Bulletin of the Psychonomic Society
1980, Vol. 15 (4), 221-224

Effects of redundancy on speeded classification of integral and nonintegral stimuli

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In three experiments, subjects sorted 32-card decks with four stimuli into two classes using one relevant dimension with four levels. Relative and absolute similarity of the stimuli was manipulated through different forms of redundancy with respect to a second dimension. With nonintegral dimensions (circle size and diameter angle), redundancy had no effect on performance. With integral dimensions, form of redundancy affected performance, but the effects depended on the stimulus dimensions (dot positions vs. value and chroma) and on the relevant dimension (value vs. chroma). Results suggest that performance in a speeded classification task with integral stimuli can be only partially explained in terms of interstimulus similarity.

Speed and accuracy in sorting multidimensional stimuli on a single relevant dimension depends on the structure of the stimulus set and the stimulus dimensions used. For some pairs of dimensions, redundant variation of an irrelevant dimension facilitates performance, and orthogonal variation interferes with performance. For other pairs, variation of an irrelevant dimension has no effect on performance (Garner & Felfoldy, 1970). Dimensions of the former type have been termed "integral," and those of the latter type have been termed "nonintegral" or "separable."

Garner (1974) suggests that integral stimuli are perceived in terms of similarity, whereas nonintegral stimuli are perceived primarily in terms of dimensional structure. In speeded classification, redundancy gains are observed with integral dimensions because redundancy improves the discriminability (decreases the similarity) of the stimuli, while orthogonal variation of an irrelevant dimension produces interference due to intraclass variability. With nonintegral dimensions there is neither a gain nor interference because the subject can selectively attend to a single dimension and filter out the irrelevant dimension.

Lockhead (1970, 1972) has expanded this notion by suggesting that integral stimuli are processed holistically and that similarity can be expressed as a euclidean distance between two stimuli in a psychological space. Absolute judgment experiments support this idea (Levy, 1973; Levy & Haggbloom, 1971; Lockhead, 1970; Monahan & Lockhead, 1977). Performance is best when hypothetical interstimulus distance (discriminability) is at a maximum. Lockhead and King (1977) also found that in speeded classification tasks with two stimuli, sorting time could be predicted from the psychological distance between the stimuli.

If stimulus similarity is an important determiner of performance in tasks using integral stimuli, then the distribution of stimuli in psychological space should also affect performance when a more complex classification task is used. For example, if subjects are required to sort several different stimuli into two classes, performance should be best when stimuli within the same class are similar and stimuli in different classes are relatively dissimilar. Since this task is probably more representative of classification responses in natural situations, it seems desirable to evaluate the general utility of the similarity model.

To test this hypothesis, we can require subjects to classify stimuli using a single relevant dimension, and we can manipulate stimulus similarity by introducing different forms of redundancy with respect to a second dimension. With integral dimensions, performance should depend on stimulus similarity; with nonintegral dimensions, neither the amount nor the form of redundancy should affect performance. These points are illustrated in Figure 1, in which four sets are shown schematically.

In the unidimensional set, there are four stimuli that vary systematically along one dimension, D_1. A second dimension, D_2, is present, but it does not vary, and the classification task involves sorting X_1 and X_2 into one class and X_3 and X_4 into another

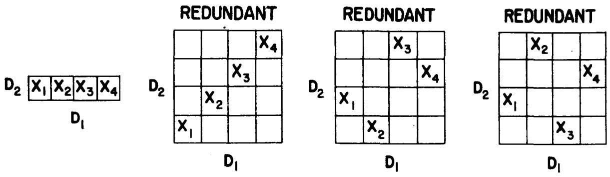

Figure 1. Dimensional structure of four types of stimulus sets.

This article is based on a paper presented at the 17th meeting of the Psychonomic Society, St. Louis, Missouri, November 1976. The authors wish to thank James R. Pomerantz and Gregory R. Lockhead for their valuable comments on an earlier version of this paper. Requests for reprints should be sent to the authors at the Department of Psychology, University of Maryland Baltimore County, Baltimore, Maryland 21228.

0090-5054/80/040221-04$00.65/0

class. This grouping task (Gottwald & Garner, 1972) provides a baseline against which to evaluate the effects of redundancy. This task is more difficult than a two-stimulus task (Garner & Felfoldy, 1970), presumably because there is intraclass stimulus variability.

In the linear redundant set, stimuli are selected such that the levels of D_1 and D_2 are perfectly correlated. In a number of absolute judgment studies, this form of redundancy has resulted in faster and more accurate stimulus identification than is obtained with nonredundant stimuli (Eriksen & Hake, 1955; Levy & Haggbloom, 1971; Lockhead, 1970). Lockhead (1972) suggests that the redundancy gain is due to the increased discriminability of the stimuli, and on that basis we would also predict improvement in the speeded classification task. If we assume psychologically equal intervals on both dimensions, then the interstimulus distances differ from those in the unidimensional condition by $\sqrt{2}$ units. The relative similarity of stimuli, however, is the same in the unidimensional and linear redundant sets because all distances are increased by the same factor. The ratio of mean intraclass distance to mean interclass distance is .5 for both sets.

In the third set, the form of redundancy is not linear. The stimuli represent the four corners of a rectangle in a stimulus space, with stimuli forming the short sides of the rectangle sorted together. Since intraclass stimulus similarity is the same, and interclass similarity is less for this set than for the previous set, we would expect a greater redundancy gain than in the previous condition. The ratio of mean intraclass distance to mean interclass distance for this condition is .47.

The fourth, or square, condition has been shown by Levy (1973), Levy and Haggbloom (1971), and Lockhead (1970) to produce excellent performance in absolute judgment tasks, presumably because of the high discriminability of the stimuli. In a classification task, however, we would predict poorer performance on this set than on the other redundant sets, because the intraclass similarity of stimuli is nearly identical to interclass similarity (i.e., the intraclass/interclass distance ratio is .83).

Three experiments were performed in which these three forms of redundancy and the unidimensional control condition were compared. In Experiment 1, both integral and nonintegral dimensions were used; in Experiments 2 and 3, only integral dimensions were included.

EXPERIMENT 1

Method

Subjects. Three male and five female volunteers served as subjects.

Stimuli. All stimuli were centered on 7.62 x 12.70 cm white unruled index cards.

For each condition, there was a deck of 32 cards with equal numbers of the four stimuli. The integral dimensions were the horizontal and vertical positions of a dot. A black dot .48 cm in diameter was located within a 4-cm square. The four levels of each dimension were 1 cm apart, measured from center to center of the dot. Horizontal position was the relevant dimension. For the unidimensional condition, the dots were centered at the midpoint of the vertical dimension.

The nonintegral dimensions were the size of a circle and the angle of its diameter. The relevant dimension was the size of the circle, with diameter values of 1.75, 2.22, 2.70, and 3.18 cm. Diameter angle had values of 135, 105, 75, and 45 deg. For the unidimensional condition, diameter angle was 135 deg.

Procedure. Subjects were instructed to sort each deck of cards into two piles as quickly as possible without making errors. For integral dimensions, dots on the left and dots on the right composed the two stimulus classes. For nonintegral dimensions, the two smaller circles and the two larger circles were sorted together. Sorting time was measured to the nearest .1 sec with a Beauwyn stopwatch; sorting errors were counted, but no feedback was given.

The subject was given one practice trial and three test trials on each of the eight decks. The order of presentation of the decks was varied systematically across subjects and trials.

The experimental design was a repeated-measures factorial with two types of dimension, four types of stimulus set, and three trials.

Results

The number of sorting errors was too small to analyze. For the integral dimensions, mean sorting times for the conditions shown in Figure 1 were 18.76, 17.45, 17.45, and 18.58 sec, respectively. For the nonintegral dimensions, the means were 17.68, 17.82, 17.33, and 17.09 sec. Analysis of these sorting times revealed significant differences among the four types of stimulus set [$F(3,21) = 3.54$, $p < .05$] and an interaction between dimensions and stimulus sets [$F(3,21) = 10.33$, $p < .001$]. As predicted, there were significant redundancy effects for the integral dimensions [$F(3,21) = 7.79$, $p < .01$], but none for the nonintegral dimensions. Sorting time was greater for the unidimensional and square redundant sets than for the others [$F(1,21) = 23.12$, $p < .001$], but there was no difference between the unidimensional and square sets or between the linear and rectangular sets.

Discussion

For nonintegral stimuli, redundancy had no effect on speed of classification. For integral stimuli, there were redundancy gains in two conditions, but the pattern of results did not conform well to predictions. The predicted difference between the linear and rectangular conditions was not obtained, and the square condition was not more difficult than the unidimensional condition, even though the distance ratio was greater (.83 vs. .50).

Since the dimensions of the integral stimuli were horizontal and vertical position, it is possible that subjects focused on only one portion of the stimulus and sorted on a dot-present vs. dot-absent basis. Such a focusing strategy could provide an ad hoc explanation for the results obtained. To eliminate such focusing strategies, Experiments 2 and 3 repeated the conditions of Experiment 1, using the integral dimensions of value and chroma of a color chip. In addition, we ran the four conditions twice: once with chroma relevant and once with value relevant.

EXPERIMENT 2

Method

Subjects. One male and seven female volunteers served as subjects.

Stimuli. The stimuli were 1.90-cm-square chips of matte finish Munsell paper (Hue 5R) mounted on 5.72 x 8.89 cm pieces of three-ply white Bristol board. The chips were placed 1.90 cm from the top and side edges of the card. For the unidimensional set with chroma relevant, the stimuli, in Munsell notation, were 5/2, 5/4, 5/6, and 5/8; with value relevant, the stimuli were 4/6, 5/6, 6/6, and 7/6. For the redundant conditions, stimuli were selected by combining Chromas 2, 4, 6, and 8 with Values 4, 5, 6, 7 according to the schemes in Figure 1.

Procedure. For each deck of 32 cards, there was a display showing which two stimuli were to be sorted into each class. Except for the presence of this display, procedures were identical to those used in Experiment 1. The order of the eight decks was varied systematically across subjects and trials, with value and chroma conditions alternating, and with the restriction that two identical decks could not occur in succession.

Results

The error rate for Experiment 2 was 1.3%; the majority of the errors (72.5%) were made in the unidimensional conditions. Mean sorting times for the four conditions with chroma relevant were 24.94, 21.20, 17.98, and 20.94 sec. With value relevant, the means were 22.70, 21.05, 18.07, and 18.54 sec. Sorting times were longer for chroma than for value [$F(1,7) = 21.77$, $p < .001$]. There was also a significant effect for stimulus sets [$F(3,21) = 18.25$, $p < .001$] and an interaction between dimensions and stimulus sets [$F(3,21) = 5.75$, $p < .01$].

Although the simple effect of sets was significant for both dimensions, and the three redundant sets were sorted faster than the unidimensional set for both dimensions, the difficulty of the square set depended on which dimension was relevant. When chroma was relevant, the square set did not differ from the linear set, and these in turn took longer to sort than the rectangular set. When value was relevant, the square set did not differ from the rectangular set, and both took less time to sort than the linear set.

Experiment 3 replicated Experiment 2, with two methodological changes. Since subjects in Experiment 2 had sorted all eight decks of cards three times each, and since the square conditions required the subject to sort the same stimuli into different classes depending on the relevant dimension, we were concerned about the possible effects of response competition across decks (Hodge, 1959). In Experiment 3, half of the subjects sorted the four decks with chroma relevant, and half sorted the decks with value relevant.

EXPERIMENT 3

Method

Subjects. Eight male and eight female volunteers served as subjects.

Stimuli. The stimuli were the same as in Experiment 2.

Procedure. Procedures were the same as in Experiment 2 except that a given subject sorted only four decks. There was one practice trial and five test trials.

Results

The error rate was only 1.6%; 70.8% of these errors were made in the unidimensional conditions. Mean sorting times for each condition were 28.79, 22.72, 19.45, and 22.84 sec when chroma was relevant and 24.78, 22.95, 19.18, and 20.53 sec when value was relevant. There were significant differences due to stimulus set [$F(3,42) = 40.45$, $p < .001$] and an interaction between stimulus sets and dimensions [$F(3,42) = 3.96$, $p < .025$]. The simple effects of stimulus set for each dimension and the comparisons among stimulus sets within each dimension exactly replicated the effects obtained in Experiment 2; however, there was a significant effect of trials [$F(4,56) = 8.01$, $p < .001$] and an interaction between dimensions and trials [$F(4,56) = 4.26$, $p < .01$], resulting from a practice effect when value was the relevant dimension.

Discussion

In Experiments 2 and 3 the redundant conditions were sorted faster than the unidimensional with the form of redundancy also affecting sorting time. The predicted difference between the linear and rectangular redundant sets was obtained. Thus, the absence of this effect in Experiment 1 may well have been due to subjects' focusing on one portion of the stimulus.

The results for the square sets in Experiments 2 and 3 are more difficult to interpret. In spite of the unfavorable distance ratio of .83, there was a redundancy gain in the square condition, and the difficulty of this set depended on which dimension was relevant. This effect does not appear to have been a function of response competition in Experiment 2, since the same result was obtained in Experiment 3. If sorting time is primarily a function of interstimulus similarity, and if the schematic representations of the stimulus space in Figure 1 are accurate, then it is difficult to explain why changing the relevant dimension has such a strong effect on performance.

There is a strong possibility, however, that the subjective similarity of the stimuli is not well represented by the schematic diagrams in Figure 1. Calculations of interstimulus distance were based on the assumption that stimuli were evenly and equally spaced on both dimensions. However, sorting time was faster when value was relevant, and this suggests that the subjective intervals were larger for value than for chroma. If so, this would have an effect on the subjective similarity of all pairs of stimuli. Also, we have assumed no interaction between the stimulus dimensions; that is, subjective intervals on one dimension are independent of the level of the other dimension. But data presented by Krantz and Tversky (1975) and by Wiener-Ehrlich (1978) strongly suggest that such interactions do occur with integral stimulus dimensions. Therefore, in order to more appropriately evaluate the role of stimulus similarity in the classification task, we conducted a small scaling study to derive an independent measure of the subjective similarity of all pairs of stimuli used in Experiments 2 and 3.

SCALING STUDY

Method

Subjects. Three male and eight female volunteers served as subjects.

Stimuli. The stimuli were 66 pairs of Munsell color chips, each 1.90 cm square, which were mounted with their centers 2.54 cm apart on 5.72 x 8.89 cm pieces of three-ply Bristol board.

Procedure. Subjects judged the similarity of each pair twice, using a rating scale from 1 to 7.

Results

The mean ratings for each pair were scaled using the

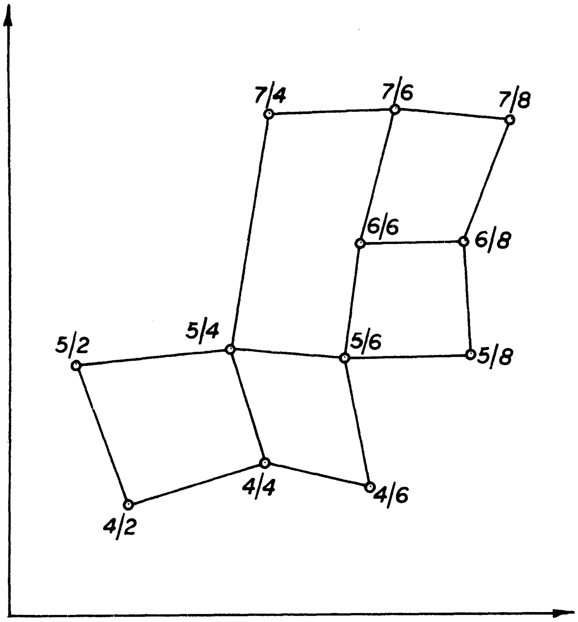

Figure 2. Multidimensional scaling solution for 12 Munsell colors.

nonmetric procedure of Johnson (1973). The obtained two-dimensional configuration is shown in Figure 2. Although the Munsell structure of the stimulus set is clearly discernible, there is evidence of dimensional interaction; intervals on the chroma dimension change across the levels of value and vice versa. The interstimulus distances derived from the scaling solution resulted in the following distance ratios for the various conditions: unidimensional, value, .55; unidimensional, chroma, .56; linear, .53; rectangular, .49; square, value, .81; and square, chroma, .85.

GENERAL DISCUSSION

Although we had assumed that the average similarity of intraclass and interclass stimulus pairs would be an important determiner of performance, the results only partially support that hypothesis. For the unidimensional, linear, and rectangular conditions, the results of Experiments 2 and 3 are compatible with the hypothesis that sorting time is faster when the distance ratio is small. Also, a comparison of the two square redundant conditions reveals that when value is relevant, the distance ratio is lower than when chroma is relevant. Thus, although the distance ratio does permit a number of valid predictions to be made about relative sorting times, the results for the square condition raise questions about its general usefulness. Although the distance ratios for the square conditions are much higher than for other conditions, performance is at worst equal to that in the linear condition.

Since other investigators have found that performance on identification tasks is very good in the square condition (Levy, 1973; Levy & Haggbloom, 1971; Lockhead, 1970), it is possible that a rapid stimulus identification process facilitates performance enough to offset the negative effects of the unfavorable distance ratio. It is also possible that if the stimuli are sufficiently discriminable, subjects will verbally label them and will classify them using verbal rules. Indeed, many of our subjects reported adopting this strategy. We would therefore expect stimulus similarity to be most strongly related to performance when the stimuli cannot be reliably coded.

In summary, the results of these studies suggest that performance in a speeded classification task with integral stimuli can be only partially explained in terms of the similarity structure of the stimulus set. If subjects can adopt special strategies such as focusing or verbal encoding, results predicted on the basis of interstimulus similarity may not be obtained.

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(Received for publication January 16, 1980.)