THE ROLE OF REDUNDANCY IN THE DISCRIMINATION
OF VISUAL FORMS

DISSERTATION

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Introduction

The history of investigations of how visual patterns are discriminated is a long one. It goes back at least as far as Fechner. When his interest turned to aesthetics about 1865, Fechner attempted to determine the important visual aspects of pattern and form in art by means of what we might now call a public opinion poll (18). In 1876 he discussed factors which determined preference for geometrical shapes (7).

Helmholtz, in his fundamental theory of perception, held that the sensory pattern of a stimulus impinging upon the sense organ does not account, by itself, for an introspective report by the subject of what is perceived. Rather, correctly perceived objects are a function of both sensory patterns and past experience (7). The emphasis upon past experience is suggestive of the approach to perception taken by many current workers.

Wundt emphasized both the importance of elementary visual sensations and the meaning given to these sensations by previously experienced associations (77).

From these beginnings various theories of form perception took shape. An empiristic theory emphasized the mosaic reception of stimuli (75). A nativistic theory regarded the organization of visual stimuli as an innate process (7). A relation theory proposed by Spearman (76) emphasized the perception of relations within a form as an important factor in the discriminability of that form. Gestalt theory proposed an interacting dynamic field which was affected by central factors. To the Gestalt psychologist the whole pattern was a more realistic perceptual unit than was a detailed part of that pattern (75). Perception has also been considered a kind of response. This theory emphasizes the effects on perception of such central factors as set and meaning (76).

Hebb has proposed a neuropsychological theory which emphasizes the central factors of attention. The important aspect of attention, according to Hebb, is that it "modifies the action of a stimulus." In opposition to Gestalt theory Hebb postulates that the excitation of specific cells at some point in the nervous system is more crucial to the problem of perception than is any postulation about a pattern of excitation whose locus is indeterminate. One of Hebb's

primary contentions is that Gestalt theory's wholistic view of perception, in reality, can be explained in terms of a rapid surveillance of parts of a stimulus. The skill of perceiving parts rapidly is learned early in life and its process remains, for the most part, undetected by the observer (30).

These theories have been suggestive in promoting specific approaches to the study of visual pattern discrimination. They have served also to point out deficiencies in other concepts. In general, however, we may agree with Graham that "...close examination of the many theories advanced reveals that they do not usually specify test operations and that, very often, the number of facts explained is no greater than the number of assumptions made. Theories exhibiting these deficiencies may be of interest for other reasons, but they are not a satisfactory stopping place in scientific progress" (26).

Despite inadequacies in theories of perception, research on this topic has contributed greatly to the present store of knowledge about the discrimination of visual form. Schuman, for example, noted certain principles of unit formation in the visual field such as subjective contour and the shifting of perceptual

groups in complex dot patterns (31). Benussi (76) demonstrated the importance of attitudes on the perception of form, especially the effects of analytical attitudes as opposed to totalizing attitudes. Rubin (67) demonstrated the importance of figure and ground. Hanawalt (27) showed the facilitating effects of past experience in finding camouflaged figures. Carmichael and associates (12) demonstrated the influence of suggestion on the reproduction of named figures. The latter results support Bartlett's notion that forms are remembered by the subject making an "effort after meaning" (3). When stimuli which are to be reproduced are not very meaningful, subjects have been found using "schema with correction" (76).

More recently Bruner and Postman (10) have shown the effects of value and need as organizing factors in perception. Poor children made larger overestimations of size of discs resembling coins than did rich children. Carter and Schooler (13) in a similar study supported further the notion that personal values assigned to stimuli affect the perception of the stimuli, provided the original value-stimulus is not present when estimates of coin size are made. Other recent studies have also indicated that perception is a

function of reinforced and non-reinforced experience (48), of reward and punishment (64), and of need intensity (50). Frenkel-Brunswick (21) has suggested that personality variables such as tolerance for authoritarian control and intolerance for ambiguity are factors which affect visual perception.

Other investigators not interested in personal, social, and emotional aspects of perception have suggested neurological variables which affect discrimination of visual patterns. Householder's (37) theoretical speculations of the neural structure in perception and response suggest, among other things, that a block or a delay in making a response to a particular stimulus pattern may be a function of conflicting neural impulses preventing the firing of appropriate neurons needed to make a correct response. Krus, Werner and Wapner (45) have proposed that the availability of an outlet for nervous energy affects a response so that non-availability of an outlet results in an increased number of responses of perceived movement in a stimulus while availability of an outlet results in a decreased number of responses of perceived movement. Orbison (59) has provided experimental data to support the gestalt notion that central electrical vector fields affect the

perceived shape of phi movement that has been induced by flashing lights. Sickles (70) has presented a discussion which, by analogy between properties of electrical fields and psychological processes, has attempted to explain psychological geometry.

Where investigation has been directed less toward the motivational and neurological aspects of the individual and more to the characteristics of the stimulus itself other factors which affect the discrimination of visual forms have had to be considered. The geometry of shape has been taken as a basic starting point by a number of studies. The most formal system was that of Birkhoff (6). He developed a quantitative measure of aesthetic value which treats only the formal or geometrical properties of form. He thought that aesthetic experience is determined by the ordered relations in an object. He expressed this ordered relation mathematically by the equation $M=O/C$ where M is the aesthetic value, O the order, and C the complexity. He specified O and C for a series of polygons and derived their aesthetic measure. However, Birkhoff's approach did not fare well in the light of later studies.

Davis (16) reported no correlation between the aesthetic measure of form and the average rank assigned

to the forms by two groups of subjects. Harsh, Beebe-Center and Beebe-Center (28) attempted to isolate "differential factors" or "principles of judgment" by means of factor analysis. Thirty subjects ranked 26 forms selected from the entire range of values as given by Birkhoff's formula. Forms which possessed possibilities of meaning or common associations, such as stars and crosses, were eliminated. Four common factors were found which were of importance in making judgments. In order of importance the factors found were 1) smoothness of contour, or complexity of design within a simple outline, 2) symmetry, 3) simplicity and regularity and, 4) presence of odd points.

Casperson (15) carried out a study on geometric forms in which he compared the effect on visual discrimination of such parameters as area, maximum dimension, and perimeter. In general he found that perimeter was best for the identification of 30 geometrical forms such as ellipses, diamonds, triangles, rectangles, crosses, and stars. Sleight (72) using a sorting task found that the most common geometrical forms such as a triangle, hexagon etc. were not the most easily sorted figures. The best figures were a swastika, circle, crescent, cross and star.

It is not uncommon to find meaning giving weight to the discriminability of figures. Bakay and Sciller (1) found that subjects would manipulate figures until they were in such a position that they appeared mechanically stable, and would seldom place them in a position where they appeared top heavy. Barnhart (2) investigated the criteria used in preferential judgments of geometrical forms. He found that while subjects could not agree very well in their individual evaluations of figures they all made use of such criteria as the formal characteristics of the figure, the connotative or associative meaning of the figure, and / or the potentialities for use of the figure design in such contexts as textiles and tile.

A somewhat indirect but rewarding approach to the problem of how visual forms are discriminated is one that takes into account the relation of decision time to the categories of response. Cartwright (14) hit on this approach in 1941. He found an increase in response time as the number of categories increased and as the end points of two different categories overlapped or became similar. Among his stimuli were angles and words. Hochberg and McAlister (36), using Kopferman cubes found "...that the probability of a given perceptual

response to a stimulus is an inverse function of the amount of information required to define the pattern". The information required to define a pattern in this experiment consisted of specifying the stimulus characteristics in terms of the number of line segments, angles, and points of intersection.

Frequency of occurrence of a stimulus has been cited as an important determinant of the discrimination of visual forms. Howes and Solomon (39) have demonstrated that the visual duration threshold of a word is a function of the probability of occurrence of that word. Braly (8), Henle (32), and others have also pointed to the influence of past experience as a determinant of visual form perception. Increased experience with a stimulus, such as a letter, inhibited its correct mirror-image reproduction in comparison with the reproductions of nonsense forms (32).

In order to analyze how form or pattern is perceived, most early investigators have used techniques which involved a qualitative assessment of the subjects' responses. Some have attempted to slow down the perceiving process in order that they could study the cogent variable in either the stimulus-object or the subject. For example, Philippe (76) presented figures

tactually instead of visually. The subject then had to indicate the object shape by drawing it. Other investigators did not allow sufficient time for complete learning or else have used a complex collection of figures. Kuhlmann (47) allowed 10 minutes for learning five to nine figures and had subjects report verbally on the shape of the figures. Judd and Cowling (41) presented a complex figure for 10 seconds and exposed it repeatedly for this time interval until the subject could reproduce the figure accurately. Piéron (61) using a similar procedure allowed five seconds for exposure. Fehrer (19), using the same procedure repeatedly exposed her stimuli for only a fraction of a second. Gibson (23) exposed many figures at once for 1.5 second intervals until subjects made accurate reproductions.

These investigators generally agreed that unless a form had meaning it could not be described very precisely. The stimuli could be put into some rank order but little could be said about the physical or psychological characteristics that most affected discriminability.

To study perception precisely certain questions must be asked. For example, "...within what limits do

stimuli arranged according to a given numerical classification ... elicit 'number' responses that meet certain criteria of classification ? ...In what manner are certain changes in stimulus configuration associated with a change in response ? ...What change on a stimulus dimension is required to produce a change in response ?" (26).

Stimulus-response relations found in a perception experiment stem in large measure from the experimental methods used. Different investigators usually have approached the problem with methods that are most sensitive to their particular theoretical biases or points of view. For example, those who are interested in the effects of personal values, needs, and motivation upon perception have used relatively ambiguous stimuli (50) (12) (58) (66). The relative lack of structure permits the maximum activation of predictions and the results of past experience to affect the report of what is perceived. Lack of structure may be found, for instance, in the presentation of vague stimuli (66) or the presentation of stimuli under impoverished viewing conditions (53).

Those who are interested in determining a strict psychophysical relation between stimuli and response

will minimize the affect of such variables as personal values, needs, and motivation by rigorously structuring the situation so that only the stimulus variables under consideration will account for the major part of the experimental variance. There are a number of ambiguous situations in which the stimulus variables can be shown to be more significant than organismic variables such as sensory threshold or set (35) (68). It is in this realm where the effects of the stimulus variables on the human organism are emphasized and the organismic variables are somewhat minimized that the present investigation concentrates its efforts.

An attempt is made to study the problems of discrimination utilizing a relatively new theoretical model. The conceptual basis for the theory stems from information theory. These concepts have been applied in a number of recent psychological investigations. They have been used in studies of reaction time (33) (40), for obtaining scales of absolute judgment (22), in estimating rates of handling information (56), in examining the information content of questions (4), in studying the sequential variability of behavior (55), and in testing new concepts which can make contributions to perceptual theory (65). It has also been pointed

out that the techniques involved in information theory are applicable to the analysis of human thinking (25), to the analysis of concept formation (38) (73) and to the determination of the most efficient coding of stimuli that must be presented to and interpreted by a human operator (71) or that must be sent through some electro-mechanical system (69). In the present instance the writer hopes that these new concepts will be profitable in suggesting enlightening interpretations of perceptual phenomena in a visual discrimination situation.

Information Theory and the Problem

The basic concepts of information theory revolve about the total number of alternatives (stimuli) that can be produced by a source and the frequency with which each of these alternatives appears. Thus a perceived stimulus conveys information in terms of the stimuli which could have but did not appear. The unit of information is an index which when plotted against some dependent criterion variable can give a measure of the effect of context. Context in this instance is not the kind of spatial context involved in figure - ground relations nor even the specific effects of preceding stimuli in a time series. It is a probability concept, the set or expectancy of the subject with regard to what can or what is likely to happen. Context can be considered a parameter which is defined by the total number of alternative stimuli and / or responses that are available to a subject in any particular experimental situation. The parameter may be either theoretical or actual. Information analysis has the advantage of permitting the experimenter to compare the effectiveness of responses that are dependent upon different psychological or physical contexts. It is also possible, as this study

will show, to investigate the effects on discrimination of various physical changes in the characteristics of a visual stimulus while this stimulus parameter is held constant.

The present investigation undertakes a systematic study of the role of redundancy in the discrimination of visual patterns. The thesis to be investigated is that discrimination time varies as a function of the amount of redundancy in a stimulus. If the human subject is considered the destination of a message sent via some communication channel then it is possible to think of certain interfering forces acting upon a message and changing it somewhat before it reaches the subject.

Changes in a message that occur so as to make the ratio of the probability of the message sent to the probability of the message received different from unity defines noise in a statistical sense.

Messages may be distorted by noise variables such as viewing stimuli from different angles, viewing stimuli of different sizes, eye movements, and the erratic selection of eye-fixation points, as well as physical distortions impinging upon the stimuli.

The subject himself can also be considered as a communication channel. In this case organismic and

motivational variables, such as quotidian variability, warm-up effects, mood, set, state of mind, and bodily needs can be considered as sources of noise.

It has been pointed out elsewhere that the most effective means of overcoming distortions introduced by noise in a communication channel is to introduce redundancy (54) (69). The present investigation explores the applicability of this generalization to human perceptual behavior.

Redundancy

Redundancy, in its technical sense, is defined by the equation $R = 1 - H/H_m$, where H is the amount of information actually transmitted by the occurrence of one of a set of possible symbols (or stimuli) and H_m is the maximum amount of information that could have been transmitted. The ratio H/H_m is a measure of uncertainty; it represents the relative entropy of a system. There is a direct relation between uncertainty and information; an increase in one is reflected in an increase in the other. The more uncertain is the occurrence of any one of a set of symbols, the more information is conveyed when a symbol appears. Maximum

uncertainty is achieved when all symbols in a given source can appear with equal probability. If a letter A were to appear with a probability of .90 while a letter B were to appear with a probability of .10, we would be right more often than wrong if we consistently said A was going to appear. But knowing that A was going to appear so much more frequently than B we would not be getting as much information from the appearance of A as we would if both A and B were each to appear with a probability of .50. This illustrates the point that more information is conveyed by symbols that appear with equal probability. The H_m in the foregoing ratio represents the maximum information that can be carried by the appearance of one of several equally probable symbols. H is something less than this in a redundant sequence. It can be seen quite easily that when $H = H_m$, the ratio is equal to one and, consequently, there is no redundancy. Redundancy appears only as the ratio H/H_m becomes less than one.

Stated in another way, redundancy is present when more symbols are used to encode a message than are theoretically necessary. In terms of the visual patterns that are used as stimuli in the present study, a redundant figure contains more physical features than are

needed to identify it perfectly in a noiseless situation. It is proposed to investigate the thesis that in certain situations redundancy enhances the reliability of discrimination. This increased probability of discrimination may be achieved at the expense of time (or space). For example, to insure the receipt of a spoken message, the message may be said twice or it may be said in two different ways. With repetition it is more certain that a message will get to its destination correctly. Two different messages could have been transmitted in the same unit of time thus conveying more information. If this were done, however, an unknown error occurring in the transmission of the message would be difficult if not impossible to detect. In this example the difficulty of detecting an error would also depend to some extent upon the redundancy introduced by the sequential probabilities inherent in the structure of the message. Redundancy, then, can be viewed as a means for reducing error. This has been its primary function in communication theory. It is possible, however, to think of redundancy as a means for reducing discrimination time. This may be brought about in an experiment where subjects are instructed to minimize their errors. In a situation in which errors are already minimized, redun-

dancy should be effective in reducing discrimination time.

Redundancy may be introduced spatially or temporally. Spatial redundancy would appear to be more effective than temporal redundancy where concern is with visual presentation of stimuli since vision is primarily a spatial sense.

The question arises what is the best way to make visual stimuli spatially redundant. This question has been answered partially in an experiment by Rappaport, Adams and Fitts (65). In this experiment they made figures redundant in two ways. One way was to make figures symmetrical. This was accomplished by reproducing a figure in its mirror-image form. Another form of redundancy was introduced by allowing the top contour of a black figure to appear in the white background at the bottom of the figure. This arrangement produced an asymmetrical form of redundancy. Redundancy was present since a subject needed to look at only one half of a figure in order to discriminate it correctly from any other figure which appeared with it in the same context. The results of this study clearly indicated that figures with symmetrical redundancy are more easily discriminated than are figures with asymmetrical redundancy. The fact

that symmetrical figures are discriminated more readily than asymmetrical figures is consistent with the findings of other studies. French found that ease of identification of dot patterns was clearly shown for dots arranged symmetrically (20). Perkins found that symmetrical figures were recalled more readily than were asymmetrical figures (60).

The present study was planned to test further the effects of type of redundancy upon the discrimination of visual patterns. It also attempts to determine the degree of redundancy that allows discrimination to take place optimally.

Experiment 1. The Role of Redundancy in the Discrimination of Visual Forms

The first experiment is concerned with the effects on discrimination of systematic increases in the redundancy of two types of visual patterns. According to the logic set forth in the previous section it is hypothesized that redundancy will facilitate discrimination of visual forms.

It is expected that the hypothesis will be supported, providing internal noise such as could arise from variations in motivation, erratic eye movements, and warm-up effects intrude sufficiently to prevent optimum discriminatory behavior.

All of the stimuli employed in the first experiment were symmetrical about their vertical axes (left-right symmetry). In an earlier study (65) employing a sorting task it was found that symmetrical figures not only were sorted more easily than were asymmetrical figures but that figures which were symmetrical about their vertical axes (left-right symmetry) were more quickly sorted than were figures which were symmetrical about their horizontal axes (up-down symmetry).

The task chosen for use as a test of discrimination was a modification of the sorting task studied by Rappaport et. al. (65). In this task the subject searches through successive rows of figures and selects one figure in each row.

Method

Stimuli. The stimulus material consisted of figures having the general appearance of a histogram. The sample of eight figures used in the study were selected at random from a population of 24 figures. The parent population consisted of all figures that can be constructed by drawing four bars such that a bar is one of four lengths and all bars are of a different length. The matrix used to generate figures is shown in Figure 1A. A representative figure is shown in Figure 1B. There are $4!$ or 24 possible figures that can be generated from this matrix. In terms of information analysis the presentation of one of these 24 figures can convey a maximum of 4.58 bits of information on the average. The maximum information that can be conveyed by a figure in which each bar could be any one of four lengths is eight bits of information. Thus the basic figure is 42.75 per cent redundant.

4X4 MATRIX

A

4X4 FIGURE

B

Figure 1. A Shows the Figure Matrix. B Shows a Representative Basic Figure.

4X8 MATRIX

A

4X8 FIGURE

B

Figure 2. A Shows the Figure Matrix. B Shows a Representative Symmetrical Figure.

Symmetry was introduced by a procedure which made it possible to hold area constant. The 4X4 matrix was changed to a 4X8 matrix as seen in Figure 2A by dividing each row of the matrix into twice as many categories while holding the lengths of the row constant. Bars which previously had been drawn to the right only were drawn to the left and right of a mid-line. This process generates figures which are symmetrical about their vertical axes (left-right symmetry). The information in this symmetrical figure remains 4.58 bits while its maximum possible information becomes 16 bits. Only the redundancy value changes (see Figure 2B).

All figures are drawn in an area that is two centimeters square.

The effects on discrimination of systematic increases in redundancy in two types of redundant figures were investigated. Each figure was reproduced and extended by some fraction of its original design. Redundancy was introduced in five steps. Step one (4 bars) is the basic figure. Step two (6 bars) is the basic figure with two of its bars replicated. Step three (8 bars) is the basic figure with all four of its Bars replicated. Step four (12 bars) represents the bar pattern of the basic figure repeated three times. Step five (16 bars)

represents the bar lengths of the basic figure repeated four times.

This procedure is carried out for two types of redundancy, congruent and mirror-image. Congruent redundancy consists of a sequential repetition of the basic visual pattern; thus, if a basic pattern consists of bar lengths of four, one, three, and two units, then congruent redundancy is introduced by repeating the pattern 413241324132... etc. Mirror-image redundancy consists of the repetition of bar lengths so that the basic figure is repeated in a reversed order; thus, if a pattern consists of bar lengths of the order 4132, mirror-image redundancy is introduced by such a pattern as 413223144132...etc. The five steps for congruent redundancy are shown in Figure 3. In Figure 4 are shown the five steps for mirror-image redundancy. The redundancy values of the five steps are, respectively, 71%, 81%, 86%, 91%, and 93%. These values, it will be recalled, are obtained from the formula $R = 1 - H/H_m$.

Subjects. Twenty-one senior college students were used as subjects (15 male, 6 female).

Figure 3. Five Steps of Congruent Redundancy for the Stimuli in Figure Sample 1.

Figure 4. Five Steps of Mirror-Image Redundancy for the Stimuli in Figure Sample 1.

Procedure

Experimental Design. Repeated measurements under all conditions were taken on the same twenty-one subjects. The order of the ten experimental conditions were assigned randomly to subjects. The first five experimental conditions were mirror-image figures with 71%, 81%, 86%, 91%, and 93% redundancy. The second five experimental conditions were congruent figures with the same five steps of redundancy. Each subject had five experimental sessions. A session consisted of two conditions. Each condition was repeated three consecutive times on the day it was given. Conditions, trials, and order of presentation of stimuli were randomized for each subject. Quotidian variability is thus considered an extraneous factor that is distributed randomly among treatments.

Each sub score is the time taken to sort six duplications of a single stimulus figure belonging to a particular condition representing a specific type and a specific degree of redundancy. The total score is the summation of the eight sub scores obtained on two trials. The criterion score is the sorting time per figure recorded in seconds.

Procedure

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The figure to be sorted is placed at the top of a sorting board and is left there throughout the trial (see Figure 5). Below this figure are six rows of figures. The figures are equally spaced over a row length of 16 inches. The figures in each row are all different. Different rows contain the same figures but in a different random order. There are eight figures in each row. The subject must locate the one figure in each row that is identical to the sample figure and flip it over. The subject proceeds in order from the top to the bottom row, designating six figures in this way.

On subsequent trials a different figure is sorted until all figures have been sorted once. The eight figures each subject sorts are the same with respect to the extent of the redundancy involved and the type of redundancy presented, and as indicated earlier are drawn at random from a population of 24 figures.

The total time to sort six identical figures in any one trial is recorded as well as the time to sort each figure from each row.

Each subject was given the following instructions:
"The present task is a sorting task. A sample figure will be placed at the top of this sorting board. (Demon -

Figure 5. Representative Sorting Board with
Figures that Are 93% Redundant.

strate). Look at the figure until I say "go". When I say "go" find and flip over the correct figure in each row. There is only one figure like the sample figure in each row. There are six rows so you will have to flip over six figures that are like the sample figure.

In order that you may check whether or not you have turned over the correct figure I will tell you the number which should appear on the back if you have flipped over the right figure. If you make an error do not stop to turn back the wrong figure but continue to look for the correct figure.

Although you will have to sort many different figures, all figures, essentially, have the same pattern as a basic figure. A basic figure has four bars of four different lengths. We may say that this figure (demonstrate) has an order of bar lengths that is 4132. We repeat this order of bar lengths in other figures a different number of times. In some figures we only repeat part of the order. In other figures we repeat the order two, three, or four times. Sometimes we repeat the order in a straight repetitive manner so that we may specify the figure, for example, by stating the bar lengths as 4132413241... etc. In other instances we

repeat the order backwards; for example, 4132231441... etc.

Sort the figures as quickly as possible, but without making a single error. It is very important that you be completely accurate.

Start when I say "go". Flip over the one correct figure in each row and check to see that it is correct by looking at the number on the back. Do not skip any rows. Do them in order. Be as accurate as possible. The noise you hear will be the counters clicking off the time, which I shall record after each trial. Are there any questions ?"

In order to minimize variance attributable to individual differences in learning to sort, each of the ten conditions in the experiment were presented three times in succession. Each presentation of a condition is considered a trial. The score used is the mean value of the last two trials on each condition.

Scoring Apparatus. The scoring apparatus consisted of seven veeder counters so arranged that one counter operated continuously from the beginning of a sorting problem until the last stimulus was sorted. Six other veeder counters were activated for the length of time

taken by a subject to sort a figure from each row. All counters were operated manually by the experimenter. The counters which record the row times operated as long as the experimenter depressed the appropriate control button. The total clock operated from the time a start button was depressed until a stop button was depressed at the end of the trial. The counters recorded once for each tenth of a second interval. The intervals were determined by a notched cam which was rotated by a Bodine motor at the speed of 60 r.p.m. Notches on the cam activated a microswitch which transmitted pulses to the counters at the rate of ten per second. A schematic circuit diagram is given in Figure 6.

Results

The raw scores of the 21 subjects for two types and five degrees of redundancy are given in Table 1. The mean scores for 21 subjects for each condition is at the bottom of the table. These mean scores are plotted in Figure 7. The mean score represents the mean time it takes each of 21 subjects to sort one figure under one experimental condition. From the curve in Figure 7 it can be seen that the function described by the values for mirror-image redundancy approximates the function

Figure 6. Schematic Circuit Diagram of Apparatus.

Table 1. Distribution of Scores for 5 Degrees of Redundancy and 2 Types of Redundancy for 21 Subjects on the Visual Stimulus Pattern in Sample 1.

Mirror-Image Redundancy

Degree of Redundancy	1	2	3	4	5
Subjects					
1	1.94	1.44	1.76	2.10	2.26
2	1.49	1.45	1.69	1.74	1.93
3	1.68	1.66	1.56	2.03	2.59
4	2.00	2.31	2.24	2.01	2.08
5	1.36	1.49	1.73	1.59	1.75
6	2.16	1.41	2.68	2.66	2.68
7	1.22	1.11	1.46	1.57	1.92
8	2.19	1.55	2.20	2.00	2.00
9	1.70	1.41	1.53	2.19	1.87
10	1.80	1.88	1.79	1.66	3.35
11	1.79	1.37	2.96	2.28	2.05
12	1.80	1.59	1.30	2.97	1.12
13	1.69	1.59	1.58	2.68	2.47
14	1.73	1.69	2.68	1.68	1.93
15	2.85	2.33	3.46	2.16	3.24
16	2.04	1.66	2.17	2.91	3.71
17	1.58	1.56	1.64	2.17	3.02
18	1.43	1.14	1.41	1.56	1.92
19	2.20	2.36	4.43	2.62	2.91
20	2.26	1.64	1.96	2.14	2.48
21	2.23	2.20	1.81	3.44	2.86
Mean	1.86	1.70	2.10	2.20	2.39

Individual scores represent the mean time in seconds to sort one figure.

Table 1. (continued)

Congruent Redundancy

Degree of Redundancy	1	2	3	4	5
Subjects					
1	2.01	1.94	2.19	2.07	2.36
2	1.36	1.26	1.90	1.69	1.69
3	2.00	1.67	2.38	2.44	2.55
4	1.70	1.62	1.89	2.37	2.20
5	1.38	1.45	1.65	1.65	1.70
6	2.72	2.46	2.93	3.19	2.89
7	1.19	.95	1.55	2.07	1.63
8	1.54	2.03	2.09	2.60	2.19
9	1.69	1.96	1.99	2.31	2.85
10	2.05	2.04	1.97	1.71	2.19
11	1.32	1.56	1.49	1.98	3.18
12	1.47	.99	2.00	1.45	2.56
13	2.23	2.35	1.76	3.38	2.34
14	1.42	1.46	2.43	1.64	2.18
15	2.02	2.67	2.27	4.59	2.89
16	1.81	2.15	2.64	2.42	2.40
17	2.91	1.51	1.70	2.23	1.92
18	1.32	1.48	1.50	1.81	1.66
19	2.88	3.16	4.05	2.87	3.29
20	1.75	2.33	2.22	3.57	2.23
21	2.28	2.23	2.27	2.57	3.45
Mean	1.86	1.87	2.14	2.41	2.40

Individual scores represent the mean time in seconds to sort one figure.

Figure 7. Curves of the Effects on Sorting Time of 2 Types of Redundancy and 5 Degrees of Redundancy. Figure Sample 1.

described by the values for congruent redundancy.

The data were analyzed by means of a three-dimensional analysis of variance design in which one dimension is type of redundancy, and a second dimension is degree of redundancy, and a third dimension is subjects. The analysis was run after the data was found to satisfy the requirement for homogeneity of variance as given by Bartlett's test. Results of the analysis are given in Table 2.

Table 2

Results of Analysis of Variance for the Effects
of Redundancy on Sorting Time for 21 Sub-
jects Using Visual Stimulus Patterns
in Figure Sample 1

Source		df	MS	F
Type of Redundancy	R	1	87,312	3.592
Degree of Redundancy	D	4	681,615	20.034**
Subjects	S	20	418,673	17.890**
	RD	4	23,402	.008
	RS	20	24,308	.008
	DS	80	33,244	.012
	RDS	80	2,876,323	

** 1% level of significance

The results of the analysis of variance fail to warrant rejection of the null hypothesis that the two types of redundancy are equivalent. The degrees of freedom, therefore, have been combined for the two types of redundancy before testing for differences between degrees of redundancy. The differences between degrees of redundancy is highly significant (P less than .001). The mean sorting time per figure for the first degree of redundancy is approximately 1.8 seconds, while the mean sorting time per figure for the fifth degree of redundancy is approximately 2.4 seconds. In Table 3 is given the significance of the difference between individual pairs of treatment means (51). The scores in the table represent differences between steps of redundancy.

Table 3

Differences between Individual Pairs of Treatment Means for Stimuli with Different Degrees of Redundancy in Figure Sample 1

		Degree of Redundancy			
		2	3	4	5
Degree of Redundancy	1	35	123*	212**	256**
	2				291**
	3				133*
	4				44

* 5% level of significance
 ** 1% level of significance

Table 4. Distribution of Rank Scores for each Stimulus Pattern under each Experimental Condition in Figure Sample 1.

	Deg. Red.	Figures							
		1	2	3	4	5	6	7	8
M	1	1	2	4	6	7	3	8	5
	2	4	5	8	6	2	7	1	3
	3	2	1	8	5	3.5	6	7	3.5
	4	1	4	2	8	3	7	6	5
	5	3	1	2	6	4	5	7	8
C	1	3	2	4	5	6	1	7	8
	2	3	5	2	6	8	4	7	1
	3	1	6	2	7	5	4	8	3
	4	7	4.5	1	6	2	3	8	4.5
	5	1	4	3	7	6	5	8	2

M Mirror-Image Redundancy
C Congruent Redundancy

Figure 8. Rank Order of Figures in Sample 1.
The Figure on the Left Has the Fastest Sorting
Time and the Figure on the Right Has the Slow-
est Sorting Time.

The scores for individual figures were examined to determine whether or not there were any outstanding individual figures. Each figure was ranked on the basis of its sorting time for each subject under each condition. Adding the rank scores for each figure through 21 subjects and ranking the sum of these ranks for each experimental condition yields the distribution of scores given in Table 4. A non-parametric chi-square test of the significance of the differences between the rank scores of the figures is highly significant (P less than .0026). The order of figures sorted in the fastest time to the slowest time is arranged, respectively, from left to right in Figure 8.

Experiment 2. A Further Study of the Role of Redundancy in the Dis- crimination of Visual Forms

The second experiment was essentially a replication of the first, using a second random sample of stimulus figures, and was carried out to test the same hypotheses as Experiment 1. The effects on discrimination of systematic increases in redundancy in two types of redundant patterns was studied. The second sample of figures was used in order to reduce the probability that the results of the first experiment are attributable to a peculiar selection of stimuli.

Method

Stimuli. The stimulus figures consisted of another set of eight basic figures drawn at random from the parent population of 24 figures. They are made symmetrical and then made redundant in the same manner as was described for the figures in experiment one. The stimuli used in this experiment are shown in Figures 9 and 10. In these figures is shown, one under the other, the same stimulus pattern made redundant by different

Figure 9. Five Steps of Congruent Redundancy for the Stimuli in Figure Sample 2. Figures Are Two-Fifths Actual Size.

Figure 10. Five Steps of Mirror-Image Redundancy for the Stimuli in Figure Sample 2. Figures Are Two-Fifths Actual Size.

amounts. The redundancy values of the rows of figures going from top to bottom are 71%, 81%, 86%, 91% and 93%.

Eighteen of the same subjects that were used in Experiment 1 were used in this experiment.

The experimental design and the scoring apparatus were also the same.

The procedure was the same as that described for the first experiment with one modification. In the first experiment it was found that allowing the subject three trials at the same experimental condition permitted him to reduce the absolute time needed to sort the stimuli but in no way changed the shape of the plotted function. Inasmuch as the same skilled subjects were used in the second experiment it was felt that more than one trial per condition was unnecessary. The use of a single trial provided a more precise design since a subject could be run on all experimental conditions on the same day, thereby reducing the effects of quotidian variability.

Results

The raw scores of the eighteen individual subjects and the group means are given in Table 5, which gives

Table 5. Distribution of Scores for 5 Degrees of Redundancy and 2 Types of Redundancy for 18 Subjects on the Visual Stimulus Patterns in Sample 2.

Mirror-Image Redundancy

Degree of Redundancy	1	2	3	4	5
Subjects					
1	1.39	1.41	1.53	1.81	2.04
2	1.47	1.43	1.99	1.70	1.87
3	1.56	1.70	2.08	1.63	1.69
4	2.12	1.79	1.80	2.66	2.33
5	1.54	1.43	2.04	2.48	2.89
6	2.21	2.81	2.25	2.30	2.84
7	1.01	1.06	1.01	1.32	1.54
8	1.66	1.50	1.74	2.30	2.31
9	1.84	2.41	1.37	2.22	1.68
10	1.85	1.57	1.89	1.82	2.01
11	1.24	1.28	1.40	2.07	1.98
12	1.49	1.59	1.89	2.38	2.46
13	3.61	2.68	3.24	3.91	3.85
14	1.68	1.93	2.50	2.07	2.79
15	2.13	2.09	2.06	2.33	2.58
16	1.31	1.38	1.77	1.79	2.11
17	2.19	2.17	2.58	3.20	2.76
18	2.02	2.14	2.13	2.47	2.77
Mean	1.80	1.80	1.96	2.24	2.36

Individual scores represent the mean time in seconds to sort one figure.

Table 5. (continued)

Congruent Redundancy					
Degree of Redundancy	1	2	3	4	5
<hr/>					
Subjects					
1	1.39	1.52	1.61	1.69	2.23
2	1.47	1.62	1.33	1.62	1.67
3	1.56	1.74	1.48	1.96	1.97
4	2.12	2.02	2.16	2.30	2.65
5	1.54	1.57	1.48	1.98	2.67
6	2.21	2.04	2.15	2.36	3.12
7	1.01	1.09	1.31	1.92	1.79
8	1.66	2.26	1.93	2.59	2.53
9	1.84	1.81	1.95	2.29	2.88
10	1.85	1.72	1.69	2.30	1.91
11	1.24	1.53	1.31	1.44	2.52
12	1.49	2.34	1.55	1.96	2.31
13	3.61	3.30	3.04	3.44	3.75
14	1.68	1.90	2.17	2.33	2.49
15	2.13	2.01	1.88	2.60	2.57
16	1.31	1.45	1.43	1.80	1.72
17	2.19	2.33	2.32	3.29	3.37
18	2.02	2.08	2.23	2.01	2.78
<hr/>					
Mean	1.80	1.91	1.83	2.22	2.50
<hr/>					

Individual scores represent the mean time in seconds to sort one figure.

the data for the two types and five degrees of redundancy. The mean scores are plotted in Figure 11. The latter scores are the means of the times taken to sort one figure under one experimental condition. It can be seen from Figure 11 that the function described by the values for mirror-image redundancy approximates the function described by the values for congruent redundancy.

The results of the analysis of variance do not provide a basis for rejecting the null hypothesis that the two types of redundancy come from a common population (see Table 6). In this respect the results confirm those from the first experiment.

Table 6

Results of Analysis of Variance for the Effects
of Redundancy on Sorting Time for 18 Sub-
jects Using Visual Stimulus Patterns
in Figure Sample 2

Source		df	MS	F
Type of Redundancy	R	1	3,337	.285
Degree of Redundancy	D	4	624,796	40.660**
Subjects	S	17	540,614	46.241**
	RD	4	22,845	.767
	RS	17	11,691	1.499
	DS	68	15,364	1.008
	RDS	68	15,240	

** 1% level of significance

Figure 11. Curves of the Effects on Sorting Time of 2 Types of Redundancy and 5 Degrees of Redundancy. Figure Sample 2.

Again the degrees of freedom have been combined for the two types of redundancy before testing for differences between degrees of redundancy. The differences between degrees of redundancy are highly significant (P less than .001). Table 7 gives the significance of the difference, according to Lindquist, between pairs of treatment means (51).

Table 7

Difference between Individual Pairs of Treatment Means for Stimuli with Different Degrees of Redundancy in Figure Sample 2

		Degree of Redundancy			
		2	3	4	5
Degree of Redundancy	1	27	48	208**	302**
	2		21	181**	275**
	3			160**	254**
	4				94*

* 5% level of significance
 ** 1% level of significance

A comparison of Table 3 and 7 shows that there are in each seven significant differences between pairs of means. In Experiment 1 there was a significant difference between conditions one (71% redundancy) and

three (86% redundancy) and also between conditions two (81% redundancy) and three (86% redundancy) . In this experiment there was no significant differences between conditions one and three, or two and three. The non-symmetry of significant differences between similar points in the two tables is interpreted as an effect due to peculiarities within the context of the two samples of stimuli.

A comparison between the effects of degrees of redundancy on sorting time for the stimuli in figure sample one and the stimuli in figure sample two is shown in Figure 12. The effects of type of redundancy are combined for each curve since these differences are not significant.

As was done in Experiment 1 each figure was ranked on the basis of its sorting time for each subject under each condition in order to determine whether or not there were any outstanding individual figures. Adding the rank scores for each figure through eighteen subjects and ranking the sum of these ranks for each experimental condition yielded the distribution of scores given in Table 8. It can be seen that in eight out of nine conditions one figure was always sorted fastest. It ranked second on the remaining condition. Another

Figure 12. Comparative Curves of the Effects on Sorting Time for 2 Types of Redundancy and 5 Degrees of Redundancy in 2 Samples of Stimuli.

Table 8. Distribution of Rank Scores for each Stimulus Pattern under each Experimental Condition in Figure Sample 2.

		Figures							
Deg. Red.		1	2	3	4	5	6	7	8
M	1	6	4	3	7	5	1	8	2
	2	8	3	7	6	4	1	5	2
	3	6.5	3	4	6.5	5	1	8	2
	4	4	5	3	6	8	1	7	2
	5	7	3	4	6	5	1	8	2
C	1	6	4	3	7	5	1	8	2
	2	6	3	4	7	5	1	8	2
	3	5	3	4	8	7	1	6	2
	4	5	3	4	8	6	1	7	2
	5	5	3	4	8	7	2	6	1

M Mirror-Image Redundancy
C Congruent Redundancy

figure is ranked second in eight out of nine conditions and is ranked first on the ninth condition. The next figure was ranked third seven times, fourth two times, and fifth once. The figure ranked fourth received this rank six times. It was ranked third three times and ranked seventh once. Beyond the fourth figure no other figure appears consistently better than any other. A non-parametric chi-square test of significance between the rank scores of the figures is highly significant (P , less than .002). On the basis of Table 8 the order of figures sorted in the fastest time to the slowest time is arranged, respectively, from left to right in Figure 13. It is of interest to note that the easiest figure to sort was a "staircase" figure in which the pattern of bars was highly regular and that the two most difficult figures to sort were vertical mirror-images of each other.

Discussion of Experiments 1 and 2

The results of the two experiments are essentially consistent. No significant difference between mirror-image redundancy and congruent redundancy was found in either case, while significant differences between degrees of redundancy were found in both cases. The second sample of figures appears to have been somewhat

Figure 13. Rank Order of Figures in Sample 2. The Figure on the Left Has the Fastest Sorting Time and the Figure on the Right Has the Slowest Sorting Time.

more difficult to discriminate than was the first. An inspection of the two samples suggests that this difference may be attributed to the greater number of similar bar lengths at the end of a figure that are the same for several figures in the second sample. Subjects reported that they often attempted to use a single bar of a figure in order to make their discriminations most rapidly. They reported that this was more difficult to do in the second sample of figures than in the first sample.

The results of both experiments lead to the tentative conclusion that in a relatively "noise free" situation redundancy neither facilitates nor hinders discriminations of visual patterns when redundant values fall between 71% and 81%. Beyond these values redundancy has a decidedly hindering effect on discrimination.

In the course of the two experiments two questions arose in regard to the above interpretation. One point stemmed from the subjects' verbal reports. Almost un-animously they agreed that once they became familiar with the sorting task they made little or no effort to look at the whole figure, but looked instead at only one bar if this was sufficient to identify the figure. If one bar was not sufficient for positive identification they

looked at two or three bars. No skilled subject believed that he surveyed an entire figure before making his response.

The second point which must be considered in interpreting the present data is size. Area was held constant in all of the figures. Introducing more and more bars while holding area constant meant that the width of the bars was reduced proportionately with each increase in redundancy. This requires that a subject discriminate smaller and smaller details. The effects of size of detail are of special importance particularly if it is true that subjects do not survey the characteristic shape of the whole figure but, instead, look only at very few parts of the figure.

These considerations suggested that a control study be run where size of detail is the independent variable. This study is reported next.

Experiment 3. A Comparison of the Effects of Size of Detail and Redundancy on the Discrimination of Visual Forms

The purpose of this experiment was to determine whether the size of detail (bar width) apart from the number of bars or degree of redundancy per se, affects discriminatory behavior in a visual sorting task. In the previous experiment the introduction of redundancy was accomplished by the reduction of the size of details in the figure. The decision to reduce the size of detail was arbitrary and it was made so that area would be held constant. When area is held constant, redundancy and size of detail are confounded; if detail size were held constant then redundancy and area would of necessity be confounded.

To account for the variance attributable to size of detail (bar width) and to redundancy (number of bars) it was necessary to examine the responses to figures identical in their size of detail but differing in their extent of redundancy. Any difference in sorting time between redundant and non-redundant stimuli of corresponding detail size will be attributable to redundancy

plus area.

Method

Stimuli. Eight symmetrical figures with four bars that were used in Experiment 1 were presented in four sizes. The reduction in size took place only about the vertical axis in order that the dimensions of the figures should correspond to the dimensions of the details in the corresponding redundant figures previously used. The sizes of the figures were 2cm.X2cm., 2cm.X1.33cm., 2cm.X1cm., and 2cm.X.5cm. These sizes corresponded to size of details in figures with redundancy values of, respectively, 71%, 86%, 91%, and 93%. The redundant figures and the corresponding symmetrical figures with only four bars that are reduced in size are shown in Figure 14.

Sixteen of the same subjects that were used in Experiment 2 served in Experiment 3.

The scoring apparatus and procedure in Experiment 3 was the same as that used in Experiment 2.

Results

The data are plotted in Figure 15 and numerical scores are presented in Table 9 for each subject separately and for the group.

Figure 14. Figures Differing in Redundancy (Number of Bars) but Identical in Size of Detail (Bar Width). Figures Are One-Fourth Actual Size.

Figure 15. Curves for the Comparison of Figures Differing in Redundancy (Number of Bars) but Identical in Size of Detail (Bar Width).

Table 9. Distribution of Scores for 4 Degrees of Redundancy and for 'Non-Redundant' Figures with Corresponding Size of Details.

	Degree of Redundancy			
	1	2	3	4
Subjects				
1	1.41	1.39	1.93	2.18
2	1.09	1.35	1.43	1.53
3	1.42	1.47	1.35	1.79
4	1.67	1.73	2.36	2.99
5	1.60	1.59	2.12	2.56
6	1.55	2.11	2.45	2.33
7	1.17	1.12	1.87	2.08
8	1.68	1.45	1.92	2.40
9	1.85	1.73	2.32	2.67
10	1.56	1.47	1.47	2.37
11	1.30	1.51	1.61	2.17
12	2.36	2.39	2.27	3.03
13	1.10	1.06	1.59	1.73
14	1.89	1.87	2.18	2.50
15	1.63	1.33	1.40	1.82
16	1.66	1.53	1.52	2.00
Mean	1.56	1.57	1.86	2.26

Individual scores represent the mean time in seconds to sort one figure.

Table 9. (continued)

	Size of Detail		
	5	6	7
Subjects			
1	1.44	1.82	1.83
2	1.29	1.37	1.59
3	1.44	1.69	1.63
4	2.05	2.21	2.99
5	1.84	1.90	2.22
6	1.78	1.94	2.42
7	1.22	1.43	1.95
8	1.58	1.91	2.10
9	1.96	2.12	2.87
10	1.47	1.75	1.97
11	1.61	1.65	1.95
12	2.02	2.44	3.11
13	1.29	1.49	1.61
14	1.88	1.88	2.39
15	1.24	1.50	2.01
16	1.74	1.92	2.04
Mean	1.62	1.81	2.17

Individual scores represent the mean time in seconds to sort one figure.

The t-tests of the differences between the pairs of points above redundancy values .81 (conditions two and five), .86 (conditions three and six), and .93 (conditions four and seven) on the abscissa of Figure 15 are not significant. There is no reason, therefore, to reject the null hypothesis that the effects due to size of detail and the effects due to bar redundancy are effects other than those that can be attributed to chance.

Discussion of Experiment 3

Several implications can be drawn from the results of this experiment. First, size may be considered a form of redundancy even when stimuli are suprathreshold. In the present instance optimum size may be considered equivalent to optimum redundancy. Therefore, an increase in sorting time should occur on either side of the optimum size. Secondly, the results suggest that the data of Experiment 1 and 2 can be accounted for by variations in size of detail.

Introspective reports suggest that skilled subjects, in a noise-free situation, do not pay attention to redundancy in the form of repeated bar patterns. Instead they appear to base their discriminations on

less than the maximum number of details available in any specific stimulus pattern.

The conclusion that appears to be most warranted in the light of the present results is that in a relatively noise-free situation figure redundancy has neither a facilitating nor a hindering affect on the responses of subjects whose task it is to discriminate one visual pattern from another; the increase in sorting time found for large values of redundancy can be accounted for by the increased time required to discriminate small details.

Experiment 4. The Effects of Visual Noise on the Discrimination of Redundant Visual Forms

It was a logical first step to investigate the effects of redundancy, if any, in a relatively noiseless situation. For this situation it has been demonstrated in a previous study (65) that visual patterns with symmetrical redundancy are more quickly discriminated than are visual patterns with asymmetrical redundancy when the degree of redundancy, in both cases, is identical. When additional redundancy is introduced in the form of repeated sequences of symmetrical bars, it is found that this further increase in redundancy with its associated change in the size of detail in a figure significantly decreases speed of discrimination as measured by sorting time. The behavior of the subject, in a noise-free situation, appears to be relatively independent of redundancy after it has reached a certain optimum point. The next logical step is to examine the effects of redundancy when noise is present.

It is proposed that the primary role of redundancy in the discrimination of visual patterns in a noisy

situation is to provide sufficient repetition of visual cues so that the probability that any identifying cue will be identified correctly in spite of the noise is increased. Where a cue for which a subject ordinarily searches in order to differentiate one pattern from another is distorted by noise, occurrence of this cue in other parts of the pattern should provide the necessary basis for a correct response.

Noise was defined previously as anything which affected the ratio of the probability of the message sent to the probability of the message received so as to make it different from unity. In the present instance the effect of many different types of noise could be studied. The particular type arbitrarily chosen for use was one which would change the unfilled (white) cells of the matrix, in which a figure was constructed, into filled (black) cells. Thus a ten percent noise level would result in changing a random ten percent of all white cells into black ones. It should be noted that the opposite possibility, changing black cells into white ones, was not studied.

The hypothesis to be tested in the present experiment is: A decrease in sorting time for a stimulus

pattern distorted by a constant level of visual noise is inversely related to the degree of redundancy presented in the pattern.

Method

Stimuli. The stimulus material consisted of eight figures reproduced so as to represent four degrees of redundancy. The first degree of redundancy was the basic asymmetrical constrained figure (see Figure 1 on page 23). The other three figures were the same as the congruent redundant figures used in Experiment 1. The respective redundancy values for the four types of figures were 43%, 71%, 86%, and 93%. The stimuli are shown without noise in Figure 16. In the noisy condition each of the eight figures for each degree of redundancy had superimposed upon it different random distributions of noise. A 17 percent level of noise was chosen, on a priori grounds, because it appeared to distort a figure sufficiently to cause difficulty of discrimination and yet not to distort it to the extent that identification was impossible. Figures distorted by noise are shown in Figure 17.

The procedure for obtaining noise patterns consisted of drawing matrices equal in size and subdivisions

Figure 16. Visual Patterns Showing Four Steps of Congruent Redundancy without Noise. Figures Are One-Fourth Actual Size.

Figure 17. Visual Patterns Showing Four Steps of Congruent Redundancy Distorted by 17% Noise. Figures Are One-Fourth Actual Size.

to the matrices from which the figures with a particular degree of redundancy were originally generated. Thus, for example, the size of the cells in the matrices from which figures with 43%, 71%, 86%, and 93% redundancy were produced was, respectively, .50cm.x.50cm., .50cm.x.25cm., .25cm.x.25cm., and .25cm.x.125cm. The cells in the matrix that were white and unoccupied by any portion of a figure were numbered. Seventeen percent of the white cells in each matrix that were to be drawn in black was determined by drawing numbers from a table of random numbers. Figures with 43%, 71%, 86%, and 93% redundancy had, respectively, one, two, four, and eight noisy cells.

Each of the eight figures in each of the four degrees of redundancy was distorted by three different random samples of noise. Each noise pattern appeared twice on a sorting board. A sorting board contained, altogether, 48 visual stimulus patterns representing one particular degree of redundancy. The four experimental conditions that were presented to a subject are shown in Figures 18, 19, 20, and 21.

Sixteen of the same subjects that were used in Experiment 3 also served in Experiment 4.

Figure 18. Sorting Board Showing Redundant
Figures (43%) Distorted by Samples of 17%
Noise. Experimental Condition One.

Figure 19. Sorting Board Showing Redundant Figures (71%) Distorted by Samples of 17% Noise. Experimental Condition Two.

Figure 20. Sorting Board Showing Redundant Figures (86%) Distorted by Samples of 17% Noise. Experimental Condition Three.

Figure 21. Sorting Board Showing Redundant Figures (93%) Distorted by Samples of 17% Noise. Experimental Condition Four.

The scoring apparatus and procedure was similar to that used in previous studies. The figure to be sorted, free of noise, was placed at the top of the sorting board as usual. The remaining figures on the board were those on which noise had been superimposed.

Results

The results are given in Figure 22 and in Table 10. The fastest sorting time (4.15 seconds) was recorded for figures with the greatest amount of redundancy (93%). Except for one value of redundancy (86%) there was a consistent decrease in sorting time with an increase in redundancy.

The time scores were analyzed by means of an analysis of variance (see Table 11). The overall test of the null hypothesis that there is no difference between the means of the conditions is rejected at the one percent level. The significance of the differences between individual pairs of treatment means is shown in Table 12. Of the six possible pairs of treatment means that may be compared, two are significant at the one percent level, two are significant at the five percent level, and two are not significant.

It takes significantly less time to sort the

Figure 22. Curve Showing the Effects on Sorting Time and Errors for Different Degrees of Redundancy in Stimuli Distorted by 17% Visual Noise.

Table 10 . Sorting Time Scores in Seconds for Different Degrees of Redundancy in Stimuli Distorted by 17% Visual Noise.

Degree of Redundancy	1	2	3	4
Subjects				
1	6.05	5.12	3.95	3.78
2	3.19	3.10	3.52	3.28
3	2.67	2.55	2.68	2.55
4	7.63	5.85	5.52	6.12
5	6.28	4.98	5.77	4.20
6	5.56	4.16	6.33	4.58
7	4.09	2.45	3.40	4.02
8	4.35	3.34	3.88	3.61
9	6.30	4.91	4.56	3.57
10	5.63	4.19	5.63	3.51
11	4.66	3.74	4.11	4.06
12	3.51	4.73	4.63	4.86
13	6.08	4.96	7.87	6.90
14	5.94	4.68	4.31	3.16
15	5.44	4.86	6.74	4.32
16	5.03	3.71	3.33	3.92
Mean	5.15	4.21	4.76	4.15

Individual scores represent the mean time in seconds to sort one figure.

Table 11

Results of Analysis of Variance for the Effects
of Redundancy on Sorting Time for 16 Subjects
Using Congruent Visual Stimulus Patterns
Distorted by 17% Visual Noise

Source		df	MS	F
Degree of Redundancy	D	3	21.18	37.82**
Subjects	S	15	.73	1.30
Error	DS	45	.56	

** 1% level of significance

Table 12

Differences between Individual Pairs of Treatment Means for Visual Patterns Distorted by 17% Visual Noise but Differing in Degree of Redundancy. Redundancy Values Increase Progressively from Condition One to Condition Four

		Degree of Redundancy		
		2	3	4
Degree of Redundancy	1	.94**	.39	1.00**
	2		.55*	.06
	3			.61*

* 5% level of significance
** 1% level of significance

Table 13. Error Scores for Different Degrees of Redundancy in Stimuli Distorted by 17% Visual Noise.

Degree of Redundancy	1	2	3	4
Subjects				
1	6	7	6	2
2	7	6	5	6
3	4	5	6	7
4	14	13	9	11
5	17	11	11	13
6	10	7	18	3
7	7	4	4	6
8	13	10	9	9
9	8	9	8	6
10	18	12	18	13
11	15	7	6	7
12	8	22	12	15
13	8	10	19	7
14	6	12	5	5
15	11	4	9	6
16	10	3	6	3
Mean	10.13	8.88	9.44	7.44

figures with 71 percent and 93 percent redundancy than it takes to sort the figures with 43 percent redundancy. It takes less time to sort figures with 86 percent redundancy than it takes to sort figures with 43 percent redundancy but the time to sort figures with 86 percent redundancy is significantly greater than the time to sort figures with either 71 or 93 percent redundancy.

The function for error scores is similar to the function for time scores (see Figure 22). The scale for error scores has been adjusted in Figure 22 so that error scores fall on the same points as do the time scores for the two end points of the graph. The numerical scores are shown in Table 13.

Figures with the least amount of redundancy (43%) represented the most difficult condition for discrimination. The best mean sorting time and the least number of errors occurred for visual patterns displaying the greatest amount of redundancy (93%). However, the effects of redundancy in a situation where noise is present apparently is not a simple monotonic one. The slight but significant rise in both sorting time and errors for visual patterns representing figures with 86 percent redundancy suggests that there may be an interaction between certain levels and types of noise and

particular degrees and types of redundancy.

In general, however, the hypothesis that there is an inverse relation between the amount of redundancy and sorting time, in a situation where visual patterns are distorted by noise, is supported.

Discussion of Experiment 4

One outstanding characteristic of the present results is the relatively slow sorting time for 86 percent redundancy. This result is inconsistent with the other obtained scores. It might have been attributable to a peculiar randomly selected sample of noise were it not for the fact that each sorting board displays the same figures distorted by three different samples of noise. An examination of the effects of these three separate samples of noise on sorting time does not demonstrate that one of the three samples inflates the scores spuriously. The score for condition three appears therefore to represent a true interaction. However, further verification of this interaction awaits a replication of the present study using a different random sample of visual stimulus patterns and different random samples of noise.

A comparison of the sorting time curves for visual

patterns presented in a noise-free and in a noise-filled situation shows, first of all, that it is more difficult to make discriminations when noise is present. The functions described by the two curves are different, however. The curve for redundant visual stimuli presented in a noise-free situations shows, generally, an increase in sorting time with an increase in redundancy. The curve for redundant visual stimuli presented in a noise-filled situation shows, generally, a decrease in sorting time with an increase in redundancy.

It will be recalled from Experiment 3 that the curve for sorting redundant figures in a noise-free situation could be attributed to size of detail (bar width) rather than to redundancy (the number of bars in a figure). The introduction of noise however, forces the utilization of the redundant aspects of the stimulus patterns.

Redundancy appears to be operating in accordance with predictions from information theory. It has a facilitating effect in the transmission of information only when noise is present. The hypothesis that there is, in a noisy situation, an inverse relation between sorting time and the amount of redundancy in a stimulus is supported.

Conclusion

The present series of experiments constitute a new and quantitative approach to the problem of form perception utilizing concepts stemming from information theory. A review of the earlier work on form perception provided few if any leads to quantitative procedures for the generation of visual patterns of known complexity and redundancy, or for the formulation of the hypotheses that have been tested here. Predictions from the early work on form perception are that discrimination of visual forms becomes more difficult when the size of details in the forms decreases and when the number of details in the forms increases. Quantitative predictions cannot be made from earlier studies regarding the relation of perception to systematic increases in the number of details in a visual form, or to the limited effects of the size detail in situations where visual forms are distorted, or to systematic changes in the symmetry of visual forms.

The present investigations indicate that systematic increases in the proportion of repetitive details of a visual form, apart from the size of the details of the figure, has little effect on discriminatory behavior in

a non-distorted or noise-free stimulus situation. There is no evidence that effects on discrimination due to ordinary internal or organic fluctuations such as variations in motivation, warm-up, erratic eye movements, and mood intrude sufficiently into a noise-free visual discrimination task to permit redundancy to help or hinder the discriminatory process. However, it is possible that redundancy in visual stimuli may have an effect when subjects are placed in a stressful situation. Tests for the existence of this effect, however, will require further experimentation.

The present results clearly indicate beneficial effect on discriminatory behavior when visual patterns are presented in the presence of visual noise. The redundant visual pattern that was most difficult to discriminate in a noise-free situation was most easily discriminated when noise was present. However figures that are distorted by noise always are more difficult to discriminate than are figures which appear without any distortions.

Subjects reported that as they gained skill in the discriminatory task they tended to look for one or more specific details in a particular figure rather than to examine the figure as a whole. This may provide a

further explanation of why, in a noise-free situation, the repetition of the figure contour (redundancy) is of no advantage, and why the size of details is a critical factor. Whether, in the presence of noise, subjects continue to look for specific details in the successive cycles of the contour of a figure, or shift to a discrimination based on the total appearance of the figure can not be answered from the present data.

However, an increase in redundancy apparently helps a subject recognize a visual pattern through noise despite a decrease in size of detail, i.e., even when the total area of the figure is fixed. The finding that an increase in redundancy hinders a subject in discriminating a visual pattern in a noise-free task apparently is due primarily to a decrease in size of detail of the figure.

It is evident from the results of this study that future investigations of the effects of redundancy on the discrimination of visual patterns should be carried out in additional noise situations. The relation between redundancy and noise does not appear to be a simple function. This suggests that it would be profitable to study the effects of different noise situations on different redundant visual patterns. The ratio of the noise

size to the size of stimulus details may be an important factor, for example. Other important variables probably are the shape of the noise details and the way in which noise is introduced. For example noise which can only add to a visual pattern should have a different effect than noise which can subtract from as well as add to the pattern. The nature of differences between a visual pattern and noise disturbances such as their relative brightness contrast, color contrast, shape contrast, and rate of appearance all seem to be cogent variables deserving attention and experimentation.

The nature of the present limited results, however, suggest applications in the field of human engineering. They are particularly pertinent in situations where symbolic visual forms must be displayed on instruments of a given size. For example a design engineer may be given the problem of presenting a signal on a particular radar scope. How should the signal be presented ? Knowledge of the effects of redundancy on perception would provide some basis for estimating how much redundancy should be introduced into the signal to overcome the effects of static or other visual noise before some other factor such as size of detail begins to outweigh disadvantageously the helpful effects of redundancy.

The present results also suggest new ways of looking at some of the perceptual concepts used in Gestalt theory. Gestalt theory for a long time has emphasized that symmetry is an important factor in perception. Symmetry was accepted as a characteristic of 'good Gestalt'. The term 'good Gestalt', however, was never defined precisely. The application of information theory and its concept of redundancy to the problem of symmetry provides a quantitative approach to this aspect of form perception. Other aspects of form perception may be examined using information theory. For example, the Gestalt concept of simplicity may be investigated by examining the information that is transmitted with the selection of a single figure drawn from a population of other 'simple' figures. A comparison of the amount of information in different sets of figures may furnish a quantitative description of simplicity and complexity in visual forms.

In general, it is felt that information theory can make an important contribution to theories of form perception. It provides a statistical consideration of perception that has not been utilized previously. It takes into account the theoretical population of stimuli that could have been selected as well as any actual

population of stimuli that is selected and presented to a subject in a particular experimental condition. It permits the experimenter to take into account the fact that the response to any particular stimulus is in part a function of the population of stimuli to which the particular stimulus belongs, in other words to deal quantitatively with such phenomena as set or expectancy. An increase in the accuracy of prediction of perceptual behavior can be expected to result from the development of theories and experimental techniques which consider parameters of the stimulus over and above the measurable characteristics of any one particular stimulus pattern. In the present experiments information theory has made it possible to hold constant one important stimulus parameter, amount of information, while two other parameters, percentage of redundancy and percentage of noise, have been treated as independent variables.

From the results of this series of experiments it may be concluded that information theory provides a fruitful approach to the study of form perception. It has been shown, in general, that redundancy is more effective in a visual discrimination situation where visual noise is present than where visual noise is not present. Further investigations of the relationship

between types and degrees of redundancy and types and degrees of noise are indicated.

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AUTOBIOGRAPHY

I, Maurice Rappaport, was born in New York, New York, February 9, 1926. I received my secondary school education in the public schools of the city of New York. My undergraduate training was obtained at The College of the City of New York from which I received the degree Bachelor of Science in 1950. From The Ohio State University I received the degree Masters Of Arts in 1951. While in residence at The Ohio State University I was employed by the Research Foundation in the Psychology Department as research assistant in the Laboratory of Aviation Psychology under the supervision of Dr. Paul M. Fitts from January 1951 to June 1953. From September 1953 to December 1953 I was a teaching assistant in the Department of Psychology at The Ohio State University under the direct supervision of Dr. Delos D. Wickens. In January 1954 I became a research fellow in the Laboratory of Aviation Psychology in the Psychology Department of The Ohio State University. In this same laboratory I was appointed

research associate in May 1954 and held this position while completing requirements for the degree Doctor of Philosophy. Prior to obtaining this degree I was appointed Scientist for the year 1954-55 at the Applied Psychology Research Unit in Cambridge University, England.