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ABSTRACT

Children's performance on multidimensional classification tasks was examined in two experiments. In Experiment 1, preschool, first-, and third-grade children were shown a standard stimulus and were then asked to judge whether several comparison stimuli were the same as or different from the standard. Comparison stimuli differed from the standard on zero to four dimensions (form, orientation, size, brightness, or combinations of these dimensions). Most of the preschool and first-grade children based their judgments on a single dimension of difference, while multidimensional judgments predominated at the third-grade level. In Experiment 2, first-grade children were pretrained to make identity matches in response to the same-different classification instructions. A second classification task, with a different set of stimulus dimensions, was then presented. Identity pretraining failed to produce multidimensional responding on the second task. Verbal posttest indicated that the children were able to detect more than one set of dimensional differences. The results indicate that there are age-related differences in the number of dimensions children utilize in stimulus comparison. The unidimensional responding of younger children cannot be attributed to failure to understand the same-different instructions or inability to detect more than one set of dimensional differences. (Author/CS)

THE DEVELOPMENT OF MULTIDIMENSIONAL CLASSIFICATION IN CHILDREN[1,2]

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Developmental studies of stimulus classification have typically attempted to determine the specific dimensions (e.g., color vs. form) which are preferred as a function of age. In a majority of these investigations, a forced-choice procedure has been used, in which the subject matches stimuli on the basis of one dimension to the exclusion of another (Brian & Goodenough, 1929; Corah, 1964; Odom & Guzman, 1972; Suchman & Trabasso, 1966a). The effects of such dimensional preferences on problem-solving behavior have also been investigated. When preferred dimensions are relevant, concept acquisition is facilitated, relative to conditions where preferred dimensions are irrelevant (Mitler & Harris, 1969; Suchman & Trabasso, 1966b; Wolff, 1966).

The concept of hierarchies of dimensional salience has been proposed to relate assessed dimensional preferences and problem-solving performance (Odom & Guzman, 1970, 1972). Preference, as defined in the forced-choice paradigm, is taken as a measure of relative dimensional salience. Salience, in turn, is assumed to determine the order in which the dimensions of a problem are processed for solution.

Few aspects of dimensional hierarchies, other than the relative rank of specific dimensions, have been studied developmentally. The purpose of the present investigation was to determine if dimensional hierarchies vary in breadth as a function of age. Basic to this inquiry is the distinction between noticing and using a dimension (Trabasso & Bower, 1968, pp. 85-86). The set of dimensions which are effective in a problem-solving situation may constitute only a subset of the dimensions that a subject detects in a forced-choice assessment paradigm, a verbal-labeling procedure, etc. The present studies are concerned with the number of dimensions which are effective in a problem-solving context.

Developmental changes in the breadth of effective hierarchies would be expected to interact with specific dimensional preferences in determining age-related changes in the rate of concept acquisition. At ages where unidimensional hierarchies predominate, specific dimensional preferences should exert strong control over problem-solving behavior. At ages where multidimensional hierarchies are present, however, the salience of an individual dimension would be less effective as a predictor of problem-solving performance.

In the present investigation, the breadth of a subject's dimensional hierarchy was defined in terms of the number of dimensions he utilized in a multidimensional free-classification task. In such a task, the subject is asked to match a series of comparison stimuli to a standard. The comparison stimuli differ from the standard along zero to n dimensions. Since no differential reinforcement is given, the subject is free to match on the basis of one dimension only or a combination of two to n dimensions. It is assumed that the number of dimensions utilized in this situation would approximate the breadth of effective dimensional hierarchies in the initial trials of concept acquisition.

Two studies are reported. The purpose of Experiment I was to determine whether the number of dimensions used in free classification changes systematically as a function of age. Experiment II was designed to test alternative explanations for the developmental changes.

Experiment I

The breadth of dimensional patterns was examined for subjects of three developmental levels: preschool, first-, and third-grade. The generality of the patterns was assessed by requiring each subject to classify stimuli of two different types: letters and geometric forms.

Method

Subjects

Subjects included 48 grade-school children from the DeKalb Illinois, Public School System. The first-grade sample consisted of 11 males and 13 females, ranging in age from 6.5 to 7.7 years (mean age = 6.9 years). Thirteen male and 11 female third graders were included, ranging in age from 8.6 to 9.5 years (mean age = 9.0 years). Twenty-four preschool children were obtained from The Growing Place, a local preschool program. Fourteen males and 10 females were tested, ranging in age from 2.8 to 5.2 years (mean age = 4.3 years).

Materials

The stimuli consisted of a set of sixteen geometric forms and a set of sixteen letters. The form stimuli were composed of all possible combinations of four bi-valued dimensions, form (triangle, rectangle), orientation (vertical, 45 degree clockwise rotation), size (1.38 inches tall, 2.25 inches tall), and brightness (light gray, dark gray). The letter stimuli consisted of eight A's and eight H's varying similarly in orientation, size, and brightness. Each stimulus figure was centered on a white card measuring 4.25 by 5.5 inches. Form stimuli were solid figures; each segment of the letter stimuli was .25 inches thick to allow for manipulation of the brightness difference.

A deck of 160 form cards was generated for each subject by including ten instances of each of the sixteen form stimuli in a random order. A deck of 160 letter cards was similarly generated.

Additional materials included two 6.0 x 6.0 x 4.5 inch black boxes into which the cards were sorted and a 6.0 x 5.0 inch vertical card holder.

Procedure

Subjects were tested individually in a research trailer by a male experimenter. Testing began with the display of a standard stimulus on the card holder centrally located in front of the subject. The standard stimuli for form and letter classification were randomly selected for each subject from the sets of sixteen possible form and letter stimuli. The subject was then shown the deck of stimulus cards and was told that he should place stimuli that "look like" the standard in one box and stimuli that "do not look like" the standard in the second box. Sorting boxes were located 6.0 inches to either side of the card holder. The direction of classification (i.e., "looks like" in the left box vs. "looks like" in the right box) was counterbalanced between subjects. Each subject sorted both the form deck and the letter deck, with the order of stimulus type counterbalanced between subjects. No feedback was given in response to the subjects' classification behavior and no attempt was made to pace the rate of classification.

Results

The frequency with which each of the sixteen stimuli was judged to "look like" the standard was determined for each subject and each stimulus type. The scores were subjected to an analysis of variance which included the factors of grade, stimulus type, order of stimulus type, direction of classification, and stimuli. A .01 level of significance was adopted for all statistical tests.

The main effects for grades (F = 18.48, df = 2/60), stimulus type (F = 7.86, df = 1/60), and stimuli (F = 109.13, df = 15/900) were significant, as was the Grades x Stimuli interaction (F = 5.89, df = 30/900). No other effects attained statistical significance.

The main effect for stimulus type resulted from the fact that fewer stimuli were classified with the standard when forms were used than when letters were used, $\overline{X}$ = 3.529 and $\overline{X}$ = 3.872 for forms and letters, respectively.

The Grades x Stimuli interaction is best understood by examining the classification patterns of individual subjects. Patterns of classification were determined for each subject and each stimulus type by means of a series of likelihood ratio tests previously described by Croll (1970). Using a .01 level of significance, subjects were classified as responding uniquely on the basis of one dimension only (form (F), orientation (O), size (S), or brightness (B)), a combination of two dimensions (FO, FS, FB, OS, OB, or SB), a combination of three dimensions (FOS, FOB, FSB, or OSB), or all four dimensions (FOSB). Subjects who could not be uniquely classified were said to have inconsistent sorting patterns.

Table 1 presents the distribution of subjects across the five classification patterns for each grade and stimulus type. A 3(grades) x

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Insert Table 1 about here

5(patterns) χ^2 performed on these frequencies was significant for both the form and letter stimuli (χ^2 = 45.24, df = 8, and χ^2 = 32.80, df = 8, respectively). The major age-related changes occurred between the first and third grades. That is, the distribution of the third-grade subjects differed significantly from that of the first graders (χ^2 = 22.31, df = 4, for forms, and χ^2 =18.10, df = 4, for letters), whereas the performance of the first-grade and preschool subjects was not significantly different (χ^2 = 4.99, df = 4, and χ^2= 1.82, df = 4, for forms and letters, respectively). The frequencies of Inconsistent and 1-Dimensional patterns declined with age (χ^2 = 9.83, df = 2, for forms and χ^2= 9.26, df = 2, for letters). The frequencies of 3- and 4-Dimensional patterns increased with age (χ^2 = 9.30, df = 2, and χ^2 = 13.72, df = 2, for forms and letters, respectively).

Examination of the data for individuals also indicated that subjects differed in terms of the specific dimensions comprising their classification patterns. There were fifteen possible combinations of specific dimensions, but only a fraction of these combinations were used. Table 2 presents the distribution of subjects, for each grade and stimulus type, across the six dimensional combinations which were represented in the data. Examination

Insert Table 2 about here

of Table 2 indicates that the form dimension was included in a majority of the classification patterns at all grade levels. The size and brightness differences were utilized predominately by the 3- and 4-Dimensional responders at the third-grade level.

Discussion

The results of Experiment I indicate that there is an increase with age in the use of multidimensional patterns relative to unidimensional patterns. This result was consistent across both stimulus types: common geometric shapes and letters.

Such a change in classification patterns might occur for several reasons. First, studies of cognitive development (Caldwell & Hall, 1969; Lepine, 1965, 1966) indicate that there are age-related changes in the way children use relational terms. When children are asked to classify stimuli as to whether they "look like" or are the "same as" a standard stimulus, younger subjects may classify on the basis of a single dimension because "same" does not imply "identity" at this developmental period. In the present experiment, therefore, the developmental differences in breadth of classification may have resulted from age-related differences in response to the classification instructions (Hypothesis 1).

Alternative hypotheses can be derived from perceptual learning theory. That is, perceptual learning theory (Gibson, 1969) would predict that an older child will use more dimensions in classification than a younger child as a result of increased experience with the dimensional variations. Developmental differences observed in the present experiment may have resulted from the fact that younger subjects failed to detect some of the dimensional differences which were varied in the stimulus set (Hypothesis 2a). A perceptual learning hypothesis might also be stated in terms of differing degrees of perceptual learning. That is, perhaps children at all of the tested levels were able to detect differences in each of the dimensions, but the absolute levels of dimensional salience were greater for the older children. Such differences in absolute salience might account for older children using more of the dimensions that they detected (Hypothesis 2b).

Experiment II was a preliminary attempt to differentiate between these alternative explanations for the developmental differences observed in the present study.

Experiment II

The classification performance of first-grade children was examined as a function of instructional pretraining. One-half of the subjects were pretrained to use an identity criterion as the basis for making same-different judgments. The remaining subjects received no preliminary classification training. Both groups were then asked to classify a new set of stimuli using the free-classification procedure. Hypothesis 1, that younger subjects displayed unidimensional patterns as a result of instructional interpretation, would be supported by the finding of multidimensional classification following identity pretraining. A failure to find pretraining effects would be consistent with hypotheses derived from perceptual learning theory. According to this theory, prior experience with one set of stimulus dimensions would not be expected to affect subsequent performance with a different and unrelated set of dimensional variations. To differentiate between Hypotheses 2a and 2b, subjects were asked to verbally describe differences between the classification stimuli. If subjects could label more dimensions that they used in classification, failure to detect dimensional differences (Hypothesis 2a) would be discounted.

Method

Subjects

Subjects consisted of 24 first-grade children from the DeKalb, Illinois, Public School System. Nine males and fifteen females were tested, ranging in age from 6.0 to 7.0 years (mean age = 6.5 years). Twelve subjects were randomly assigned to each of two groups, identity pretraining and control.

Materials

Eight different stimulus figures were used during pretraining. Each figure consisted of an array of circles vertically centered on a 8.5 x 5.0 inch white card. The eight figures represented all possible combinations of three bi-valued dimensions, color of circles (red, green), number of circles (two, three), and pattern (presence vs. absence of a black grid imposed on the circles).

The stimuli used in free classification were identical to those of Experiment I with the exception that differences in brightness were omitted. A set of eight form stimuli was generated from all possible combinations of the size, orientation, and form values. Five instances of each of the form figures were arranged in a random order to produce a deck of forty form cards. A deck of forty letter cards was similarly generated.

Additional materials and apparatus included two classification boxes, a card holder, three Fischer-Price puzzles, and a Sony-Matic tape recorder, Model 104A.

Procedure

Pretraining. During identity pretraining, subjects were trained to call a comparison stimulus the "same as" the standard if and only if it was identical to the standard on all three dimensions of variation: color, number, and pattern. The subject was first shown the standard stimulus, a card containing two red, non-patterned circles, on a cardholder centrally located in front of the subject. Comparison stimuli were then presented beside the standard, one at a time. The subject was instructed to label the comparison stimulus as either the "same as" or "different from" the standard. Comparison stimuli were presented in a random order in blocks of ten, with each block containing eight comparisons which differed from the standard by one or more dimensions and two stimuli which were identical to the standard. Subjects received verbal feedback with respect to the correctness of their judgments. The pretraining procedure was continued until the subject correctly labeled twenty consecutive comparison stimuli.

No prior classification experience was provided in the control condition. Instead, each subject was given an opportunity to examine a set of puzzles during the first few minutes in the experimental setting.

Classification. In the second phase of the experiment, all subjects were required to classify a set of stimuli varying in form, orientation, and size. Testing began with the display of the standard stimulus, either a large, upright triangle for form classification, or a large, upright A for letter classification. The subject was then given a deck of stimulus cards and was told that he should place stimuli that were the "same as" the standard in one box and stimuli that were "different from" the standard in a second box. One-half of the subjects classified form stimuli and the remaining half classified letter stimuli. The direction of sorting was counterbalanced between subjects within groups.

Verbalization. Following free classification, each subject was asked a series of questions designed to elicit verbal descriptions of dimensions of variation. Each subject was shown two stimuli, the standard and a comparison stimulus differing from the standard along all three dimensions of variation. The questioning procedure began by asking the subject whether the two pictures were different, and if so, how they differed. Following answers to these questions, the experimenter asked if there were any other ways in which the two pictures differed. This probe procedure was continued until the subject indicated that he could detect no further differences. The questioning procedure was repeated for each subject with respect to two identical pictures (two copies of the standard). In this case, the subject was asked to describe the ways in which the two pictures were the same. The verbal interactions were tape-recorded for subsequent transcription and coding.

Results

Pretraining

All subjects met the pretraining criterion of twenty correct consecutive responses with ease. The mean number of errors per subject was 0.58 (SD = 0.79).

Classification

The frequency with which each of the eight stimuli was judged to be the "same as" the standard was determined for each subject. A 2 (groups) x 2 (stimulus types) x 2 (direction of classification) x 8 (stimuli) analysis of variance was subsequently performed on these scores. A .01 level of significance was adopted for all statistical tests.

Significant effects included the main effects for stimuli (F = 61.77, df = 7/112) and stimulus type (F = 47.85, df = 1/16), and the Stimuli x Stimulus Type interaction (F = 73.48, df = 7/112). The main effect for groups and all interactions with this factor failed to reach statistical significance.

To understand the Stimuli x Stimulus Type interaction, the responses of individual subjects were classified according to procedures described in Experiment I. Table 3 presents the number of subjects who used 1-Dimensional, 2-Dimensional, and 3-Dimensional classification patterns

Insert Table 3 about here

for each stimulus type. A 2 (stimulus types) x 3 (patterns) χ^2 analysis indicated that the frequencies of the classification patterns were not equally distributed across the stimulus types (χ^2 = 17.60, df = 4). This result was produced by the fact that unidimensional strategies predominated for the letter stimuli, whereas a majority of the subjects used 2-Dimensional patterns in classifying the form stimuli.

With respect to the specific dimensions comprising the classification patterns, all subjects with 1-Dimensional patterns used form differences as the basis of classification. All 2-Dimensional subjects used a combination of form and orientation differences. Size differences were used only by 3-Dimensional subjects with form stimuli.

Verbalization

The verbal protocol for each subject was coded for frequencies in the following descriptive categories: form (including references to number of sides or points in addition to the specific shape labels), orientation (including all references to direction of the figures, e.g., "slanting" vs. "straight"), size (relational size terms, e.g., "big" vs. "little"), and other (including references to function, color, and inaudible responses). Two dependent measures were abstracted from the coded protocols: (a) the first dimension which the subject described, and (b) the number of different dimensions described in the total verbal series.

With respect to the first dependent measure, 19 of the 24 subjects described the form dimension first. Thus, the verbal data are consistent with the classification data in suggesting that form differences were more salient than the differences in orientation or size. With respect to the second dependent measure, a comparison was made between the number of dimensions subjects used in classification and the number of dimensions they described during verbalization. For subjects who classified forms, the numbers of dimensions used in classification and in verbalization did not differ significantly, $\overline{X} = 2.33$ and $\overline{X} = 2.00$ for classification and verbalization, respectively ($t = 1.84$, $df = 22$). For subjects who classified letters, however, a significantly greater number of dimensions were verbally described than were used in classification, $\bar{X} = 1.17$ and $\bar{X} = 2.08$ for classification and verbalization, respectively ($t = 5.08$, $df = 22$). Thus, these subjects were able to detect more dimensions of difference than they utilized during classification.

Discussion

The results of Experiment II suggest that age-related shifts in the number of dimensions used in classification cannot be explained in terms of differing interpretations of the classification instructions (Hypothesis 1). Two aspects of the data support this conclusion. First, subjects given identity pretraining did not use more dimensions in subsequent free classification than subjects who received no instructional pretraining. Few subjects in either group classified the second stimulus set according to an identity criterion. Secondly, the small error rate during pretraining indicates that subjects of this age can use multi-dimensional strategies if the dimensional differences are sufficiently distinctive.

The verbalization data indicate that unidimensional classifiers were able to detect more dimensions of variation than they used in free classification. Thus, little support was obtained for Hypothesis 2a, that younger subjects failed to detect some of the dimensional differences in the stimulus set.

The disparity between Experiments I and II in terms of the number of first-grade children who used two dimensions during classification may have resulted from sampling differences or from several minor procedural differences between the two studies. For example, removal of the fourth dimension of difference in the second study may have altered the salience values of the remaining dimensions.

General Discussion

The results of Experiment I indicate that there is an increase with age in the breadth of dimensional hierarchies as measured by performance in a free-classification task. Unidimensional classification was the predominant pattern among preschool and first-grade subjects. A majority of the third-grade children displayed multidimensional patterns.

Such differences in the breadth of dimensional hierarchies would be expected to affect the rate at which subjects can acquire multidimensional concepts. Older subjects, using multidimensional hierarchies, should acquire such concepts more rapidly than younger subjects with unidimensional hierarchies. Results consistent with this prediction were obtained by Odom and Corbin (1973) in a multidimensional recall task. These authors reported that both first- and fourth-grade subjects would learn multi-dimensional problems with reinforcement, but a significantly greater number of trials were required by the first graders. In addition, differences in breadth of hierarchies should affect acquisition rate on problems where the most salient dimension is irrelevant to solution. A younger subject, whose effective hierarchy includes only his preferred dimension, should perform poorly relative to an older subject whose hierarchy includes multiple dimensions. Consistent with this prediction were the findings of Odom and Mumbauer (1971) who reported that irrelevance of the most salient dimension retarded the performance of first-grade subjects to a greater extent than third-grade subjects.

The finding of age-related changes in hierarchy breadth also has implications for quantitative models of concept acquisition. In the stimulus sampling model of Trabasso and Bower (1968), for example, a subject is assumed to sample $\underline{s}$ cues per trial (the focus sample) from the set of all possible problem cues. Acquisition rate is assumed to vary directly with the ratio of relevant cue weights to irrelevant cue weights within the focus sample. The present results indicate that the size of the focus sample, *s*, changes as a function of age. As a second example, the finding of age-related changes in hierarchy breadth indicates that different forms of Zeaman and House's stochastic model (1963) might be applicable at different developmental levels. That is, a one-look model may be sufficient to fit the concept acquisition data of preschool and first-grade subjects, whereas a *n*-look model would be more appropriate for the data of third-grade subjects.

Alternative explanations for the developmental change in hierarchy breadth were tested in Experiment II. Little support was obtained for the hypothesis that younger subjects displayed unidimensional patterns as a result of their interpretation of the classification instructions. Similarly, little support was obtained for the hypothesis that younger subjects failed to detect some of the dimensional variations. A more tenable hypothesis is one based upon age-related differences in absolute dimensional salience. Assume, first, that a subject's effective hierarchy is that set of dimensions with absolute salience greater than some threshold value, *T*. Secondly, assume that the salience of a dimension is an increasing function of the amount of experience a subject has had with variations along that dimension. Then, the size of the effective subset should increase with age across a variety of stimulus situations as a result of increased opportunities for perceptual learning.

To directly test the preceding hypothesis, it would be necessary to provide a measure of absolute dimensional salience. Forced-choice classification would not be appropriate, since this procedure provides data on the frequency of utilizing one dimension in opposition to another. In free classification, absolute and relative salience are confounded. One solution might be to conduct psychophysical scaling of individual dimensions with subjects of differing developmental levels (e.g. Gliner, Pick, Pick and Hales, 1969). If salience is a measure of a subject's sensitivity (Odom & Guzman, 1970, 1972), the finding that older subjects display finer discriminative capacity on a given dimension would be consistent with the assumption that the absolute salience of that dimension is greater for the older subjects. Scaled dimensions could then be used in multi-dimensional classification to determine if age-related differences in absolute salience produce age-related differences in hierarchy breadth.

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Footnotes

[1]Paper presented at a meeting of the Midwestern Psychological Association, Chicago, May, 1974.

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Table 1

Frequencies of the Five Classification Patterns

for each Grade and Stimulus Type

Pattern	Grades					
	Preschool		First		Third	
	Forms	Letters	Forms	Letters	Forms	Letters
Inconsistent	6	5	1	2	0	0
1-Dimensional	11	15	14	16	3	5
2-Dimensional	7	3	8	5	5	7
3-Dimensional	0	1	1	1	7	3
4-Dimensional	0	0	0	0	9	9

Table 2

Frequencies of Specific Dimensional Combinations

for each Grade and Stimulus Type

Combinations[a]	Grades					
	Preschool		First		Third	
	Forms	Letters	Forms	Letters	Forms	Letters
F	10	13	13	14	3	4
O	1	2	1	2	0	1
FO	6	3	8	5	4	4
FS	1	0	0	0	1	3
FOS	0	1	1	1	7	3
FOSB	0	0	0	0	9	9

[a]F, O, S, and B denote form, orientation, size and brightness, respectively.

Table 3

Frequencies of Classification Patterns

for each Stimulus Type

Pattern	Types	
	Forms	Letters
1-Dimensional	0	10
2-Dimensional	8	2
3-Dimensional	4	0

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Frequencies of Classification Patterns

for each Stimulus Type

Pattern	Types	
	Forms	Letters
1-Dimensional	0	10
2-Dimensional	8	2
3-Dimensional	4	0