WAVELENGTH GENERALIZATION AND PREFERENCE IN MONOCHROMATICALLY REARED DUCKLINGS[1]

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Two experiments determined the effects of early color experience on gradients of wavelength generalization. In each experiment, one group of ducklings was raised in monochromatic (589 nanometers) sodium-vapor light and a second group, in white light. In Exp. I, ducklings pecked a key transilluminated by 589 nanometers. In a subsequent test, the group raised in white light produced steeper gradients. However, several monochromatically reared ducklings produced gradients as steep as those for the white-reared ducklings. In Exp. II, ducklings pecked a white line. In a subsequent test, using a fully illuminated key, subjects in both groups responded more often to "green" (510, 530, 550, or 570 nanometers) than to "non-green" wavelengths (490, 589, 610, or 650 nanometers). Ducklings raised in monochromatic light preferred shorter "green" wavelengths than ducklings raised in white light. This difference between the "green" preferences for the two groups accounted for most of the differences between the gradients of wavelength generalization obtained from the two groups in Exp. I after training at 589 nanometers.

Interest in Lashley and Wade's (1946) theory of stimulus generalization was recently revived by Peterson's (1962) experiment concerning the effects of monochromatic rearing on wavelength generalization. Peterson obtained flat gradients of wavelength generalization from ducklings raised in monochromatic light. Ducklings raised in white light, on the other hand, responded maximally during the generalization test to the wavelength used in preliminary training.

Lashley and Wade (1946) argued that "the dimensions of a stimulus series are determined by a comparison of two or more stimuli and do not exist for the organism until established by differential training (p. 74)." Thus, the Lashley-Wade theory of stimulus generalization predicts that a naive subject trained at a single point on a stimulus continuum will produce a generalization gradient with a slope of zero.

A different prediction follows from the generalization theories of Spence (1937) and of Hull (1943, pp. 183-203, 262-267; 1950). These theories postulate that a generalization gradient of non-zero slope, with maximal responding at the training stimulus, will be obtained after training at one point on a stimulus continuum. Most of the experimental literature on stimulus generalization is consistent with this postulate of the Spence-Hull position (cf. review by Mednick and Freedman, 1960). A substantial number of studies, however, have produced results consistent with the Lashley-Wade position (cf. reviews by Razran, 1949; Mackintosh, 1965; Terrace, 1966; and Ganz, 1968).

Peterson's (1962) experiment was among the first to meet unequivocally a restriction that Lashley and Wade (1946) placed upon tests of their theory: "Subjects must be inexperienced with the stimulus dimension used, in order to rule out any tendency to identify a single stimulus as belonging to a familiar graded series or to use habits of relational thinking (p. 74)." Peterson eliminated the possibility of differential reinforcement on the wavelength continuum by raising one group of ducklings in monochromatic (589 nm) sodium-vapor light. A second group of ducklings was raised in white light. Subjects in both groups obtained water for pecking a key transilluminated by sodium-vapor light (589 nm).

In a subsequent test during extinction, Peterson obtained flat gradients of wavelength generalization from the ducklings raised in monochromatic light. The gradients obtained from the ducklings raised in white light had non-zero slopes with maximal responding at 589 nm, the wavelength used in preliminary training.

It could be argued (cf. Terrace, 1966) that the ducklings raised in white light produced steep gradients of wavelength generalization because they had acquired discriminations based on wavelength in their home cages. The ducklings raised in monochromatic light, on the other hand, could not acquire discriminations based on wavelength in their home cages, and, therefore, produced flat gradients of wavelength generalization. According to this formulation, Peterson's results are consistent with Lashley and Wade's (1946) theory of stimulus generalization. It should be noted, however, that Peterson's conclusions were based on data obtained from small groups of subjects. There were only four ducklings in the group raised in monochromatic light and only two ducklings in the group raised in white light. Experiment I of the present study sought to provide a firmer basis for Peterson's conclusions by replicating his study with larger groups of subjects.

After Exp. I had been completed, the author received a manuscript describing a study on color preferences in ducklings. That study was recently published (Oppenheim, 1968). Oppenheim demonstrated that ducklings, in a choice situation, preferred to peck at "green" wavelengths (500 to 568 nm) despite the fact that responses were not reinforced. A color preference could have influenced the results of Exp. I of this study. Experiment II sought to determine whether ducklings would demonstrate a "green" preference in a successive testing situation similar to the test for wavelength generalization used in Exp. I.

EXPERIMENT I

METHOD

Subjects

Thirty three White Peking (*Anas platyrhynchos*) ducklings served as subjects. Fresh eggs were placed in an incubator located in a room illuminated by monochromatic (589 nm) so-

dium-vapor light. On the twenty-ninth day of incubation, approximately 48 hr after hatching, 18 of the 33 ducklings were transferred to individual cages in the room illuminated by sodium light. Luminance levels of the wall behind the wire cages ranged from −0.1 log foot lamberts, for the top row, to −1.0 log foot lamberts, for the fourth (bottom) row. At the end of each day, the cages in the top three rows were moved to the next lower row and the cages in the bottom row were moved to the top row.

On the twenty-ninth day of incubation, an additional 15 of the 33 ducklings were transferred to individual cages in a separate room illuminated by white light. For nine of the 15 subjects, the luminance level of the white wall behind the wire cages was −0.2 log foot lamberts (normal-intensity-white subgroup). For the remaining six subjects, the luminance level of the wall was +1.8 log foot lamberts (high-intensity-white subgroup).

Illumination for the high-intensity-white subgroup in Exp. I was approximately equivalent to the lighting condition that Peterson (1962) reported for his group raised in white light: "Four 200-watt tungsten filament lamps, located 3 feet from the cages, provided approximately 1 ft-ca of illumination (p. 774)." Wall-luminance levels for the normal-intensity-white subgroup and the sodium-light group in Exp. I were approximately equivalent to the luminance level that Peterson reported for his group raised in sodium light (1 foot lambert).

All ducklings had unlimited access to food and water for three days after removal from the incubator. On the fourth and subsequent days, water was available in the ducklings' cages for only 1 hr each day. During the training phase of Exp. I, the ducklings had access to water immediately after their daily sessions.

Apparatus

Four experimental chambers similar to the one described by Ferster and Skinner (1957, pp. 14-19) were used. Two chambers were located in the room illuminated by sodium light and two chambers in the room illuminated by white light. A translucent plastic response key, 1 in. (3 cm) in diameter, was centered 4.75 in. (12 cm) above the bottom of a recessed opening to a water dipper. A force of approximately 12 g (0.118 N) was needed to open the contact behind the key. The floor of the sub-

ject's compartment was initially 12 cm below the key. As the ducklings grew, the floor was gradually lowered to 20 cm below the key.

The response key was transilluminated by collimated light passing through a narrow-band interference filter. This light provided the only source of illumination in the experimental chamber, which was painted flat black. When a reinforcement was scheduled, a dipper cup, with a diameter of 15 mm, swung up for 2.5 sec from its resting position in a water reservoir. At the same time, a first-surface mirror reflected the beam of light, normally aimed at the key, onto the raised dipper.

Procedure

Preliminary training was similar for all subjects. At 8 to 10 days of age, the ducklings were conditioned to peck the key, which was transilluminated by light with dominant wavelength of 589 nm. Thus, the wavelength of the light projected onto the response key was the same as the wavelength of the light illuminating the home cages of the ducklings raised in sodium-vapor light. For 18 sessions, responses were reinforced on a variable-interval (VI) schedule, the mean value of which progressively increased from 15 sec to 3 min. The sequences of inter-reinforcement intervals consisted of random permutations of 12 different temporal intervals that increased according to the geometric progression described by Fleshler and Hoffman (1962). Throughout VI training, 3-sec blackouts occurred every 30 sec. During the blackout, a shutter interrupted the beam of light aimed at the key while the luminance level was changed. Luminance varied from −1.0 to +1.0 log foot lamberts in 0.4 log-unit steps according to a counterbalanced sequence. Responses were reinforced in the presence of all six luminance levels of 589 nm (S+), but not during the blackouts. During VI 3-min training (Sessions 12 to 18), each of the six luminance levels occurred 12 times for a total of 72 stimulus presentations.

A generalization test was administered on the day following the last session of preliminary training. The test consisted of 72 stimulus presentations. Each stimulus was presented for 30 sec and was followed by a 3-sec blackout. The test was subdivided into three different counterbalanced sequences of 24 distinct stimuli. Within a sequence, each of eight wavelengths (490, 530, 550, 570, 589, 610, 630, and 650 nm), was presented once at three different luminance levels (−1.0, −0.2, and +1.0 log foot lamberts). Luminance levels were matched across wavelengths on the basis of (1) the photopic visibility function for the pigeon (Blough, 1957) and (2) the spectral distributions of energy for the various interference filters. No responses were reinforced during the generalization test.

RESULTS

Preliminary training. The three conditions of home-cage illumination produced no differential effects on response measures in preliminary training. During the last session of VI 3-min training, the minimal, median, and maximal rates of responding for subjects in the various groups were as follows: 40, 77, and 125 responses per minute for ducklings raised in monochromatic sodium-vapor light; 34, 70, and 135 responses per minute for ducklings raised in normal-intensity-white light; and 40, 72, and 152 responses per minute for ducklings raised in high-intensity-white light. Distributions of responses to the six luminance levels of 589 nm were characteristically flat from −0.6 to +0.6 log foot lamberts with slight decreases at the extreme luminances (−1.0 and +1.0 log foot lamberts).

Tests for generalization. Analyzing differences between groups by visual inspection of individual gradients (*e.g.,* Blough, 1961; Terrace, 1964) is impractical for groups as large as those in Exp. I.[2] Consequently, group data are examined first, in order to acquaint the reader with the general trends in the data. Subsequently, methods are developed to demonstrate individual differences in wavelength generalization and to determine the significance of differences between groups.

Figure 1 shows the median number of responses as a function of wavelength for the three groups in Exp. I and for various divisions of the data from the generalization test. The gradients for the groups raised in sodium light, normal-intensity-white light, and high-intensity-white light appear in the top, mid-

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[2]Individual gradients are presented in tabular form in the author's dissertation, *Generalization and preference on the wavelength continuum following monochromatic rearing of ducklings,* which can be purchased from University Microfilms, Ann Arbor, Michigan (order number 69-9222; $3.00, microfilm; $8.00, xerography).

dle, and bottom rows, respectively. Data for the first third of the generalization test (one presentation of each of the 24 distinct wavelength-luminance combinations) appear in the first column, labeled "initial". Data for the entire generalization test (three presentations of each of the 24 distinct wavelength-luminance combinations) appear in the second column, labeled "overall". The wavelength gradients for the −1.0, −0.2, and +1.0 log-foot-lambert levels of luminance appear in the third, fourth, and fifth columns, respectively. The brackets above and below the median gradients indicate the interquartile ranges of responding. The interquartile range represented as a dashed line indicates the wavelength value of S+ (589 nm).

The gradients in the top row were obtained from the group of ducklings raised in monochromatic (589 nm) sodium-vapor light. The "initial" gradient is relatively flat; however, the "overall" gradient demonstrates maximal responding at S+. At the lowest luminance level, the gradient is relatively flat, especially for test wavelengths between 490 and 589 nm. At the intermediate and highest luminance levels, the median gradients demonstrate maximal responding at S+.

The gradients for the group raised in normal-intensity-white light appear in the second row of Fig. 1. Both the "initial" and "overall" gradients demonstrate maximal responding at S+. These maxima are more pronounced than the corresponding maxima for the group raised in sodium light. At all three luminance levels, the group raised in normal-intensity-white light produced gradients with peaks at or near S+.

The gradients for the group raised in high-intensity-white light appear in the bottom row
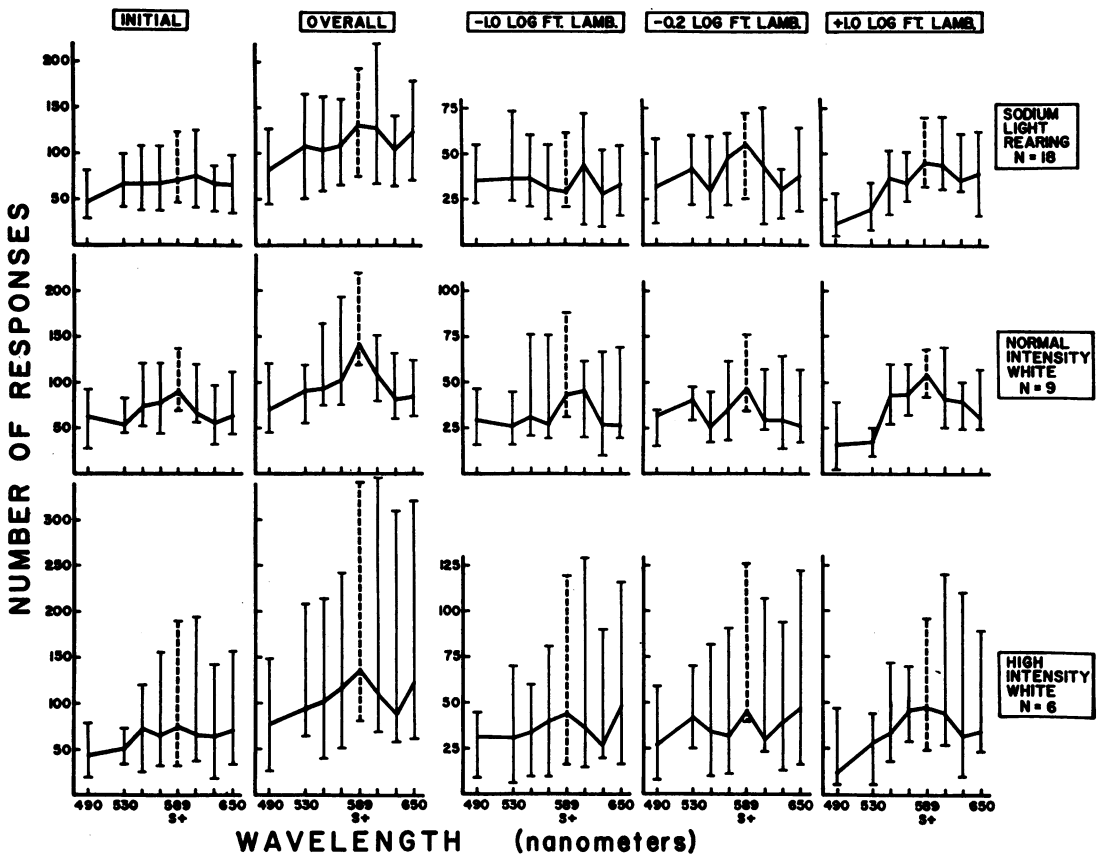

Fig. 1. Median gradients of wavelength generalization obtained in Exp. I. The brackets represent interquartile ranges of responding. The dashed brackets indicate the wavelength value (589 nm) of the stimulus used in preliminary VI training.

of Fig. 1. The shapes of these gradients between 490 and 589 nm are similar to the shapes of the gradients for the group raised in normal-intensity-white light; both groups demonstrate more responding to 589 nm and less responding to the shorter wavelengths. Between 589 and 650 nm, however, the gradients for the ducklings raised in high-intensity-white light were relatively flat, whereas the ducklings raised in normal-intensity-white light responded more often to 589 nm and less often to the longer wavelengths.

Representing individual differences. Two related ways in which gradients can differ from one another are: (1) in the location of the peak and (2) in steepness. The steepness of a gradient in Exp. I was indexed by computing a linear regression coefficient (slope) for the short-wavelength segment (490 to 589 nm) and a separate coefficient for the long-wavelength segment (589 to 650). Peak locations and slopes are presented, below, in frequency distributions that permit a direct comparison, within the confines of a single figure, of the individual data for separate groups. Data for the "initial" gradients are not presented in the subsequent analyses because the conclusions that would be drawn from them are essentially the same, although not as strong, as the conclusions that were drawn from the "overall" gradients.

Location of peaks. Figure 2 shows frequency distributions of the wavelength at which responding, in individual gradients, was maximal. The top row of Fig. 2 contains data for the group raised in monochromatic (589 nm) sodium-vapor illumination. Eight of the 18 subjects raised in sodium light produced "overall" gradients with peaks at S+ (589 nm). At the lowest luminance level, however, only two ducklings raised in sodium light produced gradients with peaks at S+; 14 of the 18 ducklings produced gradients with peaks at the short-wavelength end of the continuum (490 to 570 nm). The mode of the −1.0 log-footlambert distribution was at 530 nm, nearly 60 nm away from S+. At the intermediate and highest luminance levels, the modes of the distributions of peaks were at S+.

The second row of Fig. 2 shows frequency distributions of the peaks of the wavelength gradients for all ducklings raised in white light. Ten of the 15 subjects produced "overall" gradients with peaks at S+. At all three

luminance levels, the modes of the distributions of peaks were at or near S+.

The third and fourth rows of Fig. 2 show frequency distributions of peaks for the normal-intensity-white- and the high-intensity-white-subgroups, respectively, of the combined white-light group (row 2). The subgroup raised in normal-intensity-white light produced a relatively high proportion of gradients with peaks at S+. At least half of the ducklings raised in high-intensity-white light responded most often to a test wavelength longer than S+ (610, 630, or 650 nm). Neither subgroup demonstrated systematic changes in the locations of peaks as a function of luminance.

Analyses of slopes. The steepness of the short-wavelength segment of a gradient was determined by the linear regression of the number of responses on the following wavelengths: 490, 530, 550, 570, and 589 nm. The steepness of the long-wavelength segment was determined by the linear regression of the number of responses on the following wavelengths: 589, 610, 630, and 650 nm. Figure 3 shows frequency distributions of the regression coefficients for the short- and the long-wavelength segments of the "overall" gradients. The signs of the slopes of the 589- to 650-nm segments have been changed to facilitate comparisons with slopes of the 490- to 589-nm segments. Thus, positive slopes represent gradients that demonstrate a decreasing number of responses with increases in the distance of test wavelengths from S+ (589 nm).

In the process of computing regression coefficients, values of the statistic, r^2, were also determined. This statistic indicates the proportion of the total variance of responding that can be attributed to the linear regression of responses on the test wavelengths. Thus, r^2 provides the basis for a test of individual slopes against the null hypothesis that the population regression coefficient equals zero. In Fig. 3, segments of individual gradients with slopes that were significantly more positive than zero ($p < 0.05$) are represented as cells in which the letter "X" appears. A significant regression coefficient, of course, does not necessarily imply that a linear trend is the best fit to the data.

In these analyses of slopes, the absolute numbers of responses were regressed on wavelength. Regression coefficients were also com-
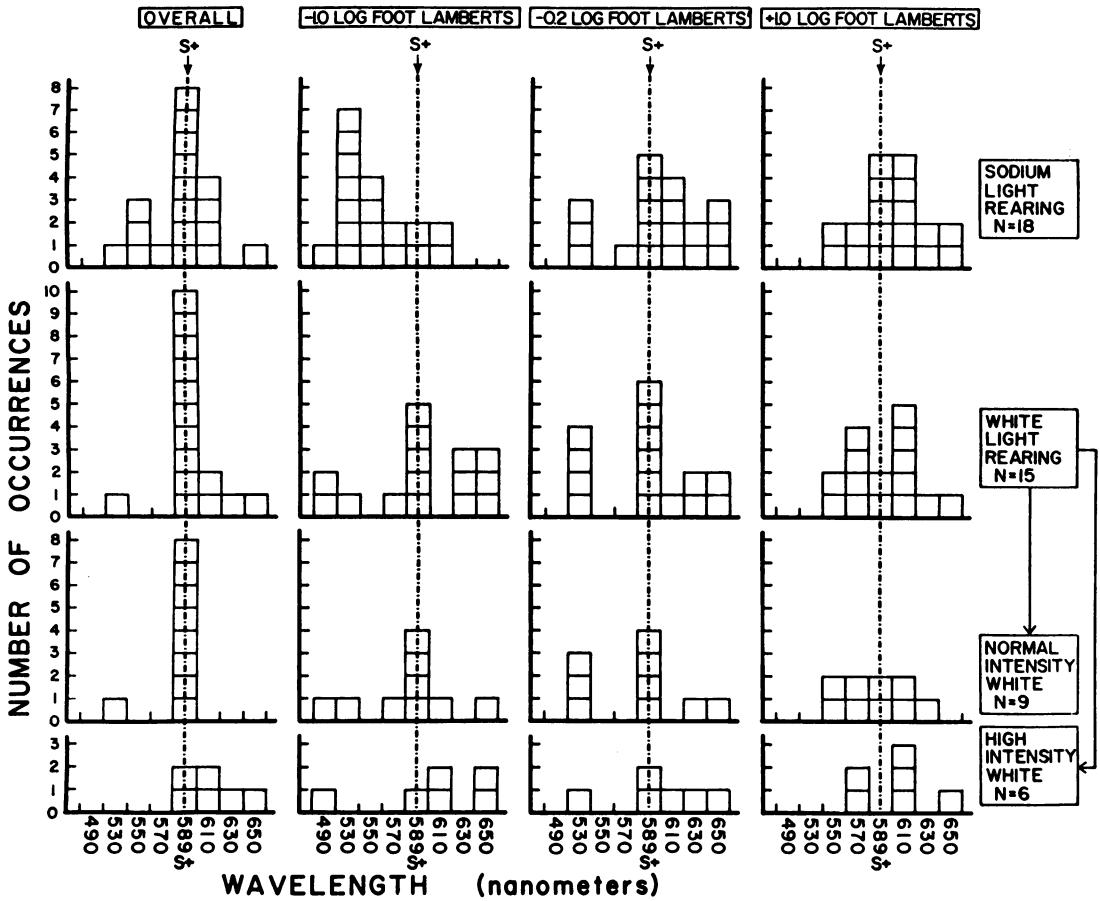
LOCATIONS OF PEAKS OF GRADIENTS

Fig. 2. Frequency distributions of the wavelength at which responding, in individual gradients, was maximal. The broken vertical lines pass through the wavelength value (589 nm) of the stimulus used in preliminary VI training.

puted after dividing the numbers of responses to test wavelengths by either the total number of responses or by the number of responses to S+. The relative analyses are not presented because the conclusions that would be drawn from them are essentially the same as the conclusions that were drawn from the slopes computed on the basis of the absolute numbers of responses.

Slopes of "overall" gradients. Frequency distributions of the slopes of the 490- to 589-nm segments of the "overall" gradients appear in the left-hand panel of Fig. 3. Several ducklings raised in monochromatic (589 nm) sodium-vapor illumination produced gradients with negative slopes or slopes close to zero. However, eight of the 18 subjects raised in sodium light produced gradients with significantly

positive slopes. On the other hand, none of the gradients for the 15 ducklings raised in white light had negative slopes and 12 of the gradients had significantly positive slopes. The combined distribution for all subjects raised in white light (left-hand panel, row 2) was representative of the distributions for the subgroups raised in normal- and high-intensity-white light (left-hand panel, rows 3 and 4, respectively). The slopes of the 490- to 589-nm segments of the gradients obtained from the 15 ducklings raised in white light were significantly steeper than the slopes for the 18 ducklings raised in monochromatic sodium light (p < 0.01, Mann-Whitney U test). The comparison between slopes for the normal-intensity-white subgroup and the sodium group was significant at the 0.05 level.
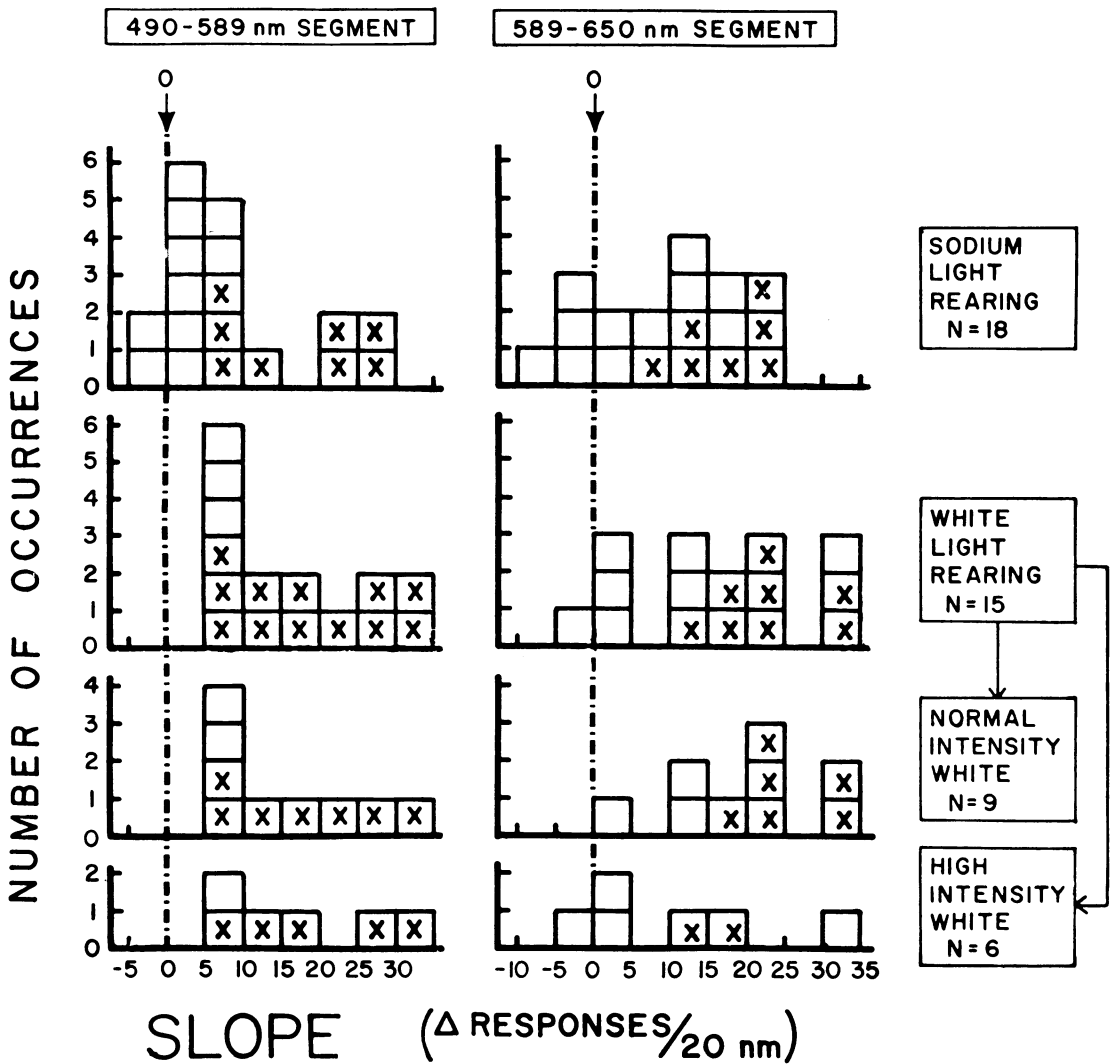
SLOPES OF "OVERALL" GRADIENTS

Fig. 3. Frequency distributions of the slopes of the 490- to 589-nm and of the 589- to 650-nm segments of the "overall" generalization gradients obtained after training at 589 nm. The signs of the slopes of the 589- to 650-nm segments have been changed. The letter "X" in a cell indicates a slope that was significantly more positive than zero (p < 0.05).

Frequency distributions of the slopes of the 589- to 650-nm segments of the "overall" gradients appear in the right-hand panel of Fig. 3. Although four of the 18 ducklings raised in sodium light produced 589- to 650-nm segments with negative slopes, seven of these subjects produced gradients with significantly positive slopes. The combined distribution of slopes for all ducklings raised in white light (right-hand panel, row 2) was not representa-

tive of the distributions of slopes for the subgroups raised in normal- and high-intensity-white light (right-hand panel, rows 3 and 4, respectively). The slopes for the ducklings raised in normal-intensity-white light were slightly, but not significantly, steeper than the slopes for the ducklings raised in high-intensity-white light. None of the nine ducklings raised in normal-intensity-white light produced gradients with negative slopes and six

of these subjects produced gradients with slopes that were significantly more positive than zero. The slopes of the 589- to 650-nm segments of the gradients obtained from the nine ducklings raised in normal-intensity-white light were significantly steeper than the slopes for the 18 ducklings raised in monochromatic sodium light (p < 0.05, Mann-Whitney U test).

Slopes as a function of luminance. Figure 4 shows frequency distributions of the slopes for the three luminance levels of the 490- to 589-nm segments of the gradients. At the lowest luminance level, gradients with negative slopes were obtained from 10 of the 18 ducklings raised in sodium light. This finding was reflected also by the fact that, at the lowest luminance level, gradients with peaks at 490, 530, or 550 nm were obtained from 12 of the 18 ducklings raised in sodium light (*cf.* Fig. 2). As luminance increased, the distributions of slopes for the group raised in sodium light changed to · more positive values (p < 0.05, Friedman analysis of variance by ranks). At the highest luminance level, gradients with

slopes that were significantly more positive than zero were obtained from 14 of the 18 ducklings raised in sodium light.

Since the distributions of 490- to 589-nm slopes as a function of luminance for all ducklings raised in white light were representative of the distributions for the two subgroups, only the combined distributions are presented in Fig. 4. The modes of all three distributions were greater than zero. As luminance increased, the distributions of slopes did not change to more positive values (p = 0.10, Friedman analysis of variance by ranks). At the lowest luminance level, the slopes of the 490- to 589-nm segments of the gradients obtained from the ducklings raised in white light were significantly steeper than the slopes for the ducklings raised in sodium light (p < 0.01, Mann-Whitney U test). Slopes for the two groups did not differ at the intermediate and highest luminance levels. Therefore, the finding that rearing in white light resulted in significantly steeper "overall" slopes of the 490- to 589-nm segments than rearing in sodium light (*cf.* Fig. 3, left-hand panel, rows 1
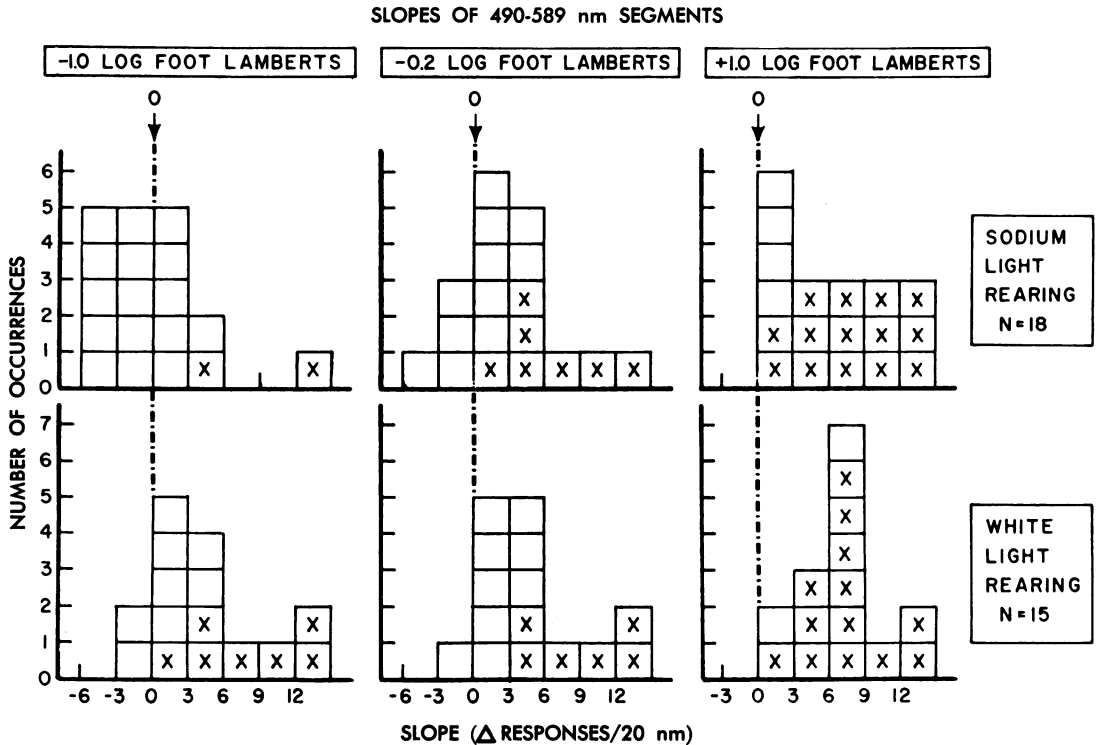

Fig. 4. Frequency distributions, at three luminance levels, of the slopes of the 490- to 589-nm segments of the gradients obtained after training at 589 nm. The letter "X" in a cell indicates a slope that was significantly more positive than zero (p < 0.05).

and 2) was primarily due to differences between slopes for the two groups at the lowest luminance level.

The slopes for the three luminance levels of the 589- to 650-nm segments of the gradients were also analyzed. None of the main groups or subgroups demonstrated significant steepening of gradients as luminance increased. Furthermore, no comparisons between the slopes obtained from the various rearing groups were significant. Therefore, the finding that rearing in normal-intensity-white light resulted in significantly steeper "overall" slopes of the 589- to 650-nm segments than rearing in sodium light (*cf.* Fig. 3, right-hand panel, rows 1 and 3) can be attributed to a summation of small differences between slopes for the two groups at each luminance level.

DISCUSSION

The major finding of Exp. I was that the wavelength of a stimulus controlled responding to a greater extent in the case of ducklings raised in white light than in the case of ducklings raised in monochromatic light. In this sense, the results of Exp. I are similar to the findings of Peterson (1962). The results of the two studies differ, however, in one fundamental respect. In Peterson's study, the gradients obtained from the ducklings raised in monochromatic light were flat. In Exp. I of the present study, nearly half of the gradients obtained from the ducklings raised in monochromatic light had non-zero slopes with maximal responding at the value of the wavelength used in preliminary training.

A second difference between the results of Exp. I and of Peterson's study concerns the effects of the luminance of test wavelengths on the steepness of gradients. Although Peterson varied luminance, he did not report any changes in the steepness of gradients as a function of luminance. In Exp. I, on the other hand, slopes of the 490- to 589-nm segments of the gradients obtained from the ducklings raised in monochromatic light became steeper as luminance increased.

Effect of Monochromatic Rearing

To account for the direction of the difference between the slopes of the gradients for the two groups, one can argue that subjects raised in white light have an opportunity to acquire discriminations based on wavelength

in their home cages. These discriminations presumably transfer to the experimental situation and result in differential responding to wavelengths during the test for generalization. Subjects raised in monochromatic light, on the other hand, cannot acquire discriminations based on wavelength in their home cages and, therefore, do not respond differentially to wavelengths during the test for generalization. Similar arguments were advanced in a study by Heinemann and Rudolph (1963), in reviews of the stimulus-generalization literature (Razran, 1949; Mackintosh, 1965; Terrace, 1966; and Ganz, 1968), and by Lashley and Wade (1946), who argued that "the dimensions of a stimulus series are determined by a comparison of two or more stimuli and do not exist for the organism until established by differential training (p. 74)." Although this kind of argument can account for the direction of the difference between the slopes of the gradients of wavelength generalization obtained in Exp. I, it cannot account for the finding that steep gradients were obtained from several monochromatically reared ducklings.

The frequent occurrence of steep gradients in the case of the monochromatically reared ducklings in Exp. I and the absence of steep gradients in Peterson's study could be attributed to a difference between the two studies in the size of the visual field surrounding the home cages of the ducklings raised in sodium light. Peterson housed his four monochromatically reared ducklings inside a small refrigerator-type enclosure. Since only four subjects were housed inside a small enclosure, it seems likely that the ducklings saw the experimenter only briefly, four times a day. In Exp. I, on the other hand, the 18 ducklings raised in sodium light were housed in individual cages located in a relatively large (6 by 9 ft) room. Each duckling could see the experimenter for relatively long periods of time while the experimenter was feeding, watering, and handling the other 17 ducklings. Consequently, the monochromatically reared ducklings in Exp. I had a better opportunity to acquire visual intensity or form discriminations on the basis of the experimenter's activities than Peterson's monochromatically reared ducklings. Subjects that developed these hypothetical discriminations may have "paid closer attention" to changes in wavelength during the generalization test and, therefore, pro-

duced steeper gradients than subjects that did not form such discriminations. Honig (1965) used a similar argument to account for his finding that pigeons given discrimination training between two wavelengths produced steeper gradients of line orientation than pigeons previously reinforced in the presence of the two wavelengths.

Effects of Luminance

Although Peterson varied luminance during his test for wavelength generalization, he did not report any differences in the steepness of gradients as a function of luminance. In Exp. I, on the other hand, slopes of the 490- to 589-nm segments of the gradients obtained from ducklings raised in sodium light were negative or close to zero at the lowest luminance level and became steeper as luminance increased (Fig. 4). This finding suggests the operation of a luminance-level threshold *at short wavelengths* for the discrimination of differences in wavelength. The slopes of the long-wavelength segments of the gradients obtained from ducklings raised in sodium light, however, did not vary with luminance level. A luminance effect at short wavelengths and the absence of a luminance effect at long wavelengths could be attributed to a difference between the duckling's photopic visibility function (which has not been determined) and the pigeon's photopic visibility function (Blough, 1957) which was used to match the test wavelengths for luminance in Exp. I. But the results of Exp. II suggest an alternative explanation of these luminance effects.

Gradients for High-Intensity-White Subgroup

The gradients obtained from the ducklings raised in high-intensity-white light also differ from the corresponding gradients obtained by Peterson. In Exp. I, the slopes of the 589- to 650-nm segments were close to zero (*cf.* Fig. 1 and 3). Peterson raised two ducklings under a similar condition of illumination, yet his subjects produced steep gradients at both ends of the wavelength continuum. Flatter 589- to 650-nm segments in Exp. I cannot be attributed to higher drive level (Thomas and King, 1959) since the slopes of the 490- to 589-nm segments for the high-intensity-white subgroup were as steep as those for the normal-intensity-white subgroup.

Regardless of what accounts for obtaining flatter 589- to 650-nm segments from the ducklings raised in high-intensity-white light, it is more reasonable to compare the gradients obtained from ducklings raised in monochromatic sodium-vapor light with the gradients for the ducklings raised in normal-intensity-white light. This conclusion follows from a consideration of the levels of home-cage illumination for the various groups in the two studies (*cf. Subjects* section, above). In Peterson's study, the levels of home-cage illumination were not equivalent. In Exp. I, the levels of home-cage illumination were approximately equivalent for the group raised in sodium light and the subgroup raised in normal-intensity-white light. Therefore, it is more reasonable to compare the gradients obtained from these two groups. After training at 589 nm, the ducklings raised in normal-intensity-white light produced steeper gradients at both ends of the wavelength continuum than the ducklings raised in monochromatic sodium-vapor illumination.

EXPERIMENT II

The possibility that ducklings have a color preference was suggested in a study by Hess (1956). Hess' experimental design did not, however, control for the intensity of the stimuli (Ostwald color chips) nor for the previous visual experience of the ducklings. Oppenheim (1968) controlled for these variables and demonstrated unequivocally that ducklings preferred to peck at "green" wavelengths, even though responding was not reinforced. Oppenheim tested 30-hr-old ducklings in an eight-sided chamber with eight response keys transilluminated by lights of different wavelengths. More than 80% of all key pecks occurred to the two "green" stimuli (531 and 568 nm).

On *a priori* grounds, it seems likely that color preferences would distort the shapes of gradients of wavelength generalization. A "green" preference would probably increase the amount of responding to short wavelengths in generalization gradients obtained after training at 589 nm. In fact, in Exp. I, the monochromatically reared ducklings produced several gradients, at the lowest luminance level, with peaks at "green" wavelengths (Fig. 2) and with slopes close to zero for the 490- to 589-nm segments (Fig. 4). In order to provide data relevant to a color-preference distortion

of the gradients obtained in Exp. I, a pilot study, using a successive testing procedure, was performed.

Operant-level tests for generalization, similar to those employed in Exp. I, were administered to individual ducklings ranging from one to eight days of age. Although most responses occurred to "green" wavelengths, the ducklings did not peck the key often enough to assess accurately the magnitudes and locations of color preferences. Therefore, in Exp. II, ducklings were rewarded for pecking a key transilluminated by a white line. Subsequently, a test for preference among monochromatic wavelengths was administered.

METHOD

Subjects

Thirty-one duck eggs were incubated as in Exp. I. Fourteen ducklings were transferred to cages in the room illuminated by monochromatic (589 nm) sodium-vapor light and 17 ducklings to cages in the room illuminated by white light. Luminance levels of the walls behind the cages were approximately +0.2 log foot lamberts in both rooms.

Apparatus

The apparatus was identical to that used for Exp. I with the following exception: during preliminary training, the response key was modified by placing two strips of opaque black tape, 5 mm apart, in a vertical orientation, on the back surface of the key.

Procedure

Preliminary training was identical to the procedure for Exp. I with the following exception: the response key was transilluminated by a vertical white line. The bulb used in the optical system had a color temperature of 3100 degrees, Kelvin.

For 18 sessions, responding was reinforced on a VI schedule. A color-preference test was administered during the nineteenth session. The test consisted of 72 stimulus presentations. The test was subdivided into three different counterbalanced sequences of 24 distinct stimuli. Within a sequence, each of eight wavelengths (490, 510, 530, 550, 570, 589, 610, and 650 nm) was presented once at three different luminance levels (−1.0, −0.2, and +1.0 log foot lamberts). During the color-preference

test, the circular key was fully illuminated and no responses were reinforced.

RESULTS

Figure 5 shows the median gradients obtained from the two groups in Exp. II for various divisions of the data from the color-preference test. The brackets above and below the functions indicate interquartile ranges of responding. The interquartile ranges represented as dashed lines indicate arbitrary limits (510 and 570 nm) of the "green" portion of the spectrum. In general, the median gradients demonstrate more responding to "green" (510, 530, 550, and 570 nm) than to "non-green" wavelengths (490, 589, 610, and 650 nm).

Figure 6 shows frequency distributions of the wavelength at which responding, in individual gradients, was maximal during the color-preference test. Each of the frequency distributions in Fig. 6 indicates that the majority of subjects responded most often to a wavelength in the "green" region of the spectrum (510, 530, 550, or 570 nm). The group raised in monochromatic (589 nm) sodium-vapor illumination produced a distribution of "overall" peaks that was flat across the "green" portion of the spectrum. The group raised in white light, on the other hand, produced a distribution of "overall" peaks with a monotonic increase across the "green" portion of the spectrum. At each luminance level, locations of peaks were not very different for the two conditions of home-cage illumination. As luminance increased, however, the modes of the frequency distributions of peaks for both groups changed from shorter to longer "green" wavelengths. Similar trends are evident in the median gradients (Fig. 5).

A measure of the magnitude of the green preference is obtained if the number of responses to green wavelengths (510, 530, 550, and 570 nm) is divided by the total number of responses that occurred during the test. Since four of the eight test wavelengths were green, the expected value of the ratio is 0.5 if neither a green preference nor a green aversion exists. Figure 7 shows frequency distributions of this ratio for the various conditions in Exp. II. For each of the eight distributions, the null hypothesis that the population ratio equals 0.5 can be rejected at a significance level equal to or less than 0.006 (one-tailed binomial tests).

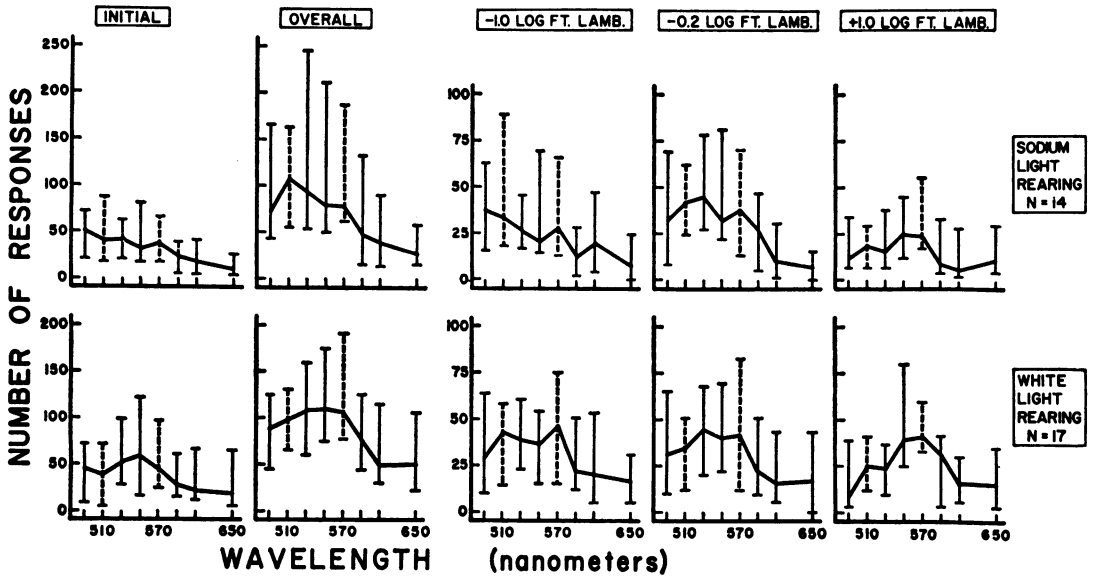## MEDIAN GRADIENTS   EXPERIMENT II

Fig. 5. Median color-preference gradients obtained in Exp. II after preliminary VI training on a vertical white line. The brackets represent interquartile ranges of responding. The dashed brackets indicate arbitrary limits (510 and 570 nm) of the "green" portion of the spectrum.

Distributions of the ratios were compared for the two conditions of home-cage illumination using Mann-Whitney U tests. No comparisons were significant at the 0.10 level. Furthermore, values of the ratios did not change systematically as a function of luminance (Friedman analyses of variance by ranks). Therefore, the *magnitude* of the green preference was independent of the conditions of home-cage illumination and of the luminance level of test wavelengths. However, Fig. 5 and 6 suggest that the *location* of the green prefer-

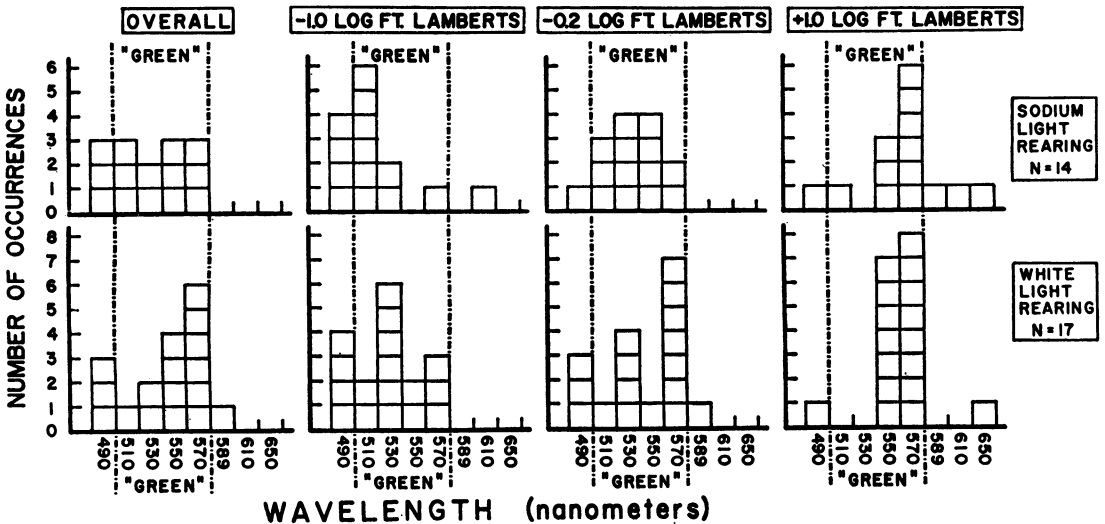## LOCATIONS OF PEAKS OF GRADIENTS

Fig. 6. Frequency distributions of the wavelength at which responding, in individual gradients, was maximal during the color-preference test administered after training on a vertical white line. The broken vertical lines in the figure indicate arbitrary limits of the "green" portion of the spectrum.

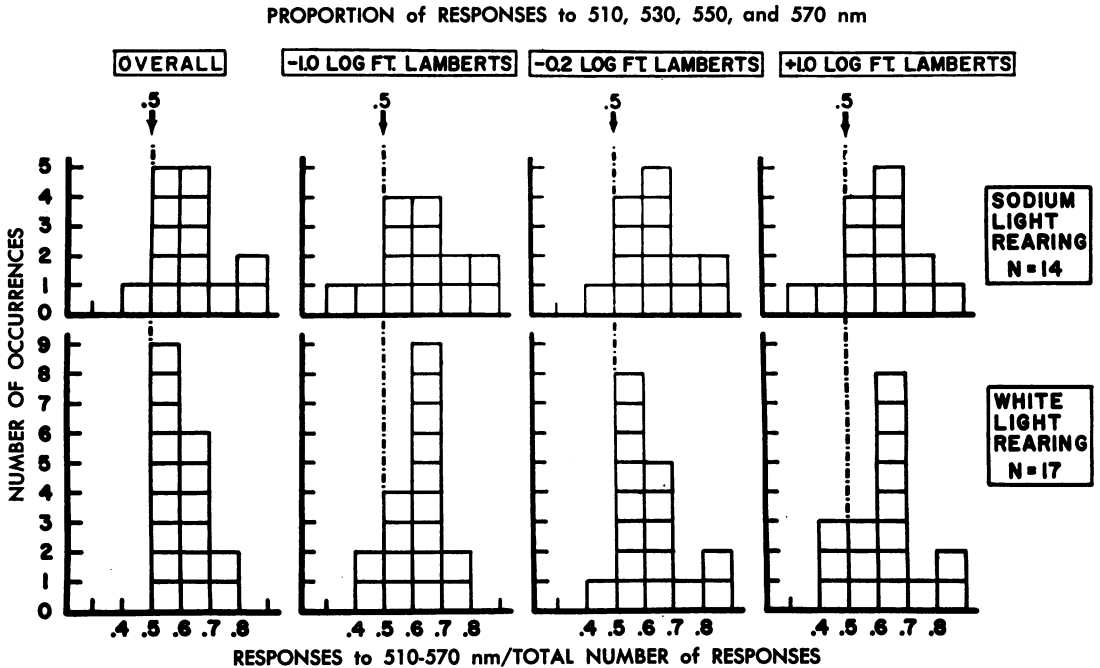PROPORTION of RESPONSES to 510, 530, 550, and 570 nm

Fig. 7. Frequency distributions of the ratio formed by dividing the number of responses to "green" wavelengths (510, 530, 550, and 570 nm) by the total number of responses in a color-preference gradient obtained after training on a vertical white line. The broken vertical lines in the figure indicate the expected value of the ratio (0.5) if neither a "green" preference nor a "green" aversion exists.

ence did change as a function of home-cage illumination and as a function of the luminance of test wavelengths.

An index of the *location* of the green preference is obtained if the number of responses to "long" green wavelengths (550 and 570 nm) is divided by the number of responses to all green wavelengths (510, 530, 550, and 570 nm). This "location" ratio is orthognal to the "magnitude" ratio presented in Fig. 7. The expected value of the "location" ratio is 0.5 if a duckling prefers shorter and longer green wavelengths equally. For the "overall" gradients, values of this ratio in excess of 0.5 were obtained from exactly seven of the 14 ducklings raised in sodium light. In contrast, 16 of the 17 ducklings raised in white light produced values of the "location" ratio greater than 0.5 (p < 0.002, binomial test). Ducklings raised in white light preferred longer green wavelengths than ducklings raised in sodium light (p < 0.02, Mann-Whitney U test). Friedman analyses of variance by ranks indicated that values of the "location" ratio increased as the luminance of test wavelengths increased (p < 0.001 for ducklings raised in sodium

light; p < 0.02 for ducklings raised in white light). In short, the green preference shifted from shorter to longer green wavelengths as luminance increased.

DISCUSSION

The major finding of Exp. II was that the ducklings pecked at "green" wavelengths more often than they pecked at "non-green" wavelengths. A similar result was obtained by Oppenheim (1968), who attributed his finding to a "green" color preference.

The existence in ducklings of a preference for "green" wavelengths complicates the interpretation of the results of Exp. I and of Peterson's (1962) study. A "green" preference could distort the shapes of gradients of wavelength generalization obtained after training on a monochromatic stimulus by increasing the amount of responding to short wavelengths. The comparisons, below, of the gradients from Exp. I and II, suggest that such distortions did occur. Before examining these distortions, however, it is important to consider a possible influence of the saturation of the test wavelengths.

Influence of Saturation

In Exp. II, the response key was transilluminated by a white line, an extremely desaturated visual stimulus. The mean "overall" color-preference gradients obtained from the two groups appear in the top half of Fig. 8. The group raised in white light produced a gradient with a peak at 570 nm. This wavelength is the most desaturated of the spectral wavelengths for humans (*cf.* the least-colorimetric-purity function of Priest and Brickwedde, 1938). Although there is an agreement between the maxima of the color-preference gradient obtained from ducklings raised in white light (Fig. 8) and of the least-colorimetric-purity function obtained from humans, the preference gradient decreases relatively slower than the purity function at the short-wavelength end of the continuum. Furthermore, only six of the 17 ducklings raised in white light produced "overall" gradients with peaks at 570 nm (*cf.* Fig. 6).

Additional evidence against the influence of saturation in Exp. II comes from Oppenheim's (1968) study. Since his ducklings had no experimental history of reinforcement before the color-preference test, his gradients were probably not influenced by saturation. The shapes of Oppenheim's gradients agree well with the shapes of the gradients obtained in Exp. II.

Color-Preference Distortions of Gradients in Experiment I

A comparison of the mean "overall" gradients from Exp. I and II (Fig. 8) suggests that distortions due to "green" preferences did occur. The specific locations of the "green" preferences differed for the two groups. The group raised in sodium light produced a mean color preference gradient that was flat from 510 to 570 nm; the group raised in white light produced a gradient with a monotonic increase from 510 to 570 nm. Values of the "location" ratio also indicated that the ducklings raised in white light preferred the longer "green" wavelengths. Similar trends were evident in the mean gradients obtained after training at 589 nm (bottom half of Fig. 8): the group raised in sodium light produced a gradient that was flat from 530 to 570 nm; the group raised in normal-intensity-white light produced a gradient that demonstrated a monotonic increase from 530 to 570 mm. These cor-

respondences suggest that patterns of color preferences influenced the shapes of the gradients of wavelength generalization obtained in Exp. I.

The influence of color preferences could also account for the effects of luminance on the shapes of the gradients obtained in Exp. I. After training at 589 nm, the group raised in sodium light demonstrated slopes of the 490- to 589-nm segments that became steeper as luminance increased (Fig. 4). Furthermore, the group raised in sodium light in Exp. I demonstrated frequency distributions of peaks with modes that changed from 530 nm at the lowest luminance level to a longer wavelength (589 nm) at the intermediate and highest luminance levels (Fig. 2). A similar effect of luminance was obtained in Exp. II: after training on a vertical white line, both groups demonstrated a shift in preference from shorter to longer "green" wavelengths as luminance increased (*cf.* Fig. 5 and 6, and the analyses of "location" ratios). Oppenheim (1968, Fig. 2) obtained a similar effect of luminance. In Exp. II, the effect of luminance was especially strong for ducklings raised in sodium light. The similarity of the effects of luminance in Exp. I and II suggests that a "green" preference greatly distorted the shapes of the gradients of wavelength generalization obtained from ducklings raised in sodium light and trained at 589 nm.

One finding of Exp. I is difficult to attribute to patterns of color preferences: after training at 589 nm, the ducklings raised in normal-intensity-white light produced gradients with significantly steeper slopes of the 589- to 650-nm segments than the ducklings raised in sodium light (*cf.* Fig. 3 and bottom half of Fig. 8). In Exp. II, after training on a vertical white line, the ducklings raised in white light responded relatively more often to wavelengths in the 589- to 650-nm range than the ducklings raised in sodium light (top half of Fig. 8). Thus, the difference between the slopes of the long-wavelength segments of the gradients obtained from the two groups in Exp. I is in the opposite direction from what might be predicted on the basis of the color-preference gradients obtained from the two groups.

In summary, ducklings raised in monochromatic light produced flatter gradients of wavelength generalization than ducklings raised in white light. However, monochromatic rearing
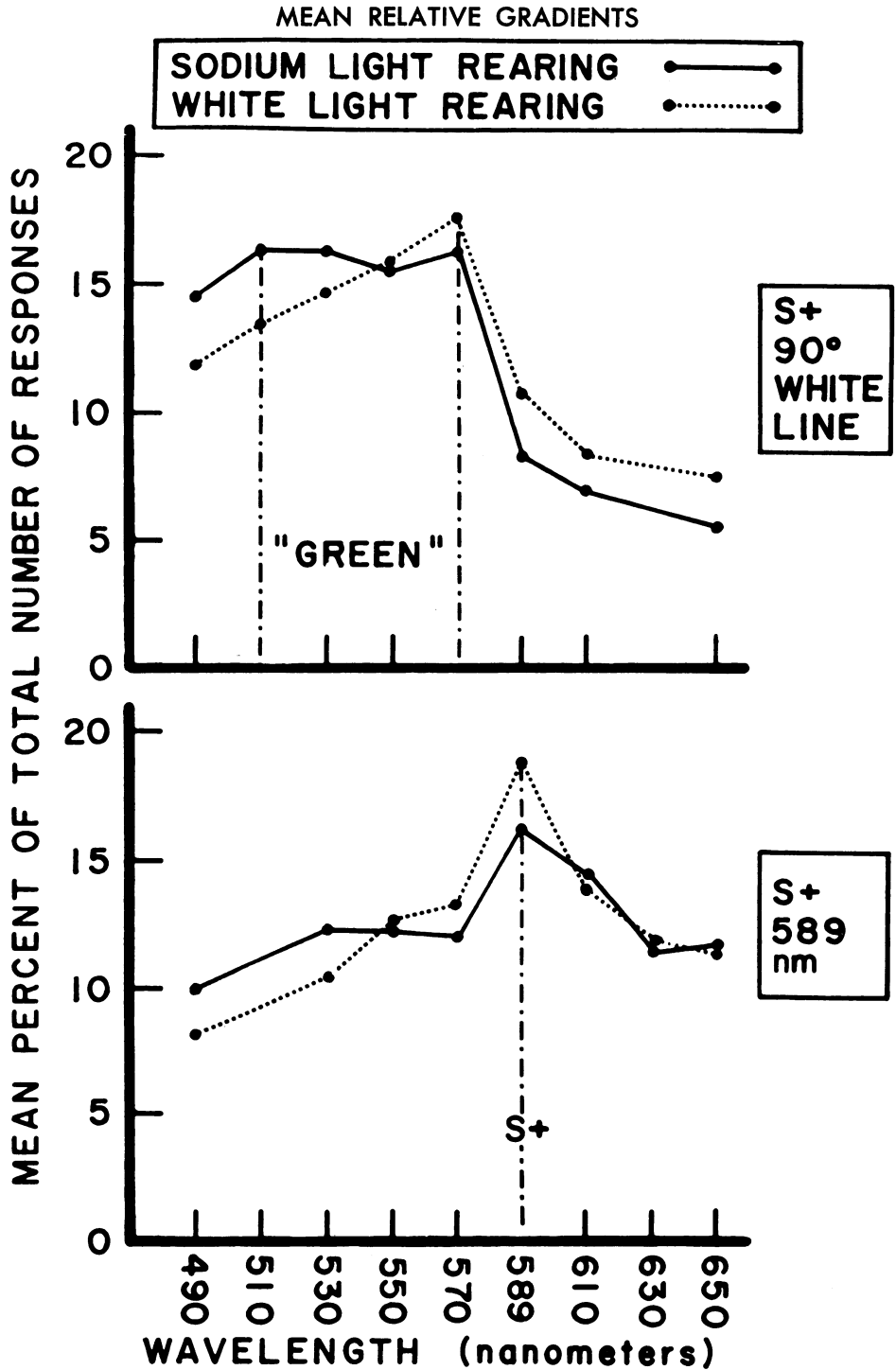
MEAN RELATIVE GRADIENTS

Fig. 8. Mean relative gradients obtained during the tests on the wavelength continuum after training on a vertical white line (top half) and after training at 589 nm (bottom half). Before averaging, the numbers of responses to the different test wavelengths in individual "overall" gradients were divided by the total number of responses in each gradient. Data for the subgroup raised in high-intensity-white light in Exp. I are not included in the mean function in the bottom half of the figure.

did not always result in a gradient with a slope of zero. The differential effects of rearing on slopes of the short-wavelength segment of the gradient may be a consequence of the differential effects of rearing on a "green" color preference. The difference between slopes of the segment longer than S+ is tenuously consistent with Lashley and Wade's (1946) argument that "the dimensions of a stimulus series are determined by a comparison of two or more stimuli and do not exist for the organism until established by differential training" (p. 74). Presumably, the ducklings raised in white light acquired wavelength discriminations in their home cages that transferred to the testing situation and resulted in differential responding to wavelengths. The demonstration of a "green" preference in ducklings, however, strongly suggests the use of a different organism in investigations of the conditions necessary and sufficient for the development of stimulus control.

REFERENCES

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.

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.

Fleshler, M. and Hoffman, H. S. A progression for generation variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 529-530.

Ganz, L. An analysis of generalization behavior in the stimulus-deprived organism. In G. Newton and S. Levine (Eds.), *Early experience and behavior: the psychobiology of development*. Springfield, Ill.: Thomas, 1968. Pp. 365-411.

Heinemann, E. G. and Rudolph, R. L. The effect of discriminative training on the gradient of stimulus-generalization. *American Journal of Psychology*, 1963, 76, 653-658.

Hess, E. H. Natural preferences of chicks and ducks for objects of different colors. *Psychological Reports*, 1956, 2, 477-483.

Honig, W. K. *The effects of irrelevant discrimination training on the slope of a generalization gradient*. Paper presented at the meetings of the Eastern Psychological Association, Atlanta City, April, 1965.

Hull, C. L. *Principles of behavior*. New York: Appleton-Century-Crofts, 1943.

Hull, C. L. Simple qualitative discrimination learning. *Psychological Review*, 1950, 57, 303-313.

Lashley, K. S. and Wade, M. The Pavlovian theory of generalization. *Psychological Review*, 1946, 53, 72-87.

Mackintosh, N. J. Selective attention in animal discrimination learning. *Psychological Bulletin*, 1965, 64, 124-150.

Mednick, S. A. and Freedman, J. L. "Stimulus Generalization." *Psychological Bulletin*, 1960, 57, 169-200.

Oppenheim, R. W. Color preferences in the pecking response of newly hatched ducks (*Anas platyrhynches*). *Journal of Comparative and Physiological Psychology*, 1968, 66 (Monograph Supplement, Number 3, Part 2).

Peterson, N. Effect of monochromatic reading on the control of responding by wavelength. *Science*, 1962, 136, 774-775.

Priest, I. G. and Brickwedde, F. G. The minimum perceptible colorimetric purity as a function of dominant wavelength. *Journal of the Optical Society of America*, 1938, 28, 133-139.

Razran, G. H. S. Stimulus generalization of conditioned responses. *Psychological Bulletin*, 1949, 46, 337-365.

Spence, K. W. The differential response in animals to stimuli varying within a single dimension. *Psychological Review*, 1937, 44, 430-444.

Terrace, H. S. Wavelength generalization after discrimination learning with and without errors. *Science*, 1964, 144, 78-80.

Terrace, H. S. Stimulus Control. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 271-344.

Thomas, D. R. and King, R. A. Stimulus generalization as a function of level of motivation. *Journal of Experimental Psychology*, 1959, 57, 322-328.