EVIDENCE FOR THE INNATE BASIS OF THE HUE DIMENSION IN THE DUCKLING¹

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Different groups of ducklings reared under sodium monochromatic light (589 nanometers) and under white light were trained to discriminate between the stimulus correlated with reinforcement (589 nanometers), and the stimulus correlated with extinction, whose value was either 570 or 610 nanometers. The peaks of subsequently obtained gradients of wavelength generalization of both groups were displaced away from the stimulus correlated with extinction. The peaks of the groups trained not to respond to 570 nanometers were located at 600 nanometers. The peaks of the groups trained not to respond to 610 nanometers were located at 580 nanometers. These results (in agreement with earlier data of Rudolph and Honig, 1972) suggest that ducklings have an innate basis for ordering stimuli of different wavelengths along the hue dimension.

Stimulus control, the covariation of stimuli and responses, is a basic concept that has proved useful in the study of a wide variety of psychological problems. Stimulus control is demonstrated by a differential responding to two or more discriminative stimuli (*cf.* Terrace, 1966). Examples include animal psychophysics (Blough, 1966; Stebbins, 1970), ethology (Hinde, 1970), discrimination learning (Terrace, 1968), attention (Sutherland and Mackintosh, 1971), and the acquisition of vocabulary (Staats and Staats, 1963; also see Blough and Lipsett, 1971; Nevin and Reynolds, 1973; Terrace, 1966, for general reviews of the concept of stimulus control). Often, a generalization gradient is used as a demonstration of stimulus control. The common, but by no means ubiquitous finding, is that the frequency of responding to test stimuli decreases with increasing physical distance between test stimuli and the training stimulus.

The minimal conditions necessary to produce this state of affairs has long been a subject of controversy that need only be mentioned in passing. (See Terrace, 1966; Tracy, 1970, for extensive reviews.) The traditional view (Hull, 1943; Spence, 1936), which de-

rives from Pavlov's theory of irradiation (Pavlov, 1927), asserts that the occurrence of stimulus control does not require a history of differential reinforcement. In 1946, Lashley and Wade took a contrary position: "The . . . stimulus dimensions [do] not occur in conditioning to a single stimulus but is somehow a function of differential training with two or more stimuli on the same dimension" (Lashley and Wade, 1946, p. 82).

At present, it appears as if stimulus control with respect to wavelength in ducklings and chicks does not require differential reinforcement (Malott, M. K., 1968; Mountjoy and Malott, 1968; Rudolph, Honig, and Gerry, 1969; Tracy, 1970). In each of these studies, subjects were hatched and raised in monochromatic light (590 nm) and their pecks at a 590-nm stimulus were reinforced in an operant-conditioning apparatus. Subsequent generalization tests, in which stimuli of other wavelengths were presented for the first time, yielded gradients of greater than zero slope, *i.e.*, gradients demonstrating stimulus control with respect to wavelength. However, Tracy's study showed that ducklings have an innate preference for the 500- to 550-nm portion of the wavelength continuum. This suggests that ducklings, and perhaps other avians, are not suitable subjects for this type of study.

But even if a more suitable combination of subject and controllable environment could be found, it remains important to

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consider another unresolved question. Does evidence of stimulus control demonstrate the psychological reality of the dimension under study? The nature of this problem can be seen by considering a psychological (behavioral) dimension occasioned by a series of physical stimuli $x_1, x_2, x_3, \dots, x_n$. Suppose that an organism experiences differential reinforcement with respect to two stimuli, x_3 and x_5 . On the basis of this experience will the organism order all of the other stimuli as specified by that dimension? Evidence that the organism responds differentially to different test stimuli is an insufficient basis for answering this question affirmatively. This can be demonstrated as follows. Suppose the generalization test consisted of 10 stimuli, $x_1, x_2, \dots, x_{10}$, and that x_5 (the stimulus correlated with reinforcement) occasioned the highest frequency of responding, x_4 and x_6 the next highest, x_2, x_7, x_8 the next highest, and x_3 (the stimulus correlated with extinction) the lowest frequency of responding. While this information is sufficient to establish the existence of stimulus control it does not allow one to order the stimuli in the manner in which they are perceived by the organism. x_4 , for example, may be perceived to occupy a position below x_5 , and x_2 a position between x_3 and x_4 . But these hypothetical data do not allow one to distinguish between x_4 and x_6 , or between x_2, x_7 , and x_8 or, in general, between any other sets of stimuli that occasion the same frequency of responding.

The problem of ordinal arrangement of stimuli has received relatively little attention in the literature on animal psychophysics, a literature that has been concerned more with absolute and differential thresholds than with the type of scaling problem that presupposes a psychological dimension. Those techniques that have been developed (e.g., Schneider, 1972; Shepard, 1965) require extensive training, and for that reason are not suitable for situations that call for limiting the amount of differential reinforcement before a generalization test.

Hanson's (1959) demonstration of the peak-shift suggests a method that allows one to assess what types of ordinal relationships exist among a set of test stimuli with a minimum of differential reinforcement. Following successive discrimination training between two

stimuli from the same continuum, the peak of a generalization gradient does not occur at S+ (the stimulus correlated with reinforcement), but is instead displaced in a direction remote from the physical value of S- (the stimulus correlated with extinction).

Rudolph and Honig (1972) reared chicks in monochromatic sodium light (590 nm). During the third and fourth weeks after hatching, these subjects were trained to discriminate 590 (S+) from 580 (S-) by a successive discrimination paradigm. While the main concern of the Rudolph and Honig experiment was to compare discrimination acquisition during white light and monochromatic rearing conditions, they also obtained generalization gradients of wavelength. The peaks of these gradients (based upon responses to five test stimuli with values ranging from 570 to 610 nm) were located at 610 nm, a peak-shift away from S- (cf. Hanson, 1959). Thus, Rudolph and Honig's results show that a chick responds to 610 nm in a manner appropriate to the stimulus' place on the physical scale.

The present study presents data² obtained from ducklings on wavelength generalization following monochromatic sodium rearing and discrimination training between S+ (590 nm) and one of two S-s: either 570 nm or 610 nm. In this study, the generalization test employed eight test stimuli, each of the same luminance. Given subjects with differential experience with only two wavelengths, would a peak-shift in the appropriate direction occur during a subsequent generalization test of wavelength?

If a peak-shift is obtained in both cases it will anchor the wavelength dimension in two directions. This is desirable not only because it minimizes the possibility that Rudolph and Honig's data may represent a stimulus preference at 610 nm, but also because it adds to the number of "paired-comparisons" one has available to define psychologically the nature of the duckling's wavelength dimension. The use of additional test stimuli (eight in the present study compared with five in the Rudolph and Honig study) should prove helpful in allowing one to infer the ordinal locations

²Data obtained from the sodium-reared groups were presented at the Columbia University Conference on Animal Psychophysics, April, 1968.

of a wider range of wavelengths than was possible in the Rudolph and Honig study.

METHOD

Subjects

Twenty-four White Peking *Anas platyrhynchos* (ducklings) were hatched from fresh eggs in an incubator located in a room illuminated by three monochromatic (589.5 nm) sodium-vapor lights. The walls of this room were painted with flat white paint. On the twenty-ninth day of incubation, approximately 48 hr after hatching, 16 of the ducklings hatched in monochromatic sodium light were transferred to cages in the same room. The remaining eight subjects were transferred to cages in a room illuminated by white light. Luminance levels of the wall behind the cage in the room illuminated by monochromatic light ranged from -0.1 log ft lamberts, for the top row, to -1.0 log ft lamberts for the fourth (bottom) row. To ensure variation in cage illumination, the cages were rotated at the end of each day as follows: 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. The luminance level of the (white) wall behind the cages in the room illuminated by white light was -0.6 log ft lamberts; these cages were rotated as described above.

All ducklings had unlimited access to food and water for three days after their removal from the incubator. On the fourth and subsequent days, water was available in the home cages for only 1 hr immediately after their daily sessions.

Apparatus

Four experimental chambers similar to those described by Ferster and Skinner (1957, pp. 14-19) were used. These chambers, as well as the optical apparatus and the interference filters, were identical to those used by Tracy (1970). Two chambers were housed in the room illuminated by sodium light and two were housed in the room illuminated by white light. A translucent plastic response key, 3 cm in diameter, was centered 12 cm above the bottom of a recessed opening to a water dipper. A force of approximately 0.118 N was needed to open the contact behind the key. The floor of the subject'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 that was passed through narrow-band interference filters. The technical characteristics of these filters were as follows. The dominant wavelength was 589 nm, the half-widths ranged between 5 and 8 nm. The transmittances ranged between 32 and 34%. The source of the collimated light and the interference filters were housed outside the experimental rooms. Collimated monochromatic light provided the only source of illumination in the experimental chambers, all of which were painted flat black. When reinforcement was scheduled, a dipper cup (diameter 14 mm, volume 0.1 cc) 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 monochromatic light with dominant wavelength of 589 nm. Thus, for all subjects, the wavelength of the light projected onto the response key was the same as the wavelength of the light illuminating the home cages for the 16 ducklings raised under sodium-vapor light. Responding was reinforced on a variable-interval (VI) schedule. During the 18 sessions that followed key-peck training, the mean value of the VI schedule was increased progressively from 15 sec to 3 min. The sequences of interreinforcement intervals consisted of random permutations of 12 different temporal intervals derived from geometric progressions (*cf.* Fleshler and Hoffman, 1962). Throughout VI training, 3-sec timeouts (TO) occurred every 30 sec. During TO, a shutter interrupted the beam of collimated light directed at the key. The TO period was used to change the stimulus appearing on the response key both during discrimination training and during a subsequent generalization test.

Before discrimination training, each subject was given seven sessions of nondifferential reinforcement on a VI 3-min TO schedule. These were Sessions 12 to 18 of the nondif-

ferential phase of training. This was followed by 10 sessions of differential reinforcement on a VI 3-min TO EXT schedule, with VI 3-min during S+ and extinction (EXT) during S-. During the VI 3-min TO EXT sessions, S+ and S- were alternated in an irregular sequence that allowed no more than three successive presentations of the same stimulus.

Four experimental groups were employed. Two were reared under sodium monochromatic light ($N = 16$), and two were reared under white light ($N = 8$). For one-half of the subjects of each of these groups, the value of S- was 570 nm; for the remaining half, the value of S- was 610 nm. The transmittances of the interference filters used to produce 570 nm ranged between 33 and 36%. The half-widths of these filters ranged between 6 and 9 nm. The ranges of the transmittances and half-widths of the filters used to generate 610 nm were 34 to 38% and 5 to 8 nm respectively. The luminance levels of the discriminative stimuli were matched across wavelengths on the basis of (1) the photopic visibility function for the pigeon (Blough, 1957) and (2) the spectral distribution of energies of the various interference filters.

The scheduled durations of S+ and S- were each 30 sec. Responding during S-, however, activated a correction procedure that prolonged the duration of S- as follows. Each response to S- interrupted the S-timer for 15 sec. Thus, each presentation of S- could not end until at least 15 sec without a response had elapsed. Each VI 3-min TO and VI 3-min TO EXT session was terminated after 25 reinforcements.

The generalization test was administered on the day following the last session of the VI 3-min TO EXT training. Monochromatic test stimuli were produced by passing collimated light through one of eight interference filters. The technical characteristics of these filters were as follows. The dominant wavelengths were 490, 530, 550, 570, 589, 610, 630, and 650 nm. The half-widths ranged between 4 and 11 nm. The transmittances ranged between 27 and 39%. The same light and optical system used to generate the discriminative stimuli was used to generate the test stimuli presented during the generalization test. The test consisted of four counterbalanced sequences, each containing eight different stimuli. Each stimulus was presented for 30 sec

and was followed by a 2-sec TO. During the generalization test, the luminance levels of the various stimuli were matched as described earlier. The luminances of S+ (589 nm) and S- (570 or 610 nm) had the same values that obtained during discrimination training. Responding was not reinforced during the generalization test.

RESULTS AND DISCUSSION

The present results confirm and extend the unidirectional peak-shifts in chicks described by Rudolph and Honig (1972). In the present experiment, peak-shifts were observed in ducklings both above and below S- during generalization tests in which the wavelength of test stimuli ranged between 490 and 650 nm (*cf.* 570- to 610-nm range of Rudolph and Honig). Since Rudolph and Honig did not use a correction procedure during discrimination training, it is not possible to compare directly their acquisition data with those obtained in the present experiment. However, in agreement with Rudolph and Honig, it was shown that the acquisition of a wavelength discrimination during monochromatic rearing was of the same order of difficulty as acquisition during white-light rearing.

Discrimination Training

Discrimination acquisition was evaluated with respect to (a) the relative frequency of responding to S-, (b) the overall frequency of responding to S- throughout discrimination training, and (c) the amount of behavioral contrast. None of the groups (white light *versus* monochromatic rearing; S- = 570 nm *versus* S- = 610 nm) could be distinguished by any of these measures.

At the end of discrimination training, the relative frequency of responding to S- was less than 0.05 for all subjects. Table 1 shows each subject's overall frequency of responding to S- as well as each subject's contrast ratio. In each case, the contrast ratio was calculated by dividing the average rate of responding during the last three baseline sessions (VI 3-min TO) by the average rate of responding during discrimination training. Ideally, it would have been desirable to have had more than seven sessions of nondifferential training for obtaining baseline rates of responding on a VI 3-min schedule. It is pos-

Table 1
Characteristics of Discrimination Performance

Subject number:	561	562	563	572	606	608	609	610
<i>Monochromatic Rearing, S—: 570 nm</i>								
Rate of Responding (Responses/min) to S+ (Baseline):	46.0	69.7	59.7	32.3	50.3	65.0	35.3	53.7
Rate of Responding (Responses/min) to S+ (Discrimination Training):	67.4	92.4	87.4	74.9	75.2	110.6	47.3	81.6
Contrast Ratio:	1.47	1.33	1.46	2.32	1.50	1.70	1.34	1.52
Number of Responses to S—:	8352	2147	10,249	5316	4156	2473	1820	6145
<i>Monochromatic Rearing, S—: 610 nm</i>								
Subject number:	650	652	653	654	685	686	687	690
Rate of Responding (Responses/min) to S+ (Baseline):	59.0	87.0	30.3	50.0	41.0	55.7	46.3	65.7
Rate of Responding (Responses/min) to S+ (Discrimination Training):	103.9	95.6	49.9	84.5	88.5	105.5	102.5	80.4
Contrast Ratio:	1.76	1.10	1.65	1.69	2.16	1.89	2.21	1.22
Number of Responses to S—:	5142	5026	1934	8601	7348	9930	2672	3364
<i>White Light Rearing</i>								
	<i>S—: 570 nm</i>				<i>S—: 610 nm</i>			
Subject number:	631	632	634	636	637	638	640	641
Rate of Responding (Responses/min) to S+ (Baseline):	91.0	60.0	51.3	44.3	45.0	36.7	64.7	57.0
Rate of Responding (Responses/min) to S+ (Discrimination Training):	133.8	94.1	104.5	74.5	108.1	69.6	89.9	119.5
Contrast Ratio:	1.47	1.57	2.04	1.68	2.40	1.90	1.39	2.10
Number of Responses to S—:	11,543	8557	4610	1757	3310	5672	7849	2156

sible, however, to determine whether contrast occurred even with only seven baseline sessions. Pilot data indicated that rate of responding at the end of 14 sessions of baseline training is not appreciably higher than after seven sessions. What is different after 14 sessions is the size of the duckling. The ducklings would have been too large for the apparatus at the end of the experiment had 14 rather than seven sessions of baseline training preceded discrimination training. Since generalization is the main focus of this study, it was decided to use only seven sessions of baseline training.

The range of the number of responses to S— of monochromatically reared subjects trained with a 570-nm S— was 2147 to 10,247. The range of errors of the monochromatically reared groups for whom S— was 610 nm was 1934 to 9930. The ranges of the subjects reared under white light were 1174 to 11,543 (S— = 570 nm) and 2156 to 7849 (S— = 610 nm).

Under monochromatic rearing, the ranges of the contrast ratios of the 570-nm and 610-nm groups were, respectively, 1.33 to 2.32 and 1.10 to 2.21. Under white-light rearing, the ranges of the 570-nm and 610-nm groups

were, respectively, 1.57 to 2.04 and 1.90 to 2.40. These data indicate that discrimination performances of the subjects of each of the four experimental groups were comparable before generalization testing.

Generalization Gradients

Individual generalization gradients showing the frequency of responding during the generalization test of each subject are shown in Figures 1 and 2. These gradients were evaluated in two ways: the location of the peak and the amount of area above and below S-.

Using Tracy's normal white-light rearing groups as a reference (Tracy, 1970, Figure 1), the expected location of the peak following nondifferential training is S+ (589 nm). Despite the fact that three test stimuli were above S+, as compared with four test stimuli below S+, Tracy obtained essentially symmetrical gradients from the group he reared

in white light. The same asymmetrical series of test stimuli was used in the present study. Thus, keeping in mind a correction for this asymmetry, one would not expect a large difference in the frequencies of responding above and below S+.

Monochromatic rearing, S- = 570 nm. Peak-shifts were observed in seven of eight of the gradients obtained from this group (Figure 1, left-hand panel). In eight of eight cases, however, the area above S+ was substantially greater than the area below S+. The percentages of areas above S+ ranged from 70.5 to 97.0%. Thus, in eight of eight instances there was a clear-cut area shift away from S-. This was true even though there were only three test stimuli above S+ as compared with four test stimuli below S+.

Monochromatic rearing, S- = 610 nm. A similar state of affairs was observed in the gradients obtained from this group (Figure

Fig. 1. Individual gradients of monochromatically reared ducklings following discrimination training between 589 nm (S+) and 570 nm (S-), left-hand panels; and 610 nm (S-), right-hand panels. The numbers in parentheses above and below S+ show the per cent of area under the gradient above and below S+ respectively.

Fig. 2. Individual gradients of ducklings reared in white light following discrimination training between 589 nm (S+) and 570 nm (S-), left-hand panel; and 610 nm (S-), right-hand panels. The numbers in parentheses above and below S+ represent the amount of area under the gradient above and below S+ respectively.

1, right-hand panels). Peak-shifts were observed in six of eight instances and area shifts were observed in eight of eight instances. Even though there were more opportunities to respond to test stimuli below (four stimuli) than above (three stimuli) S+, the magnitude of the area shifts suggest that this factor can-

not completely account for the area shifts shown in Figure 1. The percentages of areas below S+ ranged from 78.5 to 89.9%.

White-light rearing. As shown in Figure 2, the gradients obtained from ducklings reared in white light show the same characteristics as those obtained from ducklings reared in monochromatic light. Under both values of S-, peak-shifts and area shifts were observed in the gradients of each of the eight subjects of the white-light rearing group.

The data obtained during the generalization gradients were also analyzed by comparing the relative frequency of responding at each test stimulus and using these frequencies as a basis for ordering the test stimuli. The results of this analysis are shown in Table 2. Different orderings were obtained from each of the four experimental groups. Notice, however, that in each case the rank of S+ is larger than the rank of S-, but smaller than the rank of the test stimulus located physically to the other side of S+. Thus, when S- = 570 nm, the ordering of ranks is 610 nm, 589 nm, and 570 nm. When S- = 610 nm, the ordering of ranks is 570 nm, 589 nm, and 610 nm. The data in Table 2 show that an analysis based upon frequency of responding to various test stimuli during a single generalization test can serve as a sound, albeit primitive, basis for constructing a psychological dimension.

Since the monochromatically reared subjects did not experience the stimulus that occasioned the highest frequency of responding before the generalization test, the present results demonstrate that ducklings possess an innate basis for ordering stimuli of different wavelengths. It appears as if differ-

Table 2

		<i>Monochromatic Rearing S-: 570 nm (N = 8)</i>							
Average Rank of Frequency of Responding:	1.3	2.3	2.5	4.4	6.1	6.4	6.5	6.6	
Wavelength (Nanometers):	610	630	589	650	550	490	530	570	
		<i>Monochromatic Rearing S-: 610 nm (N = 8)</i>							
Average Rank of Frequency of Responding:	1.4	2.0	2.8	4.5	5.8	5.9	6.7	7.1	
Wavelength (Nanometers):	570	589	550	530	490	610	630	650	
		<i>White Light Rearing S-: 570 nm (N = 4)</i>							
Average Rank of Frequency of Responding:	1.0	2.0	3.0	4.9	4.9	6.3	6.8	7.3	
Wavelength (Nanometers):	610	589	630	490	650	550	530	570	
		<i>White Light Rearing S-: 610 nm (N = 4)</i>							
Average Rank of Frequency of Responding:	1.3	2.3	2.5	4.3	5.5	6.1	7.0	7.1	
Wavelength (Nanometers):	570	589	550	530	490	650	610	630	

ential reinforcement with respect to but two wavelengths is sufficient to activate whatever mechanism is responsible for the ordinal arrangements of a larger set of wavelengths. Some psychologists (e.g., Sutherland and Mackintosh, 1971) have cited "analyzers" as the mechanism responsible for ordering of stimuli along a particular dimension. At this stage, however, it is not clear how an appeal to analyzers goes beyond a mere description of the data.

The present results cannot be attributed to innate preferences for particular wavelengths nor to the influence of brightness on responding to different test stimuli. The fact that peak-shifts were obtained following discrimination training in which the value of S— was either 570 or 610 nm minimizes the possibility of innate preferences. For the present results to be explained by appeal to innate preferences, it would be necessary to postulate that ducklings prefer stimuli with wavelength of either 600 or 580 nm to a 589-nm stimulus. It should also be noted that Tracy's 1970 experiment (conducted in the same apparatus as the present experiment) demonstrated that wavelength preferences of ducklings show up in the 510- to 550-nm portion of the spectrum.

Brightness preferences can be ruled out on somewhat similar grounds. Even if the luminance matches, which were derived from psychophysical data obtained from the pigeon, are not appropriate for the duckling, it is doubtful that the stimuli that occasioned the highest frequency of responding were the brightest test stimuli (600 nm in the case of subjects trained with a 570-nm S—, and 580 nm in the case of subjects trained with a 610-nm S—).

While the present results indicate an innate basis for the hue dimension in the duckling, they provide no basis for generalizing these results to other dimensions or to other organisms. At best, they define an extremely simple psychological dimension. At the other extreme are psychological dimensions in which the ordering of the stimuli are clearly learned. Consider, for example, Herrnstein and Loveland's (1964) demonstration of concept formation in the pigeon. In this experiment, pigeons were trained to respond to arbitrarily defined sets of stimuli such as photographs of trees, of a particular person, and

so on. No single photograph was repeated in this experiment. An analysis of the errors revealed that false positives (i.e., responses to S—) often occurred "when the picture contained objects frequently associated with people such as automobiles, boats and houses" (Herrnstein and Loveland, 1964, p. 550). Quite obviously, the order of categories that include boats, houses, and cars on the same continuum as people is learned and cannot be attributed to any innate mechanism.

From these two examples it should be clear that psychological dimensions studied in experiments in both animal and human subjects may reflect a variety of different mechanisms and developments. At present, there appears to be only one sound answer to the question posed by Lashley and Wade concerning the existence of a psychological dimension before differential reinforcement. A simple generalization, i.e., an affirmative or negative answer, that applies to all dimensions and/or all organisms, does not exist.

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