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The primary purpose of the present investigation was to determine if the complex stimulus continuum of orientation of a three-dimensional object could serve as a dimension for stimulus generalization. Having confirmed the behavioral dimensionality of object orientation, the study was addressed to the shape of the generalization gradient for this dimension relative to the form of generalization gradients obtained for less complex stimulus dimensions.

The Ss were two groups of White Carneau pigeons, each group receiving different discrimination training. However, both groups were tested for generalization along the object orientation continuum. The first group ($n = 4$) received discrimination training involving three points on the object orientation continuum ($S^+ = 90$ deg, $S^- = 30$ deg and 150 deg), thus making object orientation relevant for responding (intradimensional training). For the second group ($n = 3$), a discrimination was trained between the presence of the object (S^+) and the complete absence of the object (S^-), thereby rendering object orientation irrelevant for the development of the discrimination (interdimensional training).

The gradients obtained following the intradimensional training demonstrated that object orientation can constitute a dimension of stimulus generalization. The gradients generated following the interdimensional training were flatter, as is generally found to be the case for gradients for less complex dimensions, following similar training conditions.

It was pointed out that a single dimensional component of the multidimensional stimulus of object orientation could be the relevant behavioral dimension. It was also suggested that the present study demonstrates the adequacy of the stimulus generalization paradigm in dealing with complex stimulus continua.

OBJECT ORIENTATION AS A DIMENSION

FOR STIMULUS GENERALIZATION

by

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INTRODUCTION

The value of the stimulus generalization paradigm for the study of sensory continua was convincingly demonstrated as a result of the Guttman and Kalish (1956) study dealing with the spectral continuum. In that study, a symmetric response decrement was obtained as stimuli differed increasingly in wavelength from the wavelength of the conditioned stimulus (S^+). Since that time, the stimulus generalization paradigm has increasingly been utilized in the investigation of other stimulus continua. For example, Butter and Guttman (1957) obtained generalization gradients with orientation of a line (line-tilt) as the stimulus continuum. A more complex stimulus was employed by Reynolds (1961) who obtained data which indicated that orientation of a planimetric isosceles triangle served as a continuum for stimulus generalization. More recently, Vetter and Hearst (1968) obtained stimulus generalization along a continuum defined as the orientations of a planimetric parallelogram.

The above-mentioned studies dealing with continua quite different from the spectral continuum have at least two characteristics in common. The stimuli employed were two-dimensional figures and the rotation of the figures was around the geometric centers in a plane perpendicular to the S's line of sight. The present investigation departs from these studies with respect to each of these two characteristics, geometric dimensionality and plane rotation. This study is an attempt to determine if stimulus generalization can occur along a continuum of orientation of a three-dimensional object. In this case, the object is rotated on its vertical axis and therefore, in a plane horizontal to the S's line of vision. Since previous studies differ from the present research with regard to geometric dimensionality and plane of rotation, it would seem that these studies would have limited relevance for the present investigation. Furthermore, a thorough review of the literature revealed no previous studies dealing with this specific problem.

When stimulus generalization has been shown to occur along a stimulus continuum, it may be said that the behavioral dimensionality of that continuum has been demonstrated. This position derives from Underwood's definition of a dimension. "When any given phenomenon or event can be demonstrated to vary reliably (consistently) with respect to some specific characteristic, we have a dimension" (1966, p. 15). For the special function of stimulus generalization, the "phenomenon or event" is the response rate and the "specific characteristic" is the various stimulus values along a continuum. Symmetric, decremental responding to these stimuli as they increasingly differ from the S^+ represents the consistent variation of the event. Thus, to repeat, when generalization is demonstrated on a stimulus continuum, the behavioral dimensionality of that class of stimuli has been demonstrated. In the case of rotation of the planimetric figures mentioned previously, orientation is considered the dimension since it is the most objective means by which to characterize the on-continuum changes associated with rotation of the figures. When a two-dimensional figure is rotated about its geometric center in a plane perpendicular to a S's line of sight, there is no change in the configuration of the proximal projection (projective geometry) as a result of this rotation. However, this is not the case for the rotation of a *three*-dimensional object about its *vertical* axis. In this instance, the configuration does change as the object is rotated. Therefore, the most salient dimension associated with rotation of a three-dimensional object about its vertical axis is the projective geometry in the form of perspective transformations effected by this rotation.

Although perspective transformation is the most salient dimension associated with rotation of an object, it is not unlikely that some simpler attribute related to this dimension is the relevant behavioral dimension. However, the design of the present study does not permit an analysis of the possible behavioral relevance of these various dimensions associated with rotation of an object. For this study, reference will be made to the broad category of object orientation as the dimension for stimulus generalization.

It would seem that object orientation may be made relevant for responding through differential discrimination training on the orientation continuum. Generalization testing could then be carried out to determine if object orientation constitutes a dimension for stimulus generalization.

If object orientation is a dimension for stimulus generalization, it would be predicted that symmetric, decremental responding would occur to test stimuli (orientations) as they increasingly differed from the S^+ orientation. There are, however, categorical alternatives with regard to the shape of the generalization gradient if object orientation does not constitute a dimension. For example, the nondimensionality of object orientation could be reflected by a gradient showing approximately equal response rates at test orientations other than those associated with extinction during discrimination training (the training S^-'s). Another possibility would be a gradient generated by random responding to test orientations lying between the S^+ orientation and the S^- orientations.

If the behavioral dimensionality of object orientation is confirmed, it would be of interest to determine whether the generalization function for this dimension is similar in detail to that for less complex dimensions, e.g., line-tilt and wavelength. The gradients obtained following interdimensional discrimination training for these less complex dimensions have characteristically been well-defined and fairly sharp (Bloomfield, 1967; Honig, Boneau, Burstein, & Pennypacker, 1963; Lyons, 1969; and Switalski, Lyons, & Thomas, 1966). Therefore, one would have some basis for expecting that interdimensional training would effect the same results for the object orientation continuum as well.

METHOD

Subjects

The Ss were seven experimentally-naive White Carneau pigeons obtained from the Palmetto Pigeon Plant, Sumter, South Carolina. All Ss were maintained at approximately 80% of their ad libitum weight throughout the experiment.

Apparatus

A 14 x 8 x 12 in. experimental chamber was constructed from 1/2 in. plywood and painted a uniform flat black. An exhaust fan provided broad-spectral noise for masking extraneous sounds in addition to supplying ventilation for the chamber. Responses were recorded and reinforcement programmed automatically by standard Grason-Stadler relay circuitry located in an adjoining room. A transparent Plexiglas response key 1 1/2 in. in diameter was located in the center of the front panel of the chamber, 8 3/4 in. from the base. A minimum force of approximately 12 grams was required to operate the key. Reinforcement consisted of grain made available automatically by a Lehigh Valley Electronics Grain Dispenser (Model 1347) for 3-sec durations, through a 2 x 2 1/2 in. rectangular opening 3 in. directly below the key. A standard 24-volt light illuminated the magazine opening during grain presentations.

The stimulus object (three-dimensional, symmetrical white cross) was located at a distance of 3 1/2 in. directly behind the key, in an enclosed box attached to the chamber. According to Catania (1964), placement of the object at this distance ensures that the object is within the range of good binocular acuity for the Ss. The arms of the cross were 2 1/8 in. in length, 3/4 in. in width, and 7/8 in. in thickness. To prevent surface shadows, the object was illuminated by two 6 in. Sylvania F4T5/D fluorescent bulbs, each placed equidistance from the sides of the object. The light was attenuated by sand-blasted plexiglas covered with two sheets of white paper. The object could be rotated about its vertical axis to any desired orientation by inserting into the stimulus box (enclosed box) a block of wood, cut at the appropriate angle, and sliding the block flush against the back side of the object. The orientations utilized in the study were

30, 45, 60, 75, 90, 105, 120, 135, and 150 deg, with 90 deg corresponding to frontal parallel. To ensure that a S's view of any of these orientations did not overlap with his view of adjacent orientations, differing by 15 deg, lateral head movement was restricted by extending wire mesh outward from the sides of the response key. To prevent Ss from observing the rotation of the object between trials, a shutter was lowered between the S and the stimulus box. The circuitry was such that pecking could not be accidentally reinforced during these "blackouts."

Procedure

Upon arrival, Ss were weighed, individually caged, and given free access to food and water. Beginning on the tenth day, free feeding was discontinued and Ss were allowed only 3 grams of grain each day thereafter until each S reduced to 80% of his free feeding weight. This weight was maintained for three days, with training beginning on the fourth day. During the first day of training, all Ss were magazine- and key-peck trained, with the method of successive approximation being employed in key-peck training. Initial training took place in the presence of the object at an orientation of 90 deg. For both groups, responses were reinforced only in the presence of this orientation.

On the day following initial training, the reinforcement schedule was reduced from continuous (CRF) to a variable interval (VI) schedule of approximately 10 sec. Each S remained on this schedule until a relatively high and stable response rate was attained. (It should be mentioned at this point that one of the original eight Ss failed to attain a stable rate in this schedule and, therefore, was not used in the study.) Shutter-down periods were gradually introduced during daily training until 30-min daily sessions consisted of 30-sec stimulus presentations alternating with 12 sec of blackout. These 30-min daily sessions continued until Ss responded at a relatively high and stable rate, at which time discrimination training was introduced on the following day.

The Ss were placed in one of two groups differing in the discrimination training to be employed. The training of one group made object orientation relevant for the development of the discrimination. For the other group, object orientation was not explicitly made relevant for the development of the discrimination. Training for the first group (n = 4) involved development of a discrimination between the object at the S^+ orientation (90 deg) and two S^- orientations (30 and 150 deg). Subsequent testing for generalization was carried out along the continuum that was relevant to the development of the original discrimination. For the second group (n = 3), a discrimination was trained between the presence of the object at 90 deg and the complete absence of the object; subsequent generalization was tested along the continuum of object orientations for this group as well. However, for this group this continuum was irrelevant for the development of the original discrimination. The term used in the literature for such discrimination training as the first group received is "intradimensional" discrimination training and, for the second group, "interdimensional" discrimination training (Switalski et al, 1966).

Discrimination training for the first group (intradimensional) involved reinforcement of responses in the presence of the object at 90 deg (S^+ condition), and extinction at orientations of 30 and 150 deg (S^- condition). A training session consisted of 20 presentations of the S^+ orientation and 10 presentations of each S^- orientation. In addition, a warm-up period of 3 successive S^+ presentations preceded each session. The three orientations involved in training were randomly presented with the restriction that no more than three S^+ or three S^- presentations occurred in succession.

When a S had demonstrated a high response rate during the S^+ period, relative to the response level during S^- presentations, four nonreinforced presentations of the S^+ orientation were interspersed among the other presentations constituting the session. Responding during these nonreinforced presentations of the 90-deg orientation was compared with the S^- response rates of the session to provide a means of assessing the development of the discrimination. After it became apparent that the discrimination was being learned, a VI-20 sec reinforcement schedule was introduced. The mean interval for reinforcement was further increased to 30 sec (VI-30) when Ss exhibited a stable response rate in the VI-20 schedule. VI-30 training continued until Ss responded to criterion, with generalization testing beginning on the following day. Criteria of discrimination learning were: (1) 80% of all responses during a daily session must be S^+ responses and (2) S must respond to every S^+ presentation of the session. Testing was not begun, however, until each S had a minimum of four days training under a VI-30 schedule of reinforcement. A minimum of four days under this schedule was required to ensure that Ss have some experience with the reinforcement contingency which was to be operative during the S^+ conditions of generalization testing.

During a daily testing session, each test orientation (30, 45, 60, 75, 90, 105, 120, 135, and 150 deg) was presented three times. A testing session consisted of presentation of three randomized blocks of test stimuli, each test orientation occurring once in each block. To maintain responding, each of the three stimulus blocks also included three reinforced 90-deg presentations. Responses during these reinforced intervals were excluded from the data. During any daily testing session, no test stimulus immediately followed a reinforced 90-deg presentation more than once. Four different daily presentation schedules were used and each S within a group received a different presentation schedule during the first four daily sessions. In addition, the order in which test orientations followed a reinforced 90-deg presentation during the first and third daily sessions was reversed for the second and fourth daily sessions, and so on for the remainder of the experiment. Each test orientation was presented for a 30-sec interval followed by a 12-sec shutter-down period during which E rotated the object to the next scheduled test orientation.

Training for the second group (interdimensional) followed the same procedure as that for the first group. However, Ss in the second group were exposed only to the object at the 90-deg orientation to which responding was reinforced (S^+ condition). The S^- condition was shutter-up with *no* object present. Criteria and generalization testing procedures were the same for both groups.

RESULTS AND DISCUSSION

Figure 1 presents individual relative generalization gradients for the intra- and inter-dimensional groups, based on number of responses to the test stimuli presented the first day of testing. For each S, the total number of responses at the 90-deg orientation (excluding responses emitted during reinforced presentations) was set at 100 and responding to each of the other test orientations was expressed as a percentage of the response level at the 90-deg orientation (relative responses). (Absolute and relative response rates for each S are given in Table 1.) The various orientations to which the object was rotated during testing are represented, in degrees, on the horizontal axis.

Discrimination training on the orientation continuum was inherent in the generalization testing procedure due to the fact that a reinforcement contingency was operative for three out of the four 90-deg presentations during each stimulus block, while responses to other testing orientations were never reinforced. Therefore, with continued generalization testing it would be expected that this additional discrimination training would effect a decrease in responding to orientations other than the reinforced orientation. Graphically, this effect would appear as a sharpening of the gradients as testing progressed. This discrimination training, however, was equivalent for both groups and consequently should have no differential effects. Thus, the initial training should reflect only the effects of the previous training of the two groups.

Relative gradients were plotted in order to equate any differences in overall response levels of the two groups and thereby permit possible comparisons between the two groups. Such comparisons between the two groups are not critical to the determination of the dimensionality of object orientation, however. The transformation to relative gradients served simply to make more salient the differences in slope of the gradients, independent of possible differences in activity level. Differences in activity level of the two groups are slightly discernible in gradients of mean responses at each test orientation (absolute gradient) across daily sessions (Fig. 2).

Figure 1. Relative Generalization Gradients for First Daily Testing Session

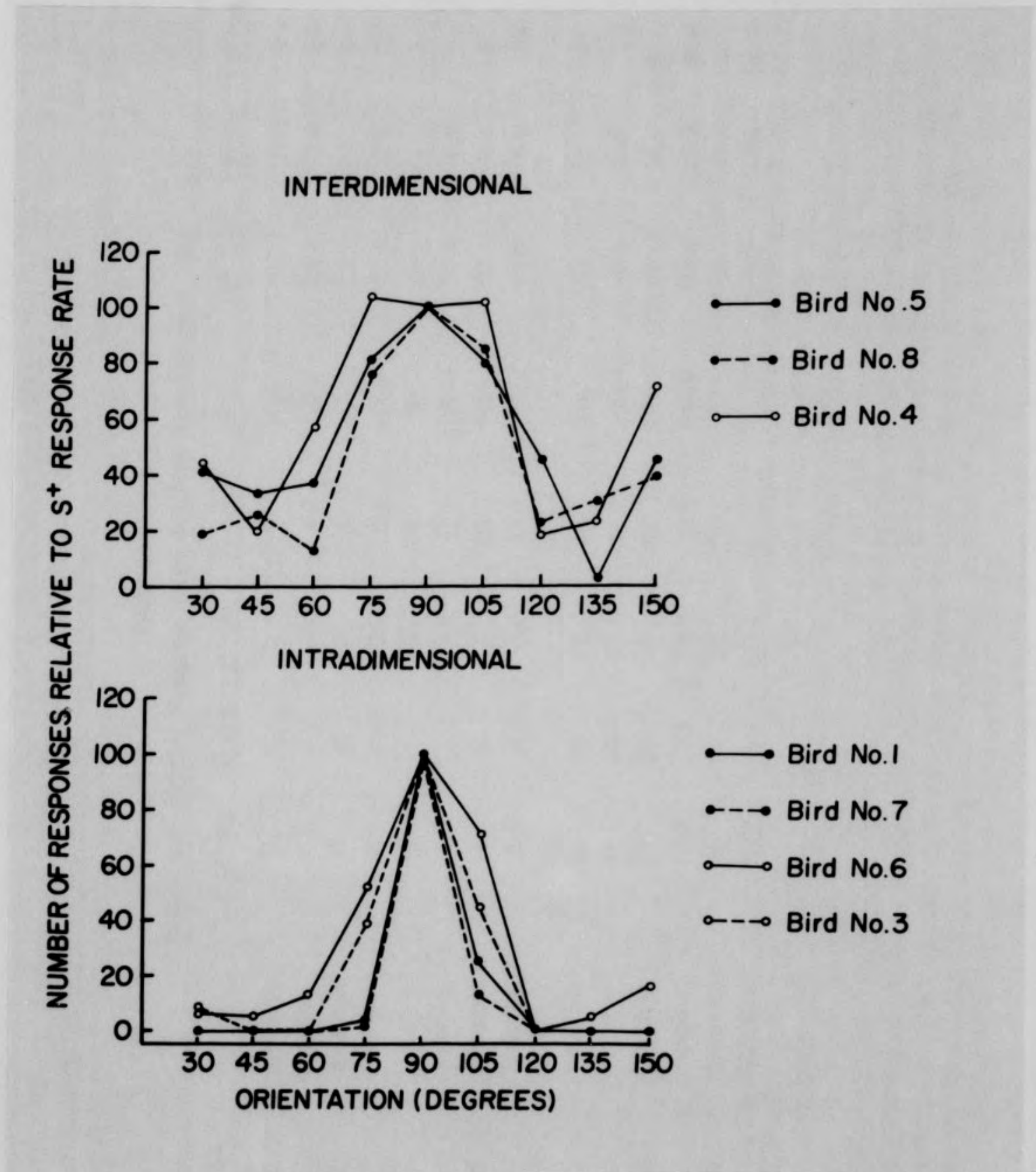
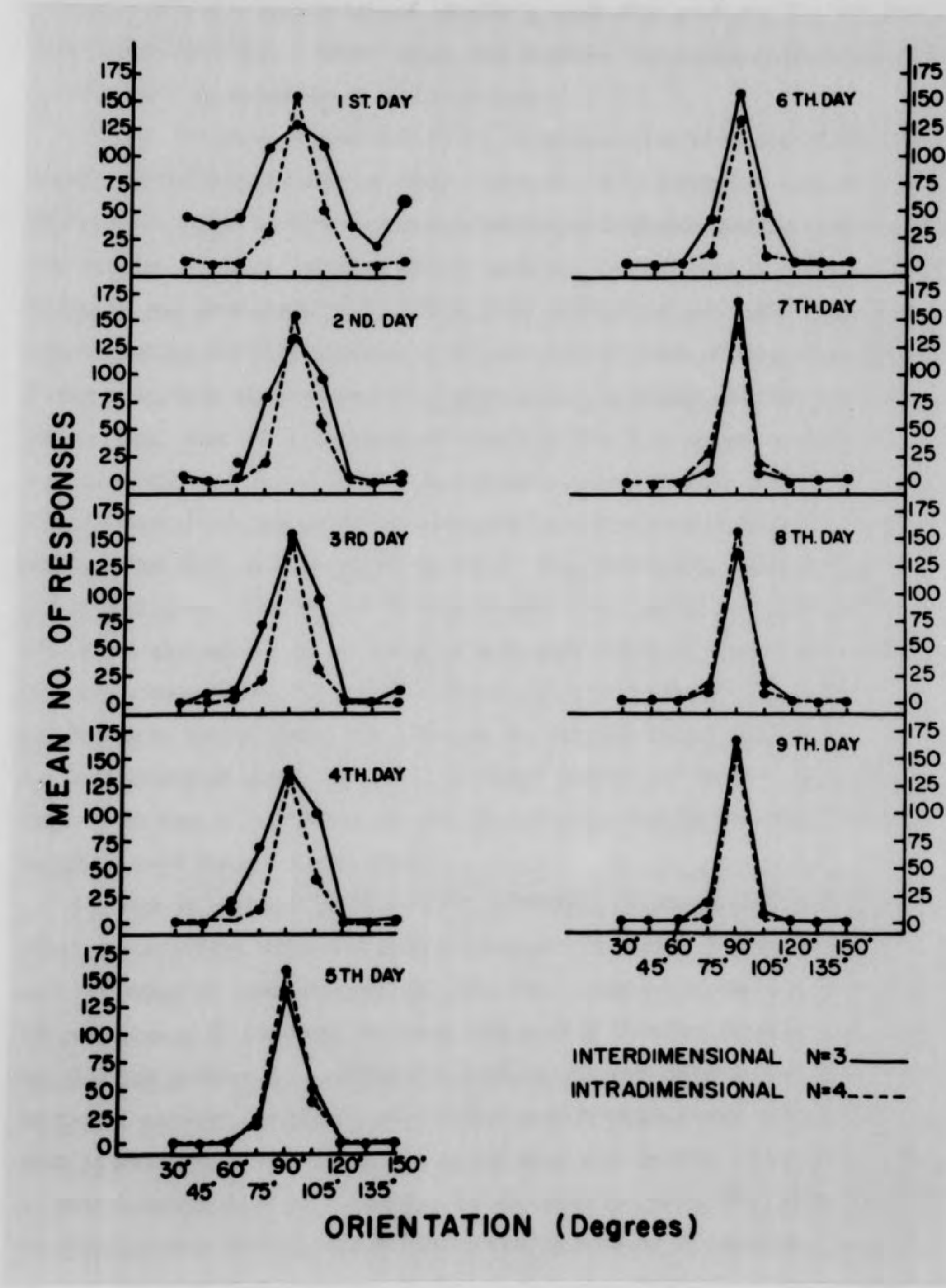


Table 1

Absolute and Relative Response Rates for First Generalization Test

	Ss No.		30 deg	45 deg	60 deg	75 deg	90 deg	105 deg	120 deg	135 deg	150 deg
Intradimensional	1	Absolute	0	0	0	9	206	51	0	0	0
		Relative	0.0	0.0	0.0	4.4	100.0	24.8	0.0	0.0	0.0
	7	Absolute	0	0	0	4	161	21	0	0	0
		Relative	0.0	0.0	0.0	2.5	100.0	13.0	0.0	0.0	0.0
	6	Absolute	6	5	13	50	96	69	0	5	16
		Relative	6.3	5.2	13.5	52.1	100.0	71.9	0.0	5.2	16.7
	3	Absolute	14	0	1	63	160	72	1	0	0
		Relative	8.8	0.0	0.6	39.4	100.0	45.0	0.6	0.0	0.0
Interdimensional	5	Absolute	81	66	73	159	196	156	88	4	89
		Relative	41.3	33.7	37.2	81.1	100.0	79.6	44.9	2.0	45.4
	8	Absolute	21	29	15	85	112	95	26	34	44
		Relative	18.8	25.9	13.4	75.9	100.0	84.8	23.2	30.4	39.3
	4	Absolute	35	17	47	85	82	83	15	19	58
		Relative	42.7	20.7	57.3	103.7	100.0	101.2	18.3	23.2	70.7

Figure 2. Absolute Generalization Gradients for Nine Days of Testing



The necessary condition for demonstration of the dimensionality of object orientation was that the gradient generated by the intradimensional group show a symmetric response decrement characteristic of stimulus generalization gradients. The intradimensional gradients of Fig. 1 clearly satisfy this condition and consequently, demonstrate the behavioral dimensionality of object orientation.

Though the gradients generated by the interdimensional Ss are not critical to the question of the dimensionality of object orientation, it is of interest to note that these gradients are similar in form to interdimensional generalization gradients obtained for less complex continua. Interdimensional gradients for less complex continua, such as line-tilt and wavelength, have typically been well-defined and fairly steep, and the interdimensional gradients obtained in this study exhibit both of these characteristics. Furthermore, it is apparent that the interdimensional gradients obtained in this study are less steep than the intradimensional gradients. This is in agreement with the findings of Vetter and Hearst (1968) that intradimensional training resulted in greater stimulus control (i.e., sharper gradient) than did interdimensional training. These authors also reported that response output to the S^+ was considerably higher for the intradimensional group than for the interdimensional group during generalization testing. This effect also appears in the initial generalization testing of the present study but to a much lesser extent. The mean number of responses to the S^+ orientation during the first daily testing session was 155.6 for the intradimensional group and 130.0 for the interdimensional group. As Vetter and Hearst pointed out for their data, however, these results must be regarded as tentative due to the fact that the comparison is between Ss with a small number in each group.

In order to compare gradients more definitively, it was desirable to obtain an objective, quantitative measure of gradient steepness. The sum of S^+ responses expressed as a percentage of total responses has often been employed to this end. The higher the percentage of S^+ responses, the sharper the gradient. However, Lumsden has pointed out that this measure ". . . differentiates among gradients differing only in the *total* number of responses" to the S^+, while failing to differentiate among different distributions of responses to test stimuli, having the *same* total number of responses (1968, p. 209). Lumsden proposed a measure, the discrimination index (DI), which does differentiate among various response distributions having the *same* total number of responses, while preserving the other sensitivities of the more conventional measure. Because of this added sensitivity, the DI was employed in the present study as a measure of sharpness of a gradient. For this experiment, the DI is defined as follows:

$$\frac{R_{S^+} + 1}{\sum_{i=1}^{N} [R(|0_i - 90| + 1)]} \times \log R_{S^+}$$

where 0_i = test orientations and R = number of responses relative to the S^+ response rate

The denominator represents the sum of the product of the number of responses at each testing orientation and the absolute number of degrees by which that orientation differs from the S^+ orientation (90 deg). The integer one is added to preclude a product of zero for the S^+ orientation. The numerator represents relative number of responses at the S^+ orientation, plus one (to preclude a quotient of zero, if there are no S^+ responses). For these relative gradients, the value of R_{S^+} is equal to 100. The quotient is multiplied by the log of the S^+ response total for a reason more paramount to the experimental context in which the measure was initially developed. The larger the value of the DI, the sharper the gradient. The flattest possible relative gradient (equal response rate to all orientations) would set a lower limit of the DI at 0.007. The largest possible DI value for a relative gradient would result when all responses were to the S^+ orientation only, giving a DI value of 2.000. However, DI values decrease quite rapidly from this upper limit when there is even the slightest response decrement to test stimuli other than the S^+, especially those furtherest from the S^+. Some basis for comparison is available when we consider that the classical wavelength gradient obtained by Guttman and Kalish (1956) yielded a DI value of 0.022, when transformed to a relative gradient.

The DI values for Fig. 1 are given in Table 2. Comparisons of these values between groups show the steepest interdimensional gradient to be less steep than the flattest intradimensional gradient. Thus, the intradimensional training of the present study resulted in consistently steeper gradients than the interdimensional training.

Figure 2, portraying daily-session gradients of the two groups of Ss, illustrates that although the interdimensional gradient was initially less steep than the intradimensional gradient, the gradients of the two groups were quite similar at the end of five

Table 2

DIs for Individual Relative Gradients of First Daily Session

Intradimensional		Interdimensional	
Ss No.	DI	Ss No.	DI
1	0.356	5	0.017
7	0.580	8	0.020
6	0.046	4	0.014
3	0.102		

Table 3
Mean Response Rates Across Days

		Orientations								
		30 deg	45 deg	60 deg	75 deg	90 deg	105 deg	120 deg	135 deg	150 deg
Day 1	Intra	5.0	1.3	3.5	31.5	150.8	53.3	0.3	1.3	4.0
	Inter	45.7	37.3	45.0	109.7	130.0	111.3	43.0	19.0	63.7
Day 2	Intra	0.0	0.3	0.8	20.0	155.0	56.5	0.3	0.0	7.5
	Inter	7.3	2.0	5.0	80.0	135.3	97.3	6.3	1.0	3.0
Day 3	Intra	1.0	0.0	5.8	23.5	149.0	33.3	0.0	0.0	0.0
	Inter	0.7	9.0	11.0	71.7	154.0	95.3	2.0	2.0	12.0
Day 4	Intra	0.3	0.0	0.5	13.3	134.0	41.5	0.0	0.0	0.0
	Inter	0.7	0.3	21.0	70.3	139.0	100.3	1.3	1.0	3.7
Day 5	Intra	2.3	0.0	2.5	21.5	158.0	39.3	1.3	0.8	1.3
	Inter	0.0	0.0	0.3	24.7	139.0	51.3	0.3	0.3	0.0
Day 6	Intra	0.8	0.3	0.3	13.3	135.3	9.3	4.0	0.0	0.0
	Inter	0.0	0.0	0.0	44.3	159.0	50.0	0.0	0.3	0.0
Day 7	Intra	0.8	1.3	1.3	29.3	146.8	19.8	0.0	0.0	0.3
	Inter	0.3	0.0	0.0	12.7	169.7	10.7	0.0	0.0	0.3
Day 8	Intra	0.5	0.3	0.3	16.0	157.8	9.5	0.5	0.5	1.8
	Inter	0.0	0.0	0.0	12.7	139.0	19.7	0.0	0.0	0.0
Day 9	Intra	0.0	0.3	0.0	4.5	157.0	0.8	0.0	0.3	0.3
	Inter	0.3	0.0	0.0	19.3	167.7	8.3	0.0	0.0	1.3

Table 4

DI Values Across Days

	Relative	
	Intradimensional	Interdimensional
Day 1	0.110	0.017
Day 2	0.166	0.067
Day 3	0.231	0.069
Day 4	0.260	0.072
Day 5	0.213	0.203
Day 6	0.396	0.191
Day 7	0.271	0.585
Day 8	0.415	0.427
Day 9	1.092	0.475

days of testing. Mean number of responses to each orientation across daily sessions are provided in Table 3.

Though the stability of the gradients across days was not critical to the main question of the study, it was decided to continue daily sessions, within reasonable limits, until the gradients appeared to be fairly stable. There was no *a priori* basis for specifying the number of sessions that would be required; thus, the exact number of testing sessions to be given all Ss was decided, *post hoc*, on the basis of the test performance of the first two Ss. Consequently, testing was discontinued at the end of nine days for all Ss, since the gradients of the first two Ss appeared to have stabilized by the completion of nine testing sessions. The groups show fairly stable and comparable response rates across and within testing sessions. DI values for relative gradients based on the data in Fig. 2 are given in Table 4.

SUMMARY AND CONCLUSION

The major aim of the present study was to determine if object orientation can serve as a dimension for stimulus generalization. The dimensionality of object orientation would be demonstrated by a resultant gradient which exhibits the characteristic symmetric, decremental responding of stimulus generalization gradients. Following the possible demonstration of the dimensionality of this continuum, it seemed in order to compare the generalization function found for object orientation with the function which has typically been found for less complex continua.

Two groups were employed in this study, differing in the S^-'s employed during discrimination training. The data paramount to the determination of the dimensionality of the continuum were generated by the Ss which received discrimination training which explicitly made orientation of the three-dimensional object relevant for responding (intradimensional). The other group received training which has commonly been called interdimensional discrimination training.

The intradimensional gradient demonstrated the behavioral dimensionality of object orientation. The interdimensional gradient also displayed the systematic response decrement which has generally been seen in interdimensional gradients for less complex dimensions.

Although the present study demonstrated the behavioral dimensionality of object orientation, the question still remains as to the critical dimension relevant to responding differentially to rotation of a three-dimensional object. It seems investigation should now be centered on the simpler dimensions underlying this multidimensional stimulus. Perhaps more important than the findings regarding the dimensionality of object orientation is the fact that the study provides substantive evidence for the utility of the stimulus generalization paradigm as a tool for determining the extent to which other complex continua are of behavioral relevance. As was the case in this study, the behavioral relevance of a continuum would be evidenced by symmetric, decremental responding characteristic of stimulus generalization gradients. Conversely, the complete behavioral irrelevance of a continuum would be reflected by a flat generalization gradient.

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