinforcement was available five times on each of the 12 types of trials, but it was never available on a test trial. Four equivalent test sequences were available and the particular sequence varied from day to day for each subject.

Probe stimuli were of a wavelength intermediate between the two training stimuli on the side keys. One probe stimulus was selected from the range 512 nm to 572 nm, another was selected from the range 572 nm to 655 nm, and a third was selected either from the range 655 nm to 641 nm or from the range 452 nm to 512 nm. For this third probe stimulus, 655 nm appeared on one side key and 512 nm on the other side key. Figure 1 shows the training stimulus wavelengths as indicated by arrows in experimental condition 1.

RESULTS

Data from the test trials for each bird and for the mean of the six birds are shown in Fig. 2. Lines were drawn through the mean data points by eye and then superimposed on the individual functions through the use of a sys-

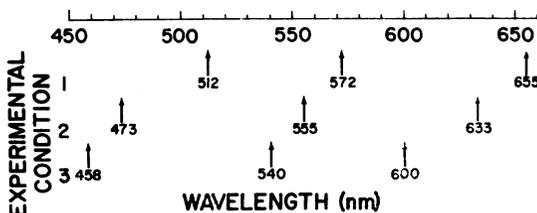


Fig. 1. Training stimulus wavelengths as indicated by arrows for Exp. I, II, and III.

tem of templates. In spite of the large number of data points, the mean functions seem to fit the data for each subject. Each data point represents the percentage of 20 trials that the subject chose a particular training stimulus on the side key for each center-key probe stimulus. For example, notice the circle in the lower right-hand corner of the mean figure. With a 641-nm probe stimulus presented on the center key, the subjects on the average chose the 572-nm side key 15% of the time. Since the only alternative response was to the 655-nm side key stimulus, the subjects on the average chose it 85% of the time, as shown by the filled square in the upper right hand corner of the mean figure. The important conclusion to be drawn from Fig. 2, is that the functions tend to cross at 540 nm and again at a little less than 600 nm.

Each probe stimulus was placed in combination with as great a variety of other probe stimuli as possible. Interactions among the three probe stimuli employed each day could not be discerned from the data. Generally, probe stimuli were presented until determinations were obtained for all 19 probe stimuli before redeterminations were obtained for any of them. With continued testing, a bias toward one of the side keys was occasionally evidenced on test trials. Generally this position preference

Table 1

Percentage of probe stimuli with a position preference equal to or greater than 75%.

Test Sessions	Bird Number					
	53	254	255	256	257	258
EXPERIMENT I						
1-12	8	28	0	33	22	28
13-24	16	5	0	14	28	50
25-36	55	14	11	0	56	56
37-50	83	14	36	18	69	59
EXPERIMENT II						
1-12	14	36	11	16	50	44
13-24	17	33	11	16	25	14
25-36	8	33	3	22	44	14
37-50	26	26	2	29	43	38
EXPERIMENT III						
1-12	14	19	19	25	83	22
13-24	8	22	31	8	33	14
25-36	33	8	39	16	53	19
37-50	73	2	67	29	45	40

NOTE—A position preference equal to or greater than 75% is obtained when one of the side keys is chosen 15 or more times out of 20 probe stimulus presentations.

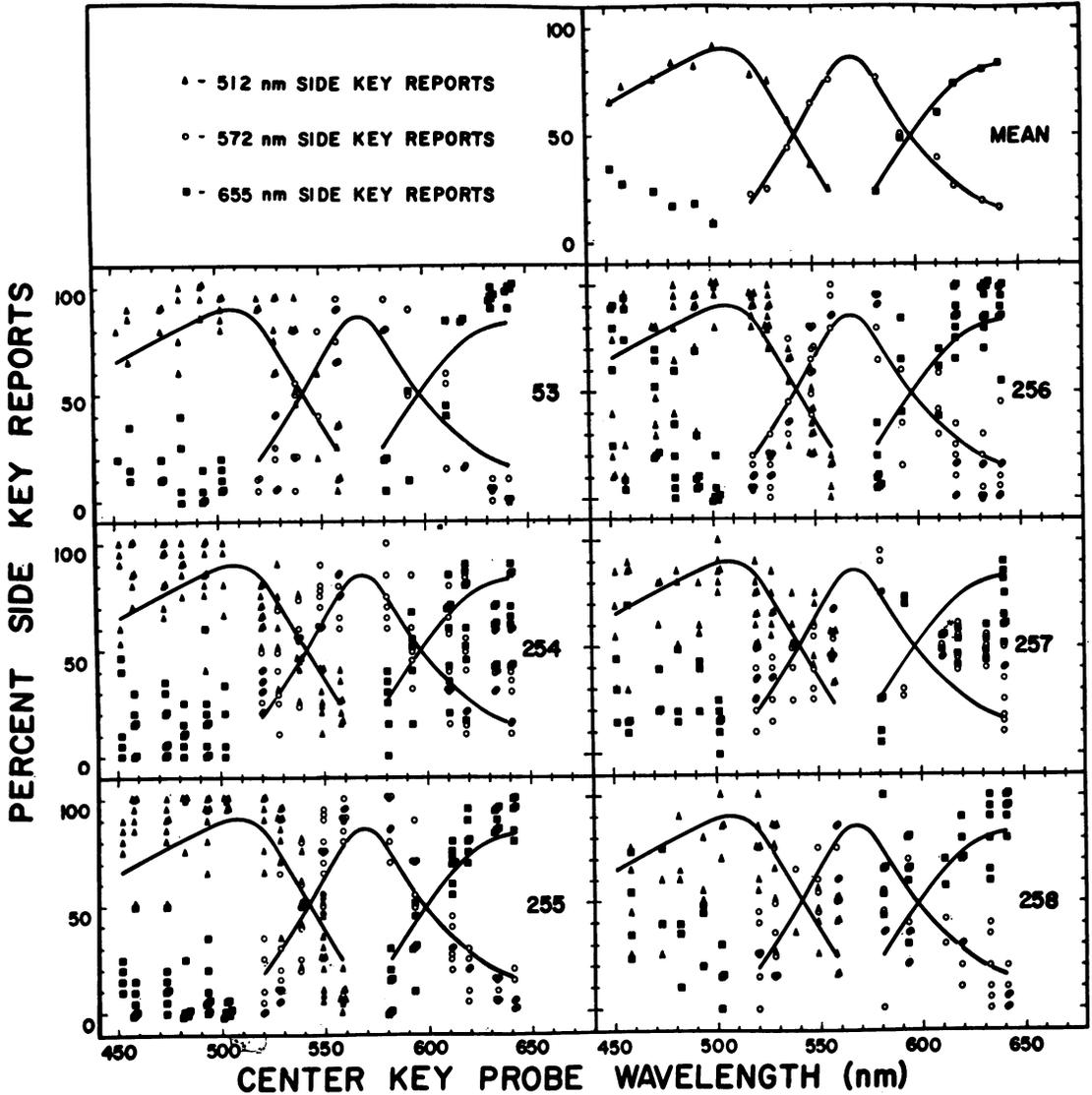


Fig. 2. Percentage of 20 trials that each of two adjacent training wavelengths were chosen for intermediate probe wavelengths on the center key.

was restricted to test trials, and was not apparent for the regular training trials. Table 1 shows the percentage of probe stimuli, for blocks of 12 sessions, to which the birds had a 75% or greater position preference. A bias toward one of the side keys would tend to compress the curves shown in Fig. 2 toward the 50% line, and would tend to obscure the position of the crossover point. Figures 2, 3, and 6 do not contain data points for probe stimuli to which there was a 75% or greater position preference.

EXPERIMENT II

Experiment II was conducted to determine what changes in crossover points, if any, would occur as a result of changes in the training stimulus wavelengths. If a crossover point represents the bisection of the interval between two training stimulus wavelengths, then changing the training wavelengths, *e.g.*, by decreasing them all 20 nm, ought to result in a crossover point that is some nanometers less than the former one. On the other hand, if the

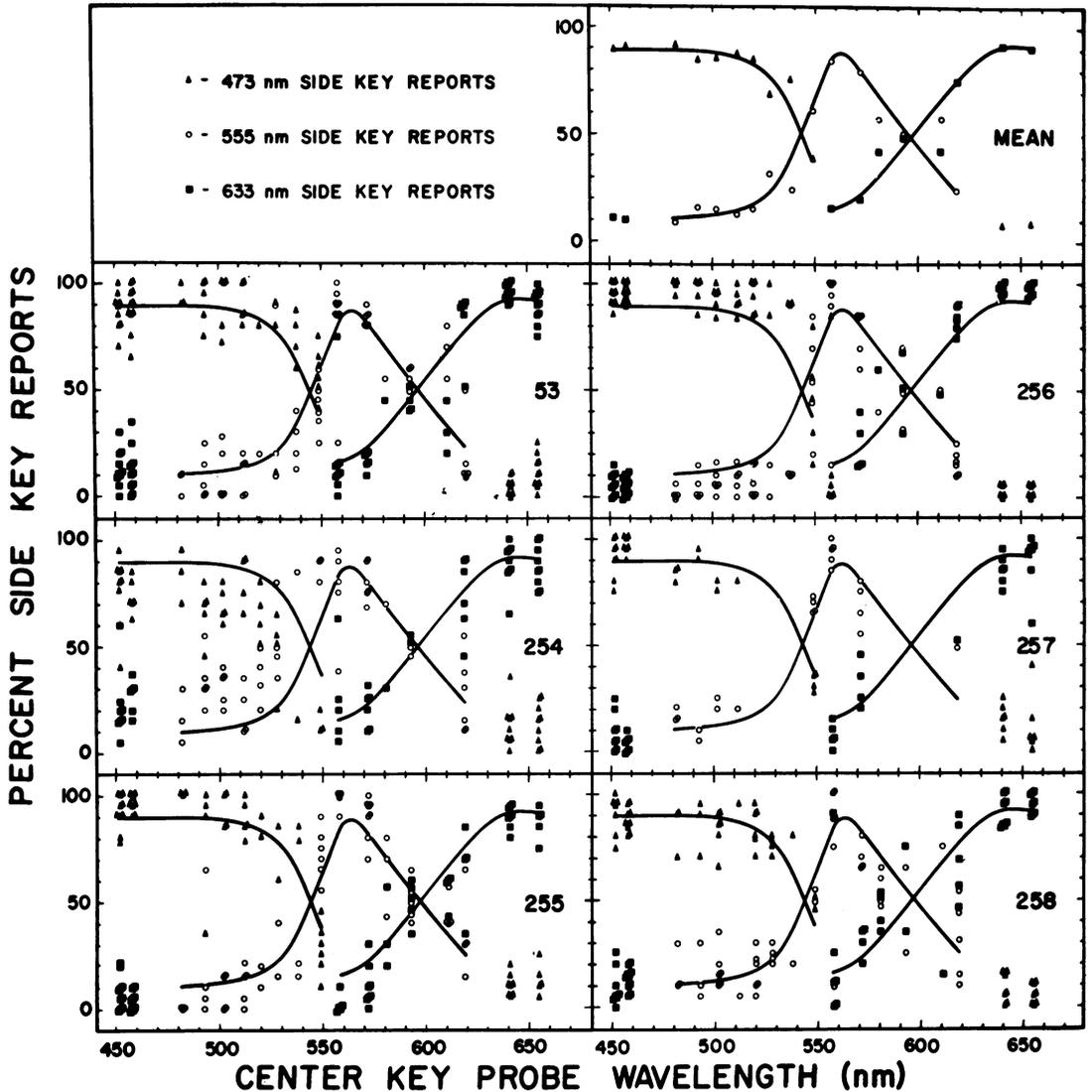


Fig. 3. Percentage of 20 trials that each of two adjacent training wavelengths were chosen for intermediate probe wavelengths on the center key.

pigeon's visible spectrum is divided into sets of wavelengths, the pigeon might be matching stimuli that are members of the same set independent of any wavelength differences among them. The center-key test wavelength might function only to represent a particular set, and the side-key choice might be made solely on the basis of whether or not it is a member of the same set. For example, with a center-key test stimulus selected from the human green (495 nm to 565 nm) it would not matter for human subjects whether the side-key training stimulus was 540 nm or 519 nm, provided that it were green.

METHOD

Subjects

The subjects and their deprivation conditions were the same as in Exp. I.

Procedure

The wavelengths of the training stimuli were changed as shown in Fig. 1 by the displacement of the arrows in row 2 relative to the position of the arrows in row 1 for Exp. I. The subjects were tested throughout Exp. II. As in Exp. I, reinforcement was available on 60 regular training trials and three probe

stimuli were each presented 20 times during the 360-trial session. For each session, a probe wavelength was selected from each of the intervals (1) 473 to 555 nm, (2) 555 to 633 nm, (3) >633 nm or <473 nm.

RESULTS

The results are shown in Fig. 3, which is a plot of the percentage of 20 trials that each subject chose a particular training stimulus on the side key for each center-key probe stimulus. Figure 3 shows the results for each subject after it reached an accuracy of about 90% (except Bird 254) on 300 regular training trials out of a 360-trial session. Because Bird 254 never reached an accuracy of 90%, all test data for this subject are shown except where there was a 75% or greater position preference. As in Exp. I, smooth functions were drawn by eye through the mean data points, as shown in the upper right-hand corner of Fig. 3. These functions were then superimposed on the individual data with the use of a system of templates.

The transition or crossover points occur at virtually the same wavelengths as in Exp. I, although these training wavelengths were changed (from 655 to 633 nm, from 572 to 555 nm, and from 512 to 473 nm). Figure 4 shows the superimposition of the mean functions for Exp. I and II. This invariance in crossover points suggests that the pigeon's visible spectrum is divided into several sets of wavelengths with the transition wavelengths between three such sets occurring at 540 and 595 nm.

EXPERIMENT III

Experiment III was conducted to test the role of the previously determined crossover point wavelengths (540 and 595 nm). If the pigeon is matching sets of wavelengths, and the particular stimuli employed function only to represent the set, then the wavelengths that are points of transition from one set to another set may be ambiguous as to which set they represent. If 540 and 595 nm are transition wavelengths, then the subjects might have difficulty matching them and there might be considerable session-to-session variability in the percentage of time that they were chosen with probe stimuli on the center key. On the other hand, if the subjects were simply bisecting the interval between the training stimuli,

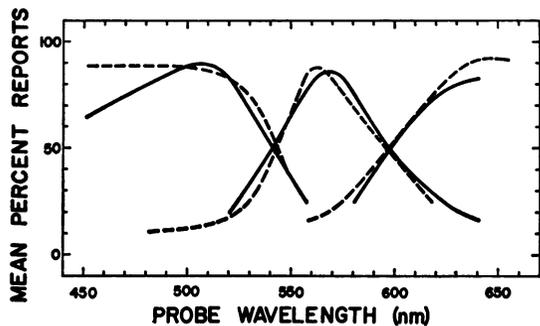


Fig. 4. Comparison of the mean function with 512, 572, and 655-nm training stimuli (solid function) to the mean function 473, 555, and 633-nm training stimuli (dashed function).

then new training stimuli positioned at the previously determined crossover points ought to generate a new pair of crossover points between the former ones.

METHOD

Subjects

The subjects and experimental conditions were the same as in Exp. I and II.

Procedure

Training stimulus wavelengths were 600, 540, and 458 nm, as shown in row 3 of Fig. 1. The subjects were tested throughout Exp. III. As in Exp. I and II, reinforcement was available on 60 regular training trials and three probe stimuli were each presented 20 times during the 360-trial session. For each session, a probe wavelength was chosen randomly from each of the intervals (1) 458 to 540 nm, (2) 540 to 600 nm, (3) >600 nm or <458 nm.

RESULTS

Figure 5 shows the acquisition of matching-to-sample for Exp. II and III. Each data point is the mean percentage of the 300 regular training trials that were correctly matched. Acquisition of matching-to-sample with the training stimuli in Exp. III (unfilled circles) was generally much slower (except for Bird 255) than with the training stimuli used in Exp. II (filled circles).

Results from the test trials are shown in Fig. 6, which shows the results for each subject after it reached an accuracy of about 90% (except Birds 254 and 257) on 300 regular training trials out of a 360-trial session. Because Birds 254 and 257 never reached an

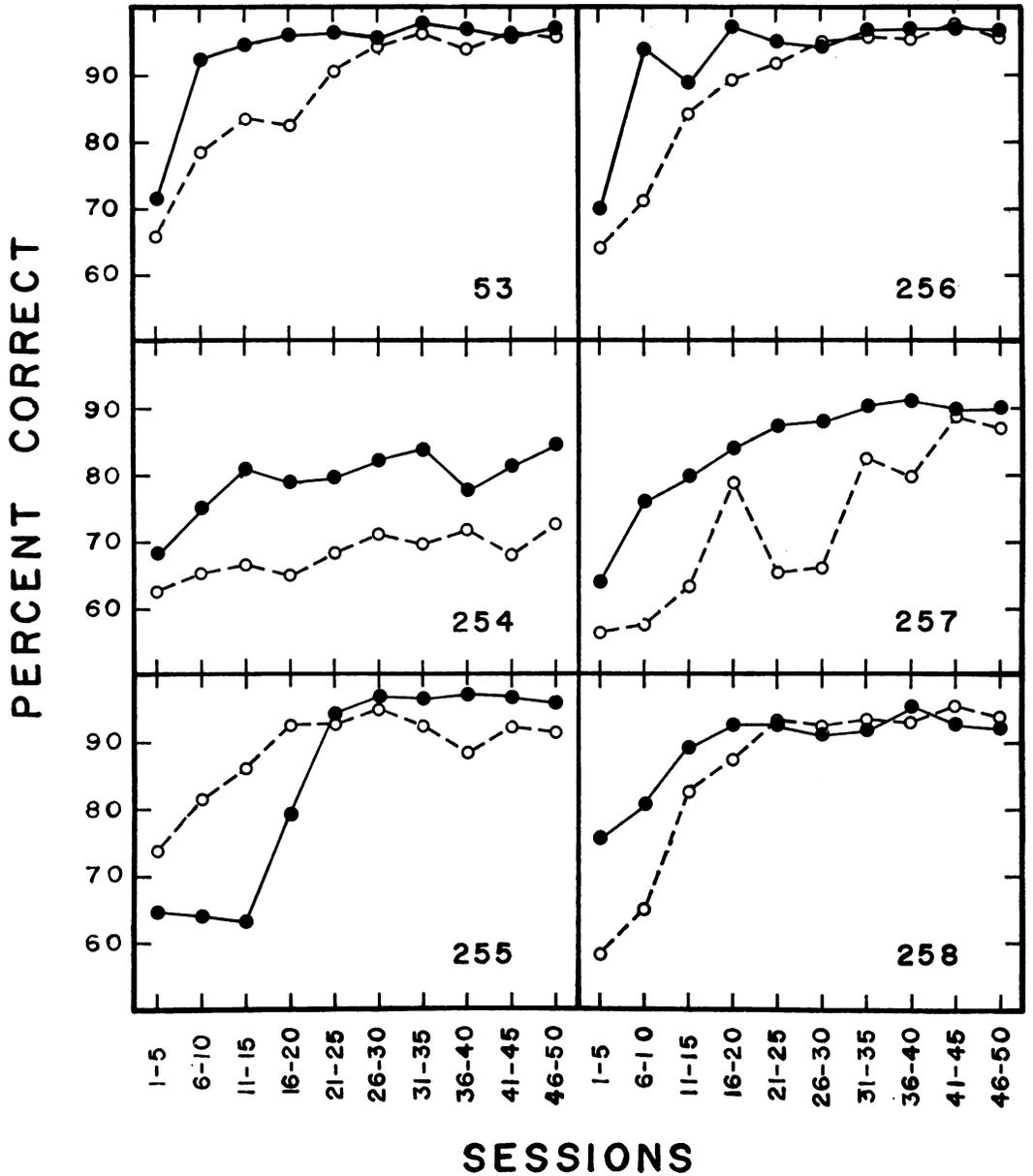


Fig. 5. Acquisition of matching with 633, 555, and 473 nm in Exp. II (filled data points) as compared to acquisition of matching with 600, 540, and 458 nm in Exp. III (unfilled data points).

accuracy of 90%, all test data for these subjects are shown except where there was a 75% or greater position preference. Considered as a group, the subjects defy summary description in the form of a mean figure. Bird 254 responded to probe stimuli of wavelengths longer than 600 nm more often to the 600-nm side-key stimulus, than to the 458-nm side-key stimulus. Bird 53 and Bird 255, however, responded to probe stimuli of wavelengths

longer than 610 nm more often to the 458-nm side-key stimulus than to the 600-nm side-key stimulus. Birds 256 and 258 showed yet a different pattern. In some sessions, Birds 256 and 258 responded to probe stimuli of long wavelengths most often to the 600-nm side-key stimulus, and in other sessions these two birds responded to the same probe stimuli most often to the 458-nm side-key stimulus.

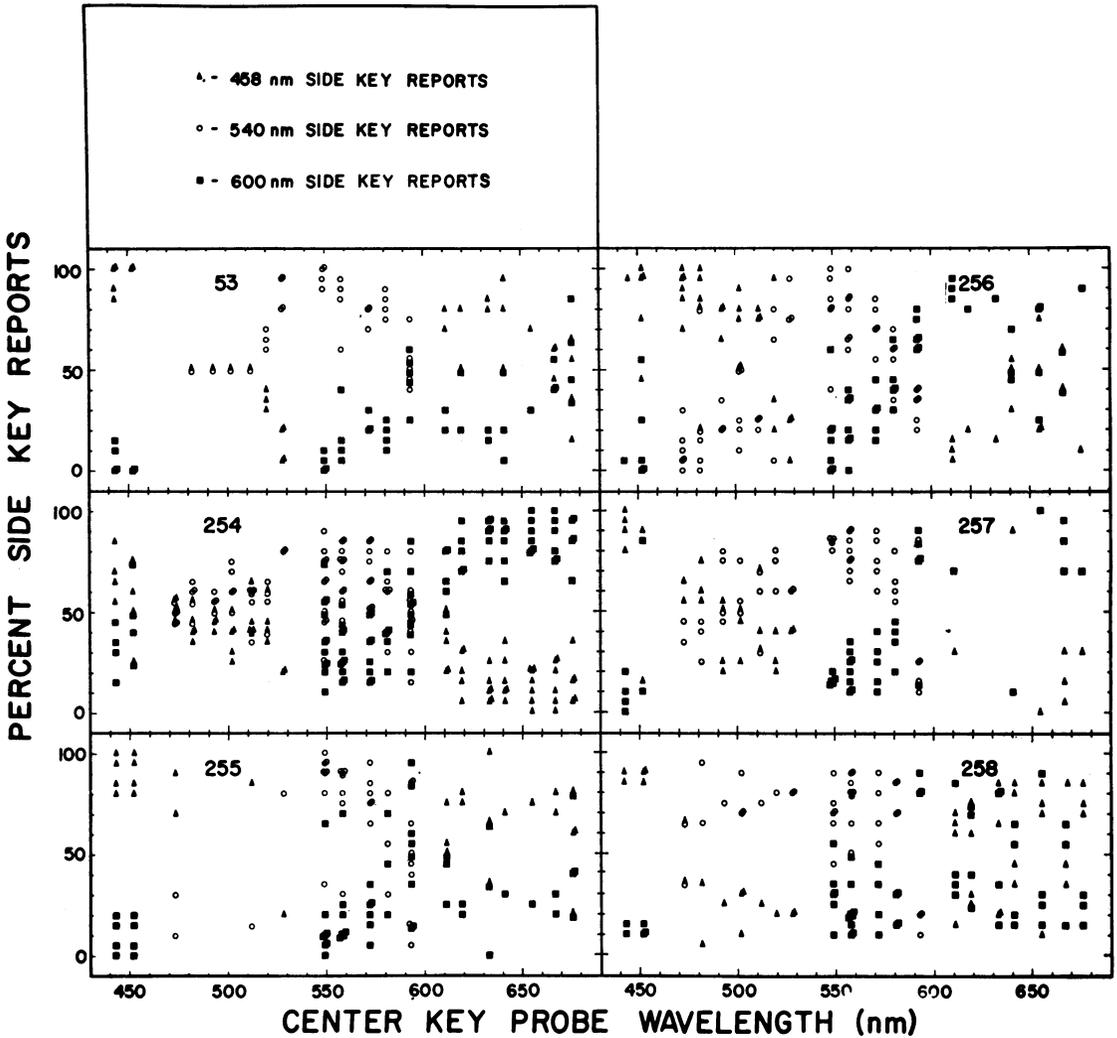


Fig. 6. Percentage of 20 trials that each of two adjacent training wavelengths were chosen for intermediate probe wavelengths on the center key.

DISCUSSION

Color-naming experiments with humans (Beare, 1963; Boynton and Gordon, 1965) have demonstrated that visible wavelengths are grouped into four or five sets (1) blue for wavelengths 450 to 495 nm, (2) green for wavelengths 495 to 565 nm, (3) yellow for wavelengths 565 to 585 nm, (4) red for wavelengths greater than 585 nm. If orange were given an independent status, it would probably occupy the range of wavelengths from 585 to 610 nm. Sets of wavelengths for pigeons do not seem to correspond to those for humans. The 540-nm transition point is in the middle of the human green (495 to 565 nm). Likewise, the

595-nm transition point does not correspond to the transition point between the human yellow and red/orange (585 nm), nor to the orange and red transition point (610 nm).

The human visible spectrum curls back on itself and forms a color wheel. This color wheel, or chromaticity diagram, joins the long-wavelength, red, spectral stimuli to the short-wavelength, blue ones by the imaginary spectral purples. The spectrum, as seen by pigeons, would also seem to curl back on itself. In Exp. III, with probe stimuli of long wavelengths on the center key, (longer than 610 nm) the birds could respond either to 458 nm, a very short wavelength, or to 600 nm, a rather long one. Birds 53 and 255 responded

much more frequently to the 458-nm side key than to the 600-nm one. Similarly, in Exp. I with probe stimuli of short wavelengths (shorter than 500 nm) on the center key, the birds could respond either to 512 or 655 nm, and 655 nm was chosen more and more frequently for progressively shorter wavelengths below 500 nm. Blough (1961) noted that pigeons trained to peck a key of 610 nm had a strong tendency to generalize their responses to 490 nm, a tendency that would be expected if the pigeon's visible spectrum fitted the circular pattern.

Blough (1961) also trained pigeons to peck a key of 530 nm. When given a generalization test, the birds responded to wavelengths shorter than 530 nm, but very little to wavelengths of 540 nm or greater. Similarly, pigeons trained to 550 nm generalized very little to wavelengths shorter than 540 nm, but generalized freely to wavelengths longer than 550 nm. Generalization data from Blough (1961) are shown in Fig. 7. These generalization data are further evidence that 540 nm is a transition point between sets of wavelengths for the pigeon. When pigeons were trained to 570 nm (Blough, 1961), a wavelength closer to the middle of the set, a more symmetrical gradient resulted. Blough (1961) concluded, "... the 'hues' of pigeon and human do not coincide; the pigeon's 'yellow' seems too broad ..."

Similar characteristics of steepness were shown around the 595-nm transition point (Blough, 1961). Generalization gradients from two of the four birds trained at 610 nm showed a sharp decrease in generalization from 610 to 590 nm. Gradients from the other two birds trained at 610 nm were quite flat across the test wavelengths (610 to 490 nm). All four birds, however, had had previous training (followed by testing) at 550, 530, 510, and 570 nm, which probably influenced the generalization

gradients at 610 nm. There may also have been some influence on the color-naming gradients obtained from Exp. II by the training and testing in Exp. I. This influence (if present) might be manifested quite differently from effects of previous training noted by Blough (1961), because of the differences between matching-to-sample and single-key generalization.

Donner (1953) recorded from single units in the ganglion layer of the pigeon retina. The resulting narrow response curves were grouped according to the wavelength that produced a peak response. Figure 8 shows the mean curves from Exp. I and II in the lower panel and the modulator type curves (Donner, 1953) in the upper panel. One might expect the intersection points of modulator curves to coincide with intersection points of color-naming curves. Instead, the relation is just the opposite. Crossover points (540 and 595 nm) of the color-naming functions correspond to peaks of the modulator curves, while intersections of the modulator curves correspond to peaks of color-naming curves. Intersection of the modulator curves cannot be precisely determined because the wavelength where each unit gave the highest response rate was set arbitrarily at 100% in order to average across several ganglion units. Indeed, Donner (1953) presented each average modulator curve separately.

The relation between modulator-type curves and color-naming functions may depend upon where in the visual system recordings were made, and may be different for different organisms. Recordings from the lateral geniculate of the Macaque monkey (DeValois, Abramov, and Jacobs, 1966) resulted in several narrow band response curves with their crossover points corresponding to the crossover points of the human color-naming functions (Boynton and Gordon, 1965). In order to make

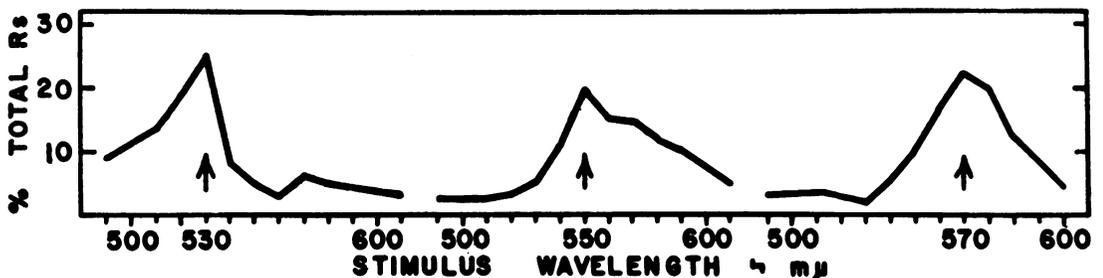


Fig. 7. Mean generalization gradients around three training wavelengths (Blough, 1961).

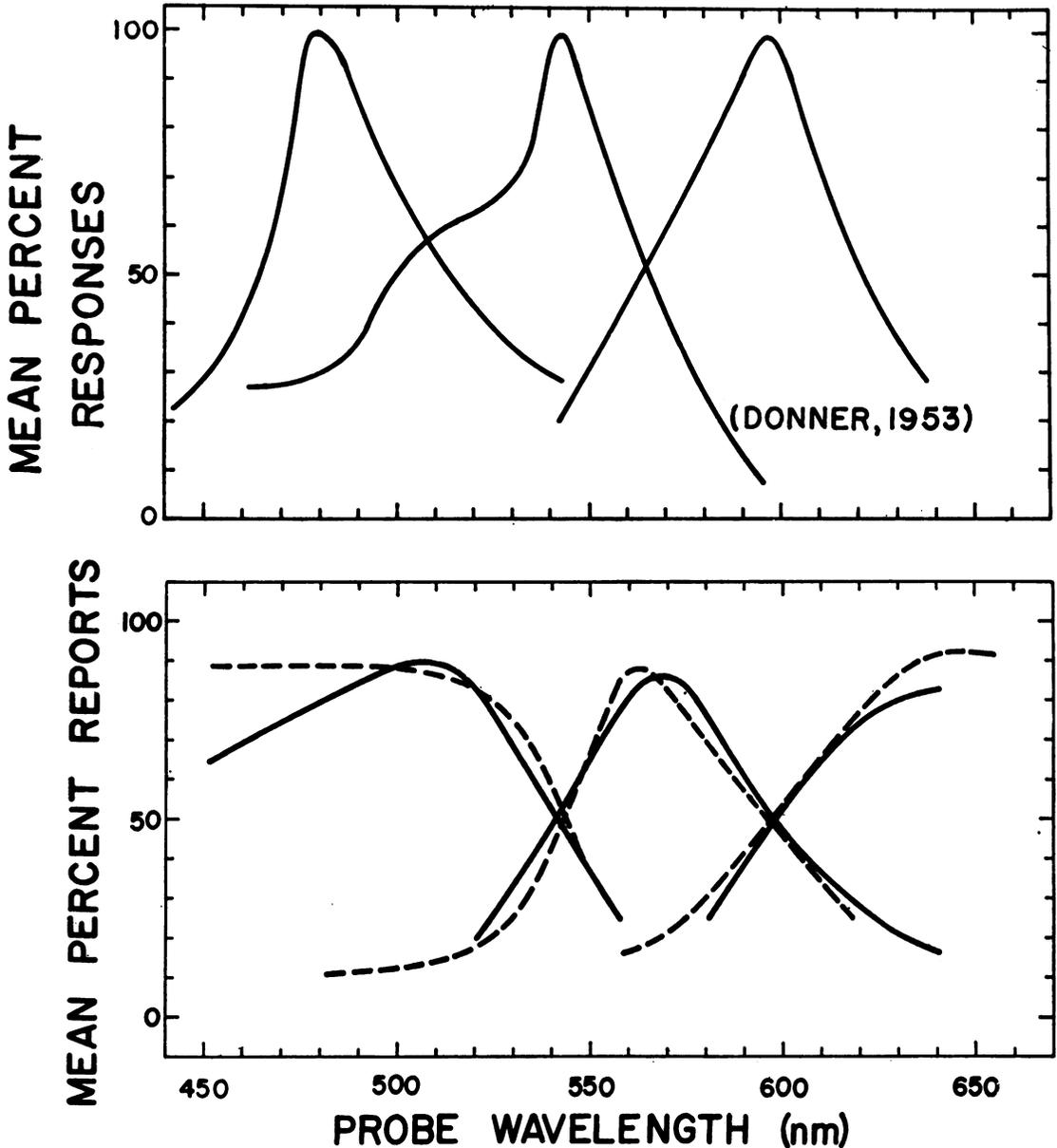


Fig. 8. Response curves for single units of the pigeon retina (upper panel) and mean color-naming curves (lower panel). Solid functions in lower panel are from Exp. I, and dashed functions are from Exp. II.

this comparison, DeValois *et al.* (1966) argued that the essential characteristics of the Macaque monkey's color system are equivalent to those for the human.

Indication that the pigeon's spectrum is divided differently from the human spectrum ought to make experimenters cautious about labeling experimental stimuli with human color names and stating, for example, that the pigeon has a "green" preference. Stimuli that

appear "green" to human observers may represent distinctly different "hues" for pigeons. Experiments I and II indicated that two wavelengths may be members of entirely different and distinct sets of wavelengths, if one is of a wavelength slightly less than 540 nm and the other is slightly greater than 540 nm. Furthermore, the broad band and irregularly distributed stimuli commonly produced by gelatin absorptive filters may not be specifiable in

terms of which pigeon hue they represent. One cannot say for sure that the green and the yellow stimulus from an in-line display unit are representative of two different pigeon "hues". In the Cumming *et al.* (1965) study, the switch from blue to yellow Christmas-tree bulbs in the transfer test probably involved adding a novel "yellow" stimulus of the same pigeon "hue" as the retained and already familiar "red" one.

REFERENCES

- Beare, A. C. Color-name as a function of wavelength. *American Journal of Psychology*, 1963, 76, 248-256.
- Blough, D. S. Spectral sensitivity in the pigeon. *Journal of the Optical Society of America*, 1957, 47, 827-833.
- Blough, D. S. The shape of some wavelength generalization gradients. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 31-40.
- Boynton, R. M. and Gordon, J. Bezold-Brücke hue shift measured by color-naming technique. *Journal of the Optical Society of America*, 1965, 55, 78-86.
- Cumming, W. W., Berryman, R., and Cohen, L. R. Acquisition and transfer of zero delay matching. *Psychological Reports*, 1965, 17, 435-445.
- DeValois, R. L., Abramov, I., Jacobs, C. H. Analysis of response patterns of LGN cells. *Journal of the Optical Society of America*, 1966, 56, 966-977.
- Donner, K. O. The spectral sensitivity of the pigeon's retinal elements. *Journal of Physiology*, 1953, 122, 524-537.
- Johnson, D. F. A device for rapid presentation of monochromatic stimuli. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 335-336.

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