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The Mechanism of Vision: XV. Preliminary Studies of the Rat's Capacity for Detail Vision

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THE MECHANISM OF VISION: XV. PRELIMINARY STUDIES OF THE RAT'S CAPACITY FOR DETAIL VISION*

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I. INTRODUCTION: OBJECTIVES OF THE EXPERIMENT

The discrimination of visual patterns and the recognition of similarities between visually presented objects may involve a wide range of functions from a direct tropistic reaction up to the recognition of intricate logical relations subsisting among the objects compared. The study of visual discrimination in animals thus offers not only an approach to problems of sensory acuity but also a method for study of the nature and limits of capacity for generalization. Current notions of the intelligence of animals are based largely upon their behavior in situations calling for motor adaptation through manipulative or orienting movements, as in experiments with puzzle boxes or mazes. The equal or greater value of studies of perceptual organization for a science of comparative psychology has been demonstrated by Klüver's investigations with monkeys (45, '33), but such methods have not been used extensively with lower mammals.

This study of the rat was undertaken primarily to establish norms of behavior as a basis for later experiments on visual amnesia and agnosia after cerebral lesions. Tests were therefore restricted to forms which would be practicable for use with operated animals; speed rather than great accuracy in measurement of thresholds, daylight adaptation, and the selection of stimuli giving maximal rates of learning were stressed, and these requirements limit the range of the investigation. In spite of such restrictions, the picture of visual organization is rather more complete than has been reported for any other animal below the primates and may serve both to illustrate the usefulness of the method and to suggest some of the early steps in the evolutionary development of sensory organization and of processes of abstraction.

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For an understanding of integration in behavior a knowledge of the essential nature of the stimulus is necessary. Descriptions of behavior in terms of stimulus-response relations are futile so long as the stimulus is defined only in terms of the total environmental situation, as "the maze" or "a paper triangle." Not until the adequate stimulus, the part, element, or property of the total situation which is effective in eliciting behavior, is known will it be possible to infer from stimulus-response relations anything concerning the intervening coordinative processes which constitute the real problem of psychology. Most of the experiments reported below are attempts to discover the adequate stimulus in the total complex of light rays reaching the retina. From the results it seems possible to infer certain general principles concerning the properties of the objective stimulus which are effective in behavior, although admittedly the range of experiments is too limited to prove the conclusions beyond question.

The range of tests of capacity for generalization which have been applied is too small to give any real insight concerning the ability of the animal. It is difficult to devise a graded series of tests covering a narrow range of ability, since we do not know beforehand what the successive steps in evolution of intelligence may have been and cannot say with certainty whether development has been by continuous quantitative change or by large, qualitatively different steps. The results at least emphasize the need for intensive investigation in this direction.

There are many studies of motor performance in instinctive behavior. The accuracy with which the web of the spider or nest of the bird conforms to the species-type has been stressed, but the possible implications of these facts for the perceptual organization of the animals has been neglected. Is the nest form determined by mechanical limitations of the animal's structure, as Bethe proposed in his theory of the building of the honeycomb, or by perceptual factors, by the fact that only a certain form "looks right" to the animal? There is a little evidence that complex sensory patterns are "recognized" independently of experience (Lashley and Russell, 57, '34; Lashley, 49, '15; Stone, 88, '22; Borovski, 6, '36; Hebb, 30-32, '37). It is quite possible that perceptual organization, the patterns of stimuli readily perceived, may vary widely in different species and be responsible for certain instinctive activities. The question is

especially intriguing when applied to higher mammals. Much of the Gestalt theory of perception implies a belief that the things we see are determined by our innate organization rather than by experience (Gottschaldt, 22, '29; Koffka, 47, '35).[1] If such an interpretation is correct, "instinct" may be as dominant in human behavior as in the life of the bee. Thorough investigation of sensory organization in various animals is thus important as providing a possible clue to the rôle of innate differences of perception in directing or limiting behavior. A major interest of this study was therefore to discover traits of vision peculiar to the rat. Failure to discover such traits and the close correspondence of data on the rat to the facts of human perception argue somewhat against the ascription of organized motor patterns of behavior to perceptual factors.

The study has extended over a period of six years, with the accumulation of too great a number of experiments to be reported in full. I have therefore selected for description those tests which seem the most significant and, if at times the conclusions drawn go beyond the scope of the experiments, this is at least in part due to the fact that the work reported is seen against the background of a more comprehensive mass of data. The tests have been largely exploratory and restricted to a few animals in each case. They therefore lack statistical reliability, yet the behavior of the animals when discriminating is so precise that there is little room for doubt of their failure or success in any given test. I have not attempted to present detailed records of the majority of experiments, since the space requirements would be too great. The few tables included illustrate the general character of the data.

In discussing the work I have not hesitated to use an anthropomorphic terminology. There is little choice between the Scylla of reflexological dogma and the Charybdis of mentalistic implication. The most significant recent studies of sensory organization have been made by members of the Gestalt school, and for the present it is more important to recognize that the same sensory problems are common to the lower animals and to man than to try to phrase these problems in a deceptively objective language. So long as we recognize that the terminology is merely one of classification of problems,

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[1]The results of Djang (11, '37) are less favorable to such a view than the earlier ones of Gottschaldt.

the danger of reading more into the animal's behavior than the objective facts of differential reaction and transfer can be avoided.

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II.   EXPERIMENTAL METHODS

In the work a modified form of the apparatus previously described (Lashley, 51, '30) has been used.   This requires the animal to jump against stimulus cards from a distance of 20 cm. with the reward of food for a correct choice, and punishment by a fall into a net for an incorrect.   The jumping platform and stimulus cards are arranged as indicated in Figure 1.   Enclosing sides and a glass cover
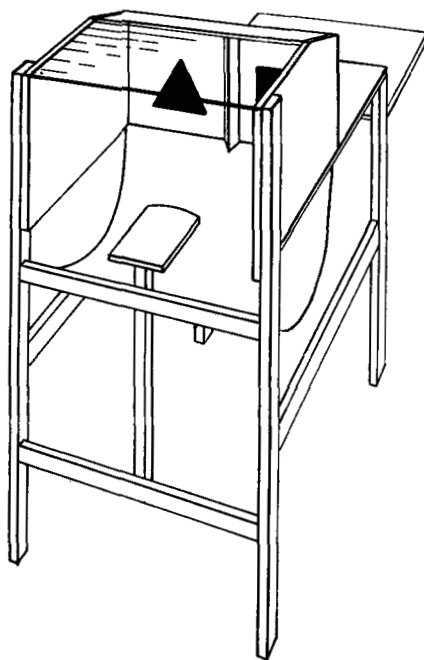

FIGURE 1

limit the animal's activities. A projecting fin between the cards forces choice of one or the other and there are no exposed edges or projections to which the rat can cling. The lower feeding platform at the rear reduces soiling of the fallen card by food. In some tests a box of similar structure presenting three stimulus cards equidistant from the jumping platform was used.

Except where indicated, the stimulus figures were cut from white paper and pasted on mat black cards. They could be readily renewed when soiled or in control tests.

The animals used were mature rats, with fully pigmented eyes, from an inbred strain derived by crossing Wistar albino stock with trapped wild. In the latter part of the experiments this stock developed a large percentage of animals with microphakia which necessitated acuity tests with all animals before they could be used in other experiments.[2]

In the earlier training and testing series the cards were alternated in an irregular order corrected for position but not for alternation habits. Since 1933 the series devised by Gellermann (20, '33) has been used. This gives chance scores for alternation, double alternation, and position habits. Except where contraindicated by the purpose of the experiment, all animals were first trained to jump to the open doors of the apparatus, then to a 10 cm. white square vs. a black card, then to horizontal vs. vertical striations of 20 mm. width, followed by acuity tests, before specific training on the problem for which they were used.

In the figures the stimulus cards are reproduced on a scale of 1/12th. In the apparatus they were, of course, completely surrounded by a black ground formed by the cloth net, sides and top of the box.

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[2]This condition has been described once before by Anderson (1, '93). Microphthalmia appeared in my colony a year after the introduction of the wild strain. Animals with severe microphthalmia, eyes less than 3 mm. in diameter, failed in all visual tests. Later defective lenses were detected in eyes of normal size and appearance. The condition ranged from complete absence of lens through various abnormalities of shape, to merely slight reduction in size. At one time nearly 30 per cent of the animals examined showed some such defects, which were sometimes bi-, sometimes unilateral. The condition seemed to be constitutional, since change in diet did not alter its incidence and an albino strain kept under the same conditions did not show it. Hain (28, '33) has reported microphthalmia as a familial character in a derivative of the Wistar stock. Microphakia occurs in the Harvard colony, so it is imperative that students of vision in the rat sample the lens condition in cases of failure on visual tests.

The Method of Equivalent Stimuli. The principal method used in the experiments is a combination of the preference tests of earlier students with preliminary training. The animal is first trained to choose one of a pair of stimulus patterns (training figures) and to avoid the other, with reward (food) and punishment (fall) as incentives. He is then suddenly confronted with a different pair of patterns and is allowed a free choice between them, receiving food at every trial, regardless of the pattern chosen. These preference tests, without punishment, will be referred to as "critical trials," following Klüver's terminology. A significant preference for one of the new figures after training may be taken as evidence that it is in some way equivalent for the animal to the positive training figure.

As a formal procedure the following tests were carried out in all critical trials.

1. Practice on the training figures with 10 trials per day until 20 consecutive errorless trials were obtained.

2. On subsequent test days 10 critical trials with the training figures, followed immediately by 10 critical trials with the new pair of figures.

3. Twenty-four hours rest. Ten critical trials with the training figures followed by 10 critical trials with the new figures.

4. In case of failure of transfer, 10 critical trials with the training figures immediately following the failure.

This sequence gives for comparison 20 trials with the training figures and 20 critical trials with the new figures. In case of failure of transfer the 10 critical trials with the training figures control any loss of the original habit. Twenty trials are usually adequate to give clear evidence of transfer or lack of transfer of training. The majority of animals in critical trials either choose one of the pair of figures in more than 80 per cent of the trials or assume a position habit and make chance scores. I have generally varied both the positive and negative figures. Pache (73, '32) substituted parts of the positive figure for the negative until the reaction broke down. His method is superior in some respects for discovering the properties of the positive stimulus which determine reaction.

Certain difficulties of the method are unavoidable. The new figures, even when identified with the familiar ones, introduce a disturbing element. The animal hesitates for long periods, turning back and forth from one card to the other. Errors are

most often made in the first trials, as if the animal were trying out both figures before settling down to a consistent selection of one. In a long series of tests for equivalence of a variety of patterns, especially after some failures of transfer, the animal apparently learns that no choice is necessary when new figures are presented and promptly adopts a position habit whenever figures other than the training series are introduced, even with figures which in earlier tests gave perfect transfer. Thus after a time the animals seem to become sophisticated in the tests and give less consistent results than others which have had less experience with the visual stimuli.

The effects of previous training may also persist over long periods and distort the results of later tests. I have not carried out systematic studies of retention, but three experiments illustrate the effects of previous training.

1. Two animals were trained on horizontal (positive) vs. vertical striations and on an upright (positive) vs. an inverted equilateral triangle. They were left for six months without training and when tested again made no errors in selection of the horizontal striations and erect triangle. Fields (13-14, '35, '36) has reported similarly good retention over periods up to seven months.

2. In training tests with ink blots two animals showed from the first an absolute preference certainly referable to previous training on triangle vs. circle, although for the experimenter the blots had no resemblance to these figures (See p. 181).

3. In the tests reported on page 151 the earlier training on striations dominated the effects of later training on geometrical figures.

4. There are also transfer effects of training when no equivalence of the stimuli is involved. The data of Lashley and Frank (56, '34) show that previous training on horizontal and vertical striations reduced the learning scores on erect and inverted triangles by 50 per cent.

Such observations made it advisable to discard each group of animals after the completion of a series of tests and to train a new group for each new problem, rather than risk unpredictable effects of earlier training. Except where indicated, therefore, each test series involves animals not recorded elsewhere.

Fields (12, '32) has claimed that with the jumping apparatus the animal is chiefly influenced by the positive stimulus; ". . . the

avoiding reaction to the negative figure which was found with the running apparatus is almost totally lacking when the jumping apparatus is used." The tests upon which this conclusion is based consisted of opposing the positive and the negative stimulus cards singly with a black card. Reaction to the positive card persisted, whereas chance scores were obtained with black vs. the negative figure. Fields' animals, however, had previously been trained to avoid a black card and even though as many as a thousand trials of training with pairs of figures had intervened before the tests with negative figure vs. black card, our data on retention indicate that this previous training would carry over. That the negative stimulus is effective is shown by critical trials in which the combination of a negative stimulus with a positive disrupts the reaction (pp. 150 ff.).

The use of pairs of figures, positive and negative, makes it somewhat more difficult to interpret some of the experiments on equivalence of stimuli than if the reaction were to a single figure, but this latter condition is really impossible of attainment and the differences between the positive and negative stimuli serve to define the basis of reaction far better than the properties of the positive stimulus alone.

Tests for Relative "Identifiability" of Figures. Discrimination problems vary in difficulty and this variation throws some light on the interrelations of discrimination, retentiveness, and recognition in the performance of the differential reaction. To measure the relative difficulty of discrimination problems a routine training technique was followed. The animals were trained to jump to the food platform with both doors open. They were next trained, with 10 trials per day, to jump to a white card and avoid a black. Pairs of stimulus cards to be tested were then presented and training continued with 10 trials per day until the animal made 10 consecutive correct choices on each of two consecutive days. These 20 consecutive errorless trials were accepted as a criterion of learning. Scores are recorded as the total number of trials and of errors preceding the 20 errorless.[3]

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[3]By a trial is meant the behavior from the time the animal is placed on the platform until he jumps to the positive stimulus and receives food. By an error, such a trial in which the animal jumped one or more times to the negative card before choosing the positive. The method seems the best one to express the behavior in relation to chance performance. When the animal is first placed on the platform the chances of his jumping to one or

For the most part the scores are based on the records of separate groups of animals, but when it was desired to compare the difficulty of two pairs of figures the animals were sometimes divided into two equal groups which were then trained in inverse order on the two pairs of figures, and the average scores of the two groups were taken as a measure of comparative difficulty. This is the usual procedure to control effects of transfer of training. It assumes that such transfer occurs equally in either direction. Actually this turns out to be incorrect in some cases, e.g., if animals are trained to choose the largest of three white figures, they will immediately choose the brightest of three gray figures of equal size but, if trained first on brightness, they do not transfer to size. Thus results with this method may be less reliable than with separate groups. In any case the reliability of these comparative tests is low.

The Influence of the Experimenter. The use of controls for cues from the experimenter, as for secondary cues from the apparatus, has become a routine procedure. They have been introduced systematically in these experiments and for the sake of brevity will not be reported in detail. Animals do learn to react to the way in which they are placed on the platform, they may be guided by the position of the experimenter behind the apparatus, by noises in shifting the cards, and the like, but these cues are readily eliminated and in no case reported has a consistent reaction been disrupted by any control except a change in the visual properties of the stimulus cards.

A more subtle influence of the experimenter arises from the fact that the work must be planned from the human point of view. If the general characteristics of visual organization are the same in animals as in man, then experimental tests derived from an analysis of human vision may give a fairly complete picture of the animal's capacity. But if the animal's vision is organized upon an unknown, different principle, the discovery of this organization will be largely a matter of chance, since experiments cannot be devised beforehand to reveal it. Lashley (50, '16) has reported a little evidence that

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other card, which may or may not have been shifted after the last trial, are equal. Five errors in 10 trials therefore represents chance performance. If the cards may be shifted after every jump, whether right or wrong, the animal is not permitted to correct his own errors and a different learning situation is introduced. If all wrong jumps are reported as errors, correct jumps must also be reported to give a means of estimating superiority of the score over chance. We do not know the relative influence of success and error in learning, so any method of counting scores is largely arbitrary.

the unity of spectral colors is not the same for the fowl as for man and Hertz (34-35, '29, '35) has reported that coherence of visual patterns is different for the facet eye of the bee and for the human eye.   Except for these two studies, experimenters have usually made the assumption that the principles of integration are the same throughout the phylogenetic series, and have sought for the presence or absence of human capacities rather than for different modes of organization.

In all of the work especial attention has been paid to aberrant behavior in the hope of picking up clues to unique visual traits. Certain peculiarities of behavior, the dominance of remote stimuli in orientation, the ineffectiveness of small figures well above the visual threshold, and an apparent ready suppression of vision seem to distinguish the rat from man.   These and certain other peculiarities of the rat's behavior in the experimental situation will be discussed in a later section.

Individual Variation.   In tests of elementary sensory functions, thresholds, difference limens, etc., consistent results are obtained from the majority of animals, but whenever the experiments require the discrimination of stimuli which differ in several attributes, marked individual differences in the behavior of the animals appear.   I have carried out a large number of experiments attempting to discover what elements in a given pair of figures determined the discrimination.   Thus, after training with white triangles on a black ground (Figure 2) all animals transfer in critical trials to outlines (Figure 3), the majority to two sides (Figure 4), a few to the bases (Figure 5), about one in ten to the lower angles (Figure 6), and one animal only was disturbed by changing the position of the center of

FIGURE 2   FIGURE 3   FIGURE 4

FIGURE 5   FIGURE 6   FIGURE 7

area of the figures (Figure 7). Munn (66, '30*b*) has reported other tests of the adequate stimulus from these figures.

Occasionally animals have reacted to the distance of the lower corner of the figure from the inner edge of the card; to the slope of the inner line; or to discolorations on old cards. A few animals have transferred without error from horizontal striations (Figure 8) to the horizontal base of the erect triangle.

FIGURE 8   FIGURE 9   FIGURE 10

The results are much like those of a human experiment in testimony; for each subject particular aspects of the situation are conspicuous and the reports of no two may stress the same details. Such individual differences, due to chance in what is noted, are to be expected with complex situations. They lead to apparently contradictory results with different animals, so that norms cannot be established. Nevertheless, the contradictions do not invalidate clear cut results with individuals, although they decrease the reliability of any negative findings.

III. LIMITING CONDITIONS FOR DISCRIMINATION

As a preliminary to study of organization within the visual field, data concerning acuity and differential thresholds must be available, so that we may be sure that the test conditions involve differences which are supraliminal for the animal. No attempt has been made in this study to determine the optimal conditions of adaptation and illumination for vision. Interest was directed rather to the limits of discrimination set by differential thresholds under conditions practicable for tests of the animal's ability to deal with complex visual situations. The tests were therefore made with light adapted animals under diffuse daylight illumination, with light reflected from mat surfaces.

Since in tests of detail vision it was desirable to train the animals to a standard of errorless performance (20 consecutive errorless trials), it was necessary to determine what differences could be discriminated with this degree of accuracy. The threshold was therefore arbitrarily defined as that difference which the

animal could distinguish without error in 20 consecutive trials after not more than 150 trials of training at the given interval. The constants are somewhat higher than might have been obtained, had the more usual criterion of 75 per cent correct after unlimited training been adopted. The difference is probably not great, however, if the indications from studies of acuity can be taken as representative. Extensive tests have been made with striated fields and neither long training nor a criterion of 70 per cent reduces the threshold significantly. It seems likely that the jumping technique forces a maximum of attention, so that the relatively large steps in the series of threshold tests do not reveal the limited range of uncertainty.

Visual Acuity. In an earlier study (Lashley, 53, '30) tests of visual acuity on three albino and five pigmented rats were reported. These placed the acuity of pigmented animals under daylight illumination with black and white striations as between 26 and 52 minutes of arc, and that of albinos between one and two degrees. Similar tests with striations have been carried out with 10 additional pigmented animals. Threshold tests were made with the animal at such a distance that he could bring his eyes not closer than 15 cm. to the stimulus cards. The test objects were cards ruled with alternate black and white lines of equal width. The animals were trained to jump to horizontal and avoid vertical stripes. In training, stripes 2 cm. in width were used (Figure 8). Successive tests were made with 5, 2, 1.5, 1, 0.8, 0.6, and 0.3 mm. lines, with training until the animal failed to make better than chance score in 100 trials. Five animals discriminated 1.5 mm. lines and failed with 1 mm.; three failed at 0.8 mm.; two discriminated at 0.3 mm. striations.

We have found it difficult to rule large areas with fine lines uniformly enough to avoid secondary lines through fusion at threshold limits. This effect was controlled by reducing the size of the stimulus cards from 15 x 25 cm. to 5 x 5 cm. The two animals which had discriminated 0.3 mm. striations failed under these conditions to discriminate lines narower than 1.5 mm. They had evidently been reacting to some irregularities in the ruling. Reduction in the size of the targets also disturbed other animals which had been discriminating below 1 mm.

The figures confirm the results of the previous study. The threshold for the majority of animals lies between 24 and 35 minutes of

arc and it is probable that all records better than this are due to irregularities in ruling the cards.

Ten albinos were tested under similar conditions. The majority discriminated 3.5 mm. lines. None discriminated 3 mm. lines. This again confirms the earlier results, with the threshold located between 1 degree, 10 minutes and 1 degree, 20 minutes.

Tests have also been made with pigmented animals for perceptible distance of separation of solid areas such as those shown in Figures 9 and 10. A horizontally as well as vertically divided square was used, and a single broken circle versus a continuous one. With these figures no animal discriminated when the separation was less than 5 mm. and the majority failed below 5.5 mm. This gives a threshold of approximately two degrees for resolution of large white objects on a black ground under average conditions of daylight illumination.

The majority of rat eyes show marked astigmatism (Lashley, 54, '32). In human vision astigmatism seems to exaggerate the apparent difference in the striations of Figure 8 and to obscure the differences of Figures 9 and 10, unless the black spaces coincide with the axis of sharpest focus. The marked difference in thresholds with the two sets of test objects may thus be due to defects of refraction.

Discrimination of the Direction of Striae. Five animals were trained to discriminate horizontal and vertical striated fields with alternate black and white stripes 1 cm. in width, forming a circular field. They were then tested with horizontal versus sloping striations of the same width at angles of 45°, 22°, 12°, and 6° from the horizontal. All animals transferred without error to the 22° slope, one to the 12° slope. When failure of transfer occurred the animals were trained until they discriminated or until they showed no improvement in 150 trials. One failed to discriminate the 12° slope, 4 reached the criterion of 20 errorless trials with this angle. All failed to discriminate at 6°. The figures discriminated at 12°, by 4 of the 5, are shown in Figure 11.

Fields (13, '35) estimates the threshold for discrimination of an

FIGURE 11   FIGURE 12   FIGURE 13

equilateral triangle with horizontal base from one slightly rotated as between 10° and 5°, which corresponds closely to that found for striations. Johnson (41, '16) reported a threshold between 2° and 5° for a cebus monkey and between 25° and 40° for a fowl, under somewhat different conditions of training.

The Discrimination of Brightness. Several writers have reported measurements of the difference limen for brightness. Yerkes (104, '07), and Moody (63, '29) have studied the mouse and Lashley (52, '30 b) and Slater and Munn (85, '32) the rat. Yerkes reported the lowest thresholds, a discrimination of an increase of 10 per cent above the standard. This was attained by his animal only after long training. The others have reported the difference limen at from 50 to 100 per cent of the standard.

All these investigators used stimulus objects separated by an appreciable distance. Graham and Nafe (23, '30) have criticized this method and have shown that its use with human subjects gives very unreliable results in comparison with studies in which the test fields are contiguous. Crawford (10, '35) has obtained somewhat more consistent results than did Graham and Nafe, but his limens for human subjects are considerably higher than those obtained by other methods.

To avoid this difficulty test objects presenting a lighter shade upon a darker ground have been used in the present experiment. Hering papers were used. The negative stimulus consisted of a 15 x 15 cm. card covered with paper of the standard shade, upon which was pasted a 7 x 7 cm. square of the same paper. The positive stimulus was a card covered with paper of the same shade as the negative stimulus upon which was centered a 7 x 7 cm. paper square of the comparison shade. Both cards thus presented the outline formed by the edges of the central square and the animals were trained to choose the card in which the central square differed in shade from the ground.

Two standard shades were used, a darker matched by 15 per cent white on the color wheel, and a lighter, matched by 30 per cent. Three animals were trained with each standard shade. With the darker, two of three animals failed to reach the criterion of 20 successive errorless trials when the ratio of intensity was 1 to 1.33. All failed when the ratio was 1 to 1.16, although one made better than chance scores at this ratio. With the higher intensity all ani-

mals discriminated when the ratio was 1 to 1.16 and all failed to reach the criterion when the ratio was 1 to 1.08. These figures place the difference limen as roughly one-sixth of the standard intensity. This is considerably better than the results obtained for rats when separated stimulus cards were used and approaches the limen determined by Yerkes for the mouse after protracted training.

Discrimination of Size. Four animals were trained, two to choose the larger, two the smaller of two circles. Four pairs of circles were used, 12 vs. 9 cm.; 8 vs. 6 cm.; 6 vs. 4 cm.; and 4 vs. 1.5 cm. When with each pair 20 consecutive errorless trials were obtained, the size of the smaller circle was increased by gradual steps until each animal made four errors in 10 trials.

Except with the smallest pair, all animals made errorless scores when the ratio of diameters of the figures was as 1.3 to 1.0. A few of the tests were passed when the ratio was 1.2 to 1.0. With the smallest figures the ratio was the same when the animals were trained to the larger of the pair and the smaller was the variable, but animals could not be induced to jump to the 1.5 cm. circle.

Training was not continued beyond the series of trials in which chance scores were made. Somewhat lower values might have been obtained by continued training with differences near the threshold, but the object of these tests was chiefly to determine the differences readily discriminable by the animals. In this experiment it is not clear whether the animals were reacting to the dimensions of the figures or to the amount of reflected light. The ratio of surface areas at the liminal value is at approximately the liminal value for discrimination of intensity under these conditions. In the analysis of "size" discrimination presented later it appears that both linear dimensions and total luminosity may serve as a basis for discrimination. In that experiment the animals discriminated circular outlines of unequal size and of equal total luminosity at a ratio of 1 to 1.5. No tests were given at a lower ratio.

The Discrimination of Visual Distance. The experiments of Russel (83, '32), Lashley and Russel (57, '34), and Lashley (55, '37) have agreed in placing the rat's threshold for depth discrimination over a range of from 20 to 50 cm. at somewhere near 2 cm. This is almost as good as human achievement under comparable conditions, where the subject is required to take an initial set for visual distance, then to touch the stimulus object with eyes closed,

eliminating current control by vision. No new data on depth discrimination are presented in this study, since the discrimination apparatus uses a constant distance, but the data should be kept in mind in later discussion as evidence of the high development of the rat's vision for spacial orientation.

IV. ORGANIZATION OF THE VISUAL FIELD

A. Figure-Ground Relations.

Many of the studies of vision in animals have been dominated by the concepts of "pattern," "shape," and "form" which were formulated by Hunter (38, '13) and Bingham (3, '14) in the early days of the discrimination experiment. Hunter suggested that the most primitive level of visual perception might involve no differentiation of figure from background but merely the differentiation of one total visual field from another. Thus in the discrimination box the animal might learn to react differently to such fields as are shown in Figures 12 and 13, not by distinguishing the triangles as objects, but because the total field of Figure 12 differs from that of Figure 13. To this hypothetical form of organization Hunter applied the term "pattern vision."

Bingham differentiated between "shape" and "form." He defined shape as the specific distribution of light in the visual field. Thus an equilateral triangle with the base horizontal presents a different distribution of light from one with the base inclined. This constitutes a difference in shape. The recognition of the triangle in any orientation constitutes a recognition of its "form" and involves a further step in generalization beyond that required for differential reaction to shape.

These concepts had only a speculative basis and represent only a few of many possible steps in the evolution of visual organization. Moreover, there is no evidence that pattern or shape, as defined, are ever the basis of reaction. In the most primitive eyes capable of giving a differential distribution of light on the visual elements, the rhabdomes are divided into two groups whose stimulation determines antagonistic reflexes (Taliaferro, 90, '20; Mast, 59, '24). Thus the most primitive organization appears to be one in which stimulation of a specific part of the retinal surface initiates a specific reaction; a condition just the reverse of that postulated for pattern vision. In the progressive levels of disintegration of vision described by

Poppelreuter (77, '23) the ability to identify position within the visual field appears as the lowest stage of detail vision. This condition involves differential reaction to different parts of the visual field rather than a reaction to different total fields. Thus neither phylogenetic studies nor evidence from pathology reveals pattern vision as a primitive function.

The logical distinction of form as corresponding to an indefinite series of shapes is no assurance that shape is the more primitive type of organization. If the mechanism of reaction were one of point-to-point correspondence of reflex paths, then shape should be the more primitive. But if seeing the outline of a figure involves some such processes of organization as those postulated by Rachevsky (78, '35), then form should be more primitive than shape. Actually, as will appear in the following sections, the ability to recognize a figure in any orientation is only one of a variety of abstractions concerning figures of which the animal is capable and which require an accurate appreciation of the outlines of the figure. Failure to identify a rotated figure does not mean that the animal is reacting to the absolute distribution of light on the retina, for the animal which fails this problem may give evidence of reaction to other relational properties of the figure.

Figure vs. Total Situation. Most of the experiments reported in the following sections of this paper give evidence that the rat responds immediately to organized visual objects as such and, without special training, disregards the characteristics of the background. They show also that the adequate stimulus is almost always some relational property of the figure such as direction, size, or relative proportion of parts and that some elementary generalization is involved in all visual discrimination. The following two experiments show the figural properties of the adequate stimulus and its independence of the concrete pattern of the total situation.

1. Four animals were trained with cross and triangle (positive) vs. circle and triangle (Figure 14). Learning was slow, re-

FIGURE 14   FIGURE 15

quiring an average of 140 trials with 49 errors. Critical trials were
given with the cross and circle alone, centered on the cards. The
animals selected the cross 16, 17, 19, and 10 times respectively in
20 trials. With the one animal which made a chance score in the
critical trials, the figures were changed to the position off-center
which they had occupied when combined with the triangles. In
critical trials with this change he selected the cross in 19 of 20 trials.
Without further training he then made a perfect score with the
figures centered on the cards.

Other experiments have shown that the triangle is one of the
most readily identifiable of figures for the rat. Nevertheless in
this experiment the triangle was entirely disregarded and the ani-
mals came to react only to those elements with respect to which
the cards differed.

2. Two animals were trained with triangle (positive) and cross
(Figure 15). They were then given critical trials with the patterns
shown in Figures 16 to 27. Their scores in these trials are given
in Table 1. Twenty trials with the training figures, with an aver-

TABLE 1

SCORES IN CRITICAL TRIALS WITH FIGURES 16 TO 27 FOR TWO ANIMALS

The columns at the right give the number of times that the triangle was
chosen in 20 critical trials. Chance scores are italicized.

Figure No.	Description	Animal A	Animal B
16	Outlines	17	20
17	Gray ground	20	20
18	Black on white	*13*	*12*
19	Small figures	18	20
20	Patterned ground, figures centered	18	18
21	Patterned ground, figures excentric	16	16
22	On 2 cm. striae	*8*	*12*
23	Encircled figures	17	20
24	Reduplicated figures	18	20
25	Reduplicated lines	*16*	*10*
26	Figures rotated 90 degrees	*10*	*8*
27	Simple, reduplicated	19	18

age above 95 per cent correct, intervened between each test with
new figures and the next. Failure of transfer occurred with the
reversal of brightness (Figure 18), with coarsely striated ground
(Figure 22), with reduplicated lines (Figure 25) and with rotated
figures (Figure 26). Successful transfer to the other figures shows
that the animal reacts to a limited part of the total visual field and

FIGURE 16

FIGURE 17
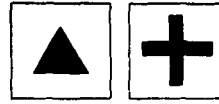
FIGURE 18

FIGURE 19

FIGURE 20

FIGURE 21

FIGURE 22

FIGURE 23
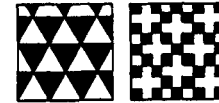
FIGURE 24
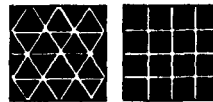
FIGURE 25

FIGURE 26

FIGURE 27

is relatively indifferent to the surrounding ground (Figures 20, 21, and 23), that the exact retinal distribution of light is unimportant (Figures 16, 19, and 24), and that some property of the figure can be identified when the figure is masked in a different total pattern (Figures 23, 24, and 27).

The experiments of Turner (93, '35) and of Hebb (30-31, '37) dealing with the reactions of rats during their first visual experiences also indicate a definite organization within the visual field, such that small masses of light or shade are effective in orienting the animal. In their experiments the isolation of figure from ground by association of visual experiences with manipulative movements was ruled out, so that some innate "forces" of organization must be postulated to explain the results (cf., Senden, 84, '32). The problem of perception is thus primarily one of discovery of the external and internal conditions which determine the functional articulation of the figure.

The studies of Rubin (82, '21) and Wertheimer (99, '23) and other members of the Gestalt school have defined some of the factors which lead to the differentiation of figure and ground in human perception. Among the more important of these are continuity of sur-

face or outline, contrast in brightness or color, the grouping of dis-
crete elements in geometrically simple patterns, orientation with
respect to a frame of reference, closeness of articulation of the figure,
minimal organization, and the like. Few of these are objective and,
indeed, if the forces of organization are within the organism rather
than in the stimulating situations, objective statement, save in terms
of a neurological mechanics of which we know nothing, seems im-
possible.

Studies of perception with human subjects give far less equivocal
data than similar studies with animals, so that there is little hope
of advancing our knowledge of the factors determining visual
organization by experiments with the latter. Nevertheless such
information as we can get, especially from lower animals, may be
suggestive of the nature of the more primitive types of organization.

The methods available for analysis of vision in animals cannot
provide conclusive information concerning the organization of the
visual field. We can only train the animal to give a definite reac-
tion to a visual situation, present another, and ask, is this like the
first? If the habitual response appears, it is accepted as an affirma-
tive reply to the question. The method is therefore concerned pri-
marily with the similarity or identity of attributes of different visual
situations. It can deal with questions of visual organization only
by stating that in two situations differing in specified respects, such
and such factors produce equivalent stimuli for the animal. From
analysis of the situations something of the nature of the total or-
ganization can be inferred, but the method is indirect and obviously
open to errors of interpretation.

In all experiments with visual objects it has been questioned whether
or not the animal ever reacts to the total figure, as it is conceived
by the experimenter, a unified white object on a black ground for
example. The most conclusive evidence that the rat does so is
provided by the experiments on discrimination of size (pp. 167 ff.).
After training on circles of different sizes animals reacted imme-
diately on the basis of linear dimensions, surface area, and total
luminosity. These are attributes of the total figures, not derivable
from any part-figure reaction. Although similar analyses have not
been made for the majority of the stimuli used, there are many indi-
cations that the configurations to which the animals react have for
them essentially the same properties as for the human observer.

Brightness Relations of Figure and Ground. When the figure and ground both present continuous homogeneous surfaces, marked changes in the luminous intensity of either figure or ground do not disturb reaction so long as the brightness relations of figure and ground are not reversed. In one experiment animals were trained to choose a white triangle and avoid a white cross on black fields (Figure 15). Light gray figures (50 per cent white) were substituted for the white in critical trials. The triangle was chosen by all animals without error. The gray figures were than placed on a darker gray ground (40 per cent white). The reaction was undisturbed.

Once the habit of reacting to a given figure is established, it is recognized so long as its difference in shade from the background exceeds liminal value. In original training, however, lack of contrast between figure and ground results in a significant retardation in learning. In the experiments on threshold for brightness (p. 136) the initial training was with a gray square containing 55 per cent white upon a gray ground containing 15 per cent white. The six animals required an average of 153 trials and 48 errors to reach 20 consecutive errorless trials. For a white square on a black ground the average practice required to reach the same criterion has been less than 10 trials with 2 errors for several hundred animals tested.

In all cases where the brightness relations of figure and ground were reversed complete loss of discrimination has resulted. The following experiments are typical of a considerable number of attempts to obtain transfer under such conditions.

1. Five animals were trained to jump to an erect and avoid an inverted triangle on a black ground (Figure 2). They were then given critical trials with black figures on a white ground. Four of the five made chance scores. The fifth jumped 18 of 20 times to the white triangle formed between the black figure and the black frame of the door (Figure 28a).

2. The animals were retrained to the criterion with white figures

FIGURE 28

on black ground. The entire apparatus was then painted white and black figures on white cards presented. All animals made chance scores. Black cards with white figures were then presented in the white apparatus. All animals chose the erect triangle in at least 19 of 20 trials. This is contrary to the result which Fields ('33) obtained in a similar experiment. He used the original form of jumping apparatus. With the modified form shown in Figure 1 the edges of the apparatus give reference lines for orientation of the figures, but there is little evidence that the apparatus forms a ground comparable to that constituted by the stimulus cards.

3. A triangle and cross were cut from the centers of black stimulus cards and the cards presented so that various light colored objects placed on the landing platform might be seen through the holes by the rat. After training under these conditions, white cards with similar openings were presented in critical trials. No animal made better than chance scores.

4. Four animals were trained on erect (positive) and inverted triangles, white on black ground. Gray triangles on a darker gray ground were substituted and the difference in shade reduced to near threshold value without disturbing the reaction. The brightness relations were then reversed, darker gray figures on a lighter ground. All animals made chance scores.

In these and similar experiments no animal has ever identified a figure when the brightness relations of the figure and ground were reversed. Fields (12, '32) has reported a similar result in his studies. He found no direct transfer from white to black triangles. When, however, a reaction was established to a black triangle, following long training with white, the ability to identify the triangle in any orientation, acquired during training with white, did transfer. The ready solution of this problem by the cat (Smith, 86, '36) and chimpanzee (Gellermann, 19, '33b) is in sharp contrast to results with the rat. Neet (70, '33) likewise failed to obtain transfer with reversed brightness relations from Macacus monkeys.

Reaction to Surface Color (?). Various human experiments (Katz, 43, '24) have revealed phenomena of surface texture and sheen related to the appearance of visual depth. The following experiment indicates that the rat as well as man can utilize such cues in the discrimination of objects.

Two animals were trained to jump to a dark gray card and to

avoid a black one. Tests with lighter grays gave transposition to the brighter. A five-sided cubical box lined with black velvet was substituted for the gray card, and presented with the formerly negative "black" card. It was placed on the landing platform with the open side behind the window, so that its interior was visible from the jumping platform. To the human eye the velvet was much darker than the "black" card but lacked solidity of surface. The previous experiments on transposition led me to expect that the animals would choose the black card and avoid the box. In fact, the box was constructed as a means of testing transposition beyond the range of the black card.

In critical trials with the black card vs. the black-lined box both animals after long hesitation chose the box in 20 of 20 trials. Most animals which are jumping accurately to a white figure will jump to an open door of the apparatus in preference to the positive figure. The reversal of the previous behavior in transposition tests with substitution of the black box suggests that the animals may have been reacting to it as to the open door.

The Relation of Figure to Surrounding Patterns. Once a reaction is established to a definite figure, indifferent patterns in the ground do not disturb the reaction.

1. The animals were trained to choose an erect and avoid an inverted triangle. The triangles were then mounted on cards ruled with 5 mm. striations (Figure 30) and presented in critical trials. All animals chose the erect triangle. Unfamiliar figures and changes in the shade of the ground delay but do not disturb the accuracy of reaction, as is shown by the transfer of reaction to Figures 17, 20, and 21, summarized in Table 1.

2. When markings on the ground distort the outlines of the figure beyond undefined limits, reaction is abolished. With the two animals trained on erect and inverted triangles, which had been undisturbed by the 5 mm. striated ground, two cards having the ground ruled with 20 mm. striations (Figure 29) were presented in critical

FIGURE 29   FIGURE 30

trials.   Both animals made chance scores.   The same result was obtained with the triangle and cross of Figure 22.

If the ground contains a pattern which has previously served as a basis for reaction this pattern may dominate the figure, or the combination may interfere with reaction to either, as shown in the following tests.

3.   Four animals were trained to choose horizontal and avoid vertical striations of 10 mm. width.   They were then trained to choose a cross and avoid a circle.   These test objects were then combined so that the cross and circle appeared on striated fields.   With the cross on the vertical striations (Figure 31), the positive figure

FIGURE 31   FIGURE 32

on the negative ground, the scores of the four animals in 20 critical trials were:

	No. 1	No. 2	No. 3	No. 4
Cross (vertical striae)	10	7	10	10
Circle (horizontal striae)	10	13	10	10

The cross was next placed on the horizontally striated field (Figure 32).   The scores under these conditions were:

	No. 1	No. 2	No. 3	No. 4
Cross (horizontal striae)	10	18	16	16
Circle (vertical striae)	10	2	4	4

Without retraining the animals were given critical trials with the original cross and circle and with the striations alone.   All made 90 per cent or better in the selection of the originally positive figures. This experiment shows an interference between figure and surroundings when both have acquired significance for reaction in previous training.   This result is confirmed by the experiments on the relations of internal and external position of the figure, reported below.

Simultaneous Contrast.   Two animals previously trained in a three-door apparatus to a differential reaction with three grays of unequal intensity were used in this experiment.   The test objects used in training were three 10 cm. circles of Hering papers matched with 45, 35, and 15 per cent white on the color wheel and exposed on a

black ground.   One of the animals (No. 1) had been trained to choose the lightest, the other (No. 2) the darkest.   For tests of simultaneous contrast three 10 cm. circles of a light gray (55 per cent white) were mounted upon darker gray papers of 45, 35, and 15 per cent white respectively, corresponding to the shades used in original training.   The least difference in shade between figure and ground was well above the threshold and the fact that the sign of reaction was opposite for the two animals controls any question of the visibility of the figures.   Each animal was given 20 critical trials with this series.   The records of choice were the following.

	Shade of ground		
	Light	Medium	Dark
No. 1 (positive to light)	2	6	12
No. 2 (positive to dark)	10	5	5

Each animal showed a distinct preference for one of the stimulus cards and in each case the selection was against the shade of ground corresponding to the shade of the stimulus patch to which the animal had been positive.   It is clear therefore that the animals were not reacting directly to the shade of the ground, so we must assume a change in the apparent brightness of the stimulus circles corresponding to the phenomenon of simultaneous contrast reported by human subjects under the same conditions.

The Influence of Continuity of Figure.   The importance of continuity of contour or surface in determining figure has been frequently stressed.   The following tests show that for the rat as for man continuity of surface or closed contour contributes to identification of figures, though it is not a prime essential.

1.   Six animals were trained on horizontal striations (positive) vs. vertical striations, 2 cm. in width (Figure 8).   They were then

FIGURE 33   FIGURE 34   FIGURE 35
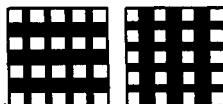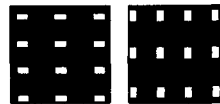
FIGURE 36   FIGURE 37   FIGURE 38

given critical trials with single lines, either continuous (Figure 33) or interrupted by 2 cm. gaps (Figure 34). The three animals tested with the continuous lines chose the horizontal 20, 18, and 20 times respectively in 20 trials. The other three, tested with the interrupted lines, chose the horizontal 19, 18, and 17 times respectively. Interruption of the line interfered slightly, but not significantly with the transfer.

2. Four animals trained on horizontal (positive) and vertical striations, 2 cm. in width, were all given critical trials with the variously interrupted lines shown in Figures 35, 36, 37, and 38. All chose the two horizontal lines of Figure 35. One animal chose the narrow horizontal stripes (right side of Figure 36) in 18 of 20 trials. All did better than chance with Figure 37. Only chance scores were made in all other tests with Figures 36, and 38.

3. The four animals used in the foregoing test were next given critical trials with the zigzag lines shown in Figure 39. All made

FIGURE 39

chance scores. The same result was obtained in other tests with narrower lines and with wavy lines, whenever the deviations from a straight line exceeded the width of the striations.

In these tests with striations, direction of the lines is the determining factor. The width of the lines may be reduced to nearly threshold value or their contrast reduced by half without affecting the accuracy of response. The interrupted figures are equivalent to the striations, so long as they show a dominant direction of masses. Continuity of line, on the other hand, is not alone sufficient to determine direction.

4. Two animals were trained on cross (positive) vs. circle (Figure 40). They were then given critical trials with the interrupted cross and circle of Figure 41. Both made chance scores. The in-

FIGURE 40   FIGURE 41   FIGURE 42

terrupted circle was then rotated 45 degrees (Figure 42) and 20 critical trials given. One animal made a chance score, the other chose the interrupted circle, now a Maltese cross, 20 times.

5. In various experiments animals have been trained with continuous contours such as those shown in Figure 3 and comparison groups with similar figures in which the outlines were interrupted by 1 cm. gaps. In brief, no consistent difference in rate of learning under these conditions has been found. There is no consistent difference between learning of solid figures and outlines in the tests made.

6. Four animals were trained on the interrupted circle (positive) and triangle of Figure 43, four others with the irregular dots of

FIGURE 43   FIGURE 44
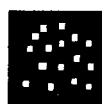
Figure 44, and four with solid white circle and triangle as controls. There was no significant difference in the learning of the solid and interrupted regular figures. No animal made better than chance scores with the irregular dots of figure 44 in 150 trials.

7. Two animals were trained with the pairs of dots of Figure 45.

FIGURE 45   FIGURE 46

Both then chose the sloping line of Figure 46 in 18 of 20 critical trials. Direction, rather than pattern, was the determining factor.

8. Two animals were given initial training on solid erect triangle (positive) vs. inverted (Figure 2) and two others on outlines (Figure 3). They were then given critical trials with the other pair of figures. From outlines to solid figures both animals made no errors. From solid figures to outlines one animal made 4, the other 3 errors in 20 trials. Transfer from outlines to solid figures thus seemed somewhat more certain than the reverse.

The data here are not sufficient to define the conditions under which separate elements are combined into a figure equivalent to a continuous one. Closeness of approximation of the dots is ap-

parently a factor. With geometrically simple figures continuity of outline is apparently not of great importance for recognition. With the striations the animals seem to react to direction, disregarding other attributes of the figures. As will appear in many of the experiments described later, most visual reactions seem to be determined by some such abstraction. Where a pattern of discrete elements might be learned as a pattern, some more general attribute of the figure is likely to form the basis of the reaction, as in Experiment 7 above. Certain types of organization, such as direction and perhaps some simple forms, seem most readily achieved and identifiability of figure depends more upon the closeness with which arrangement of elements conforms to these abstract forms than upon the number of elements which are combined.

Relation of Internal and External Figures. Fields (12-13, '32, '35) has reported for the rat that the external of two superimposed figures dominates reaction. Koffka (47, '35, p. 199) is uncertain about the matter for man. The following experiments show that other factors are more important than internal or external position and that the latter may not be a determining factor of itself.

1. Four animals were trained successively on horizontal (positive) vs. vertical striae (Figure 8), on solid triangle (positive) vs. square (Figure 47), on outline triangle (positive) vs. outline

FIGURE 47   FIGURE 48   FIGURE 49

FIGURE 50   FIGURE 51   FIGURE 52

FIGURE 53   FIGURE 54   FIGURE 55

square (Figure 48), and on cross (positive) vs. outline circle (Figure 49). They were then given critical trials with a combination of triangle with circle vs. cross with square, arranged so that one positive figure was external, the other internal to a negative figure

(Figure 50). The enclosing triangle was chosen 20, 16, 16, and 14 times in 20 trials by the four animals. Definitely, the outer figure dominated.

The white circular outline was next blocked in solid (Figure 51) and critical trials again given. The triangle-enclosing-circle was now chosen 8, 10, 20, and 9 times in 20 trials by the four animals. For three of the four the more conspicuous solid circle, though not previously seen, interfered with the positive reaction to the outer figure.

2. The animals were retrained to 20 errorless trials with the solid triangle and square (Figure 47). They were next given critical trials with these figures combined with internal striations. They had been trained positive to horizontal striations at the beginning of the experiment, but had not seen the striated cards for 90 days or more.

With the triangle (positive) striated vertically (negative) and the square horizontally (Figure 52) the triangle was chosen 0, 0, 2, and 8 times in 20 trials by the four animals respectively. The striations dominated over the external form of the figure. With the positive striations combined with the positive triangle (Figure 53) all animals chose the triangle without error.

3. Solid white triangle and square were next presented on striated grounds, combining positive figure with negative ground (Figure 54), and positive figure with positive ground (Figure 55). With Figure 54 (positive figure on negative ground) the animals chose the triangle 10, 10, 10, and 7 times respectively in 20 trials. With Figure 55 (positive on positive) the triangle was selected 10, 18, 12, and 16 times. Immediately after these tests the animals made errorless scores with striated fields and with triangle and square on black ground. The combined patterns therefore interfered, even when positive was combined with positive. The external figure interfered with but did not dominate the reaction.

When either the figure or the ground was striated, the striations tended to determine the reaction. With the outlines of Experiment 1, the outer figure dominated until a more conspicuous inner figure was introduced, whereupon the dominance of outer figure was abolished. In the transfer experiment with Figure 23 a white circle around each familiar figure did not disturb reaction.

In the experiment on simultaneous contrast described earlier (p.

146) the reaction of the animals was in direct opposition to what it would have been had they transferred their reaction to brightness to the outer figure. Clearly the dominance of inner or outer position of a figure in a complex is secondary to other factors which cannot at present be defined.

Part-figures. Systematic tests have shown that the majority of animals do not react to the entire figure presented in the stimulus patterns. With the same patterns, individuals vary considerably with respect to the effective parts, as was noted above. The most important factor in defining the part-figure is the relation of the stimulus card to the surrounding frame. With the jumping apparatus used the animals tend to jump in such a way as to catch at the inner edges of the frame, where they can sometimes cling and avoid a fall after a wrong choice. Under these conditions the lower or inner margins of the figures most frequently determine the reaction, as is illustrated by the following experiments.

1. Five animals were trained on square (positive) and diamond (Figure 56). They were then given critical trials with the upper,

FIGURE 56   FIGURE 57   FIGURE 58

FIGURE 59   FIGURE 60   FIGURE 61

the lower, and the lateral halves of both figures blackened out. With the lower halves shown (a rectangle vs. a right triangle with apex down) all chose the rectangle 20 times in 20 trials. With the lower halves obscured (a rectangle vs. a right triangle with base down), all made chance scores. With the lateral halves, the scores were 15 to 17 times out of 20 to the rectangle, and all errors were made when the apex of the triangle pointed away from the inner margin of the frame.

This and similar experiments indicate that the animal often does not react to the total figure, as determined by continuity of surface or outline. In various systematic attempts to determine the effec-

tive part of the pattern, such as that illustrated in Figures 2 to 7, animals have been detected in reactions to such various characters as the distance of one figure from the frame, the relative surface areas of the figures, a conspicuous projecting point, and the like. The results suggest that the part-figures are largely determined by functional relations and by chance noting of conspicuous elements.

Usually, however, an animal is able to identify many parts of a figure. Thus several animals trained on the triangles of Figure 2 made better than 80 per cent correct in critical trials with all figures from 3 to 7, and also when the figures were reduced to half size, thus controlling distance from the frame. The most striking instance of this kind is the following experiment.

An animal was trained on the complex arrangement of lines adopted from the "figures lacking identifiability" of Thorndike (92, '31) and shown in Figure 57. He was then given critical trials with parts of the figures, as indicated below. The first tests (Figures 58 and 59) were attempts to guess the effective parts of the figure from the apparent fixation of the animal. Between each set of critical trials, at least 90 per cent discrimination of the full figures was obtained. The numbers on the right represent the times that the part of the positive figure was chosen in 20 trials.

Lines from lower margin (Figure 58)	5
Lines from center (Figure 59)	8
Right halves blocked out (Figure 60)	17
Left halves blocked out	16
Upper left quadrant exposed	9
Lower right quadrant exposed (Figure 61)	20
Upper right quadrant exposed	8
Lower left quadrant exposed	19
Lower halves exposed	19
Upper halves exposed	10
Figures rotated 180 degrees	8

On completion of these tests training with the inverted figures was carried for 100 trials as a control of secondary cues. In the 100 trials the animal did not improve above chance. Subsequent critical trials with the figures in their original position gave 80 per cent correct.

In this series the animal disregarded the upper halves of the figures, but obtained cues from both the lower right and left quadrants.

This behavior confirms the result with Figure 56. The animals must identify the figures in either the right or left position and, reacting to the lower inner margin, they found some cue in each lower quadrant.

Definition of "Figure" in Comparative Psychology. Are we justified in attempting to extend the conception of figure-ground relations developed from studies of human perception to interpretation of animal behavior? Figure is generally described as something perceived as coherent and unitary in contrast to ground, which is somewhat lacking in this property. We cannot, of course, apply such a subjective definition in comparative studies but, if we seek a definition of unity in perception, we may reach an objective expression. Unity is the exhibition of properties which are not inherent in the component parts of an unorganized system and which arise only when the parts are grouped in a functional aggregate. Thus size or direction are properties of a figure which must be distinguished as a unit, if the properties are recognized. With this definition it is quite legitimate to apply the concept of figure-ground relations to the animal's visual field, when a reaction is found to a property which can be derived only from a total aggregate of elements in the stimulus.

The experiments described in this section have shown that the animal reacts to a limited part of the total visual field and disregards variations in the remainder. They have shown that the constants to which he reacts in an otherwise variable situation are properties which can be derived only from a total figure, hence that his reaction is dependent upon some sort of unification of the elements within a part of the field. They have shown that some of the same factors are instrumental in determining this unification as are at play in the production of "figure" in human perception.

B.   The Identifiability of Figures.

The rate at which differential reactions are established with different pairs or groups of figures varies greatly. The tests reported in the following section are attempts to discover some of the factors which determine this rate, as they may bear upon the nature of discrimination and its relation to learning and recognition. Thorndike (92, '31) has used the term "identifiability" to designate the readiness with which figures may be recognized and has pointed out its

importance for learning. This ease of recognition depends, however, upon the characters of other members of the group of figures from among which the one must be selected. It may be, then, that identifiability is not a factor in learning, but in discrimination, in discovering what is to be learned. It is with problems of this sort that the following experiments are concerned.

In Table 2 are given the average scores of a number of groups

TABLE 2

AVERAGE TRAINING SCORES OF GROUPS OF ANIMALS WITH VARIOUS PAIRS OF FIGURES

Training was not continued for more than 150 trials when the animals were making chance scores at this stage.

Description of figures	Trials	Errors	Percent failed in 150 trials
10 cm. white square vs. black	6.6	0.7	0
10 cm. gray square (10 per cent white) vs. black	18.0	5.2	0
2 cm. horizontal vs. vertical striations	20.9	5.7	0
Cross vs. circle, equal areas	30.0	11.6	0
2 white circles, diameters 2:3	37.5	5.5	0
Outlines of triangles, base down vs. up	*43.0*	*10.5*	*0*
X vs. upright rectangle	*49.7*	*11.5*	*0*
Equilateral triangles, base down vs. apex down	53.0	13.0	0
U-figures, upright and inverted	71.0	14.0	15
Triangle, apex down vs. square	85.0	32.0	0
Reduplicated lines (Figure 25)	*86.0*	*26.5*	*33*
Thorndike figures	*91.0*	*24.0*	*66*
Triangle, base down vs. square	95	34	0
Square vs. circle	103	34	75
H-figure vs. *X*	120	24	0
3 white circles, diameters 1:2:4	*125*	*41*	*0*
Cross and triangle vs. circle and triangle	*140*	*49*	*0*
Horizontal *H* vs. 5 pointed star	137	46	20
Cross vs. 2 circles, 3-door apparatus	*150*	*49*	*.0*
Gray squares, 15 and 55 per cent white	153	48	0
Ink blots	*156*	*46*	*75*
S- and N-figures, symmetrical			*100*

of animals in learning a differential reaction between pairs of simple geometrical figures. Most of the groups range from 8 to 48 animals. Scores of groups containing less than 8 animals are italicized. No great reliability can be claimed for the tests, since the number of cases is small and the experiments were carried out over a period of years under somewhat varied conditions. Nevertheless individual

variation is not great and the major differences are certainly significant.

Inspection of the table suggests that the easiest situation is the presence vs. absence of a figure. Next is a clearly marked direction in the axis of one or both figures. Complication of the figures (*H* vs. *X*; cross and triangle vs. circle and triangle) or of the total situation (three figures to be discriminated) increases the difficulty.

Influence of Liminal Differences. The most obvious limitation in discrimination of figures is that set by visual acuity. The distinguishing features of practically all the figures used in this study extend more than 2 cm. from the circle which most closely fits the figure. Patterns such as Figures 19 to 24 have been discriminated, which require more acute vision than any of the patterns with which animals failed.

The pair of figures giving greatest difficulty of discrimination, where the element of acuity might play a part, are the square and circle. In several experiments these have required from 60 to 300 trials for learning and only one-fourth of the animals trained have shown any improvement above chance. Yet acuity is certainly not the chief limiting factor in this case. When the square is rotated through 45 degrees, learning may be rapid with few failures. It is not a question of similarity of the base line of the figures, for circle vs. equilateral triangle with horizontal base is learned very rapidly. Neither with the square and circle nor with any of the other figures reported here is there evidence that the difficulty of discrimination is due to an acuity factor. With the circle and square and other figures lacking contrast for the human observer there is rather great variability in the success of different animals in learning, as if a few hit upon the differentiating character immediately while the majority are hard put to find any difference.

Brightness contrast of figure and ground makes little difference within a wide range, but with both figure and ground gray there was marked retardation.

The Significance of Geometrical Regularity. In human visual perception relatively simple geometrical form seems greatly important. Regular forms are much more readily memorized and recognized than ink blots or any other irregular forms, with the exception of human faces. Whether this ease of recognition is due to familiarity, to simplicity and repetition of structure, or to some innate organiz-

ing tendency remains obscure. Some of the theories of aesthetic proportion imply innate factors, as do the observations of Fuchs (16, '21) upon the completion of figures in the hemianopic field.

A number of tests of the comparative rates of learning with regular and irregular figures have been carried out. The two following are typical.

1. Four animals were trained on the regular forms of Figure 62 and on the ink ·blots of Figure 63. Two were first trained on

FIGURE 62   A   FIGURE 63   B   FIGURE 64
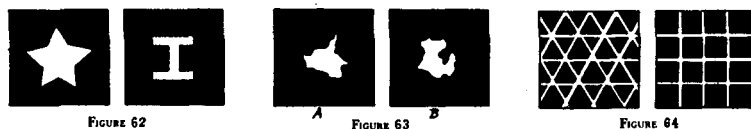
the regular forms, two on the blots, followed in each case by training on the other figures. One of the four failed to make better than chance scores with the regular figures in 220 trials. Two failed to reach the criterion of 20 errorless trials with the blots, though both did better than 70 per cent correct after 150 trials. The averages for those which met the criterion were:

	Trials	Errors
Regular figures	137	46
Ink blots	156	46

No significant difference is shown by these results, which have been verified in several similar experiments.

2. Six animals were trained with the repetitive patterns shown in Figure 64 and with the irregular arrangement of lines modified from two of Thorndike's "figures lacking identifiability" (Thorndike, 92, '31) shown in Figure 57. Four of the six learned the regular figures with an average of 86 trials and 27 errors. The others showed no improvement after 180 trials. Five of the six failed the Thorndike figures, with no improvement in 150 trials. The sixth, after learning the geometrical figures in 90 trials, 21 errors, reached the criterion with the Thorndike figures in 91 trials, 24 errors. (For control tests to determine the basis of reaction to these figures, (see p. 153).

From such results the indications are that a somewhat larger number of animals fail to discriminate irregular than regular geometrical figures, but those which do discriminate require no longer to

learn the one than the other type. There is evidence that those animals which learn do so by isolating some simpler cue or part-figure.

In contrast to these results with continuous figures, simplicity of geometrical arrangement seems essential for the recognition of patterns of dots (p. 149).

Discrimination of Symmetrical Pairs of Figures. In human reading confusion of symmetrical letters is often reported. Confusion of horizontal symmetries is more frequent than of vertical. Thus *b* and *d*, and *p* and *q* are confused; *b* with *p*, and *d* with *q* rarely. Mirror writing is common, inverted writing rare.

The confusion of symmetries may represent a more primitive level of organization than their differentiation; an effectiveness of the configuration of excitation, irrespective of its orientation. Or differentiation may represent the lower level, with tendency to confusion arising with the development of symmetrical movement systems in turn controlled by some mechanism of hemisphere dominance, as postulated by Orton (72, '25).

Tests of the ease of discrimination of symmetrical pairs of figures have been carried out with a number of rats.

1. Fifteen animals were trained on each of the patterns shown in Figures 65 to 68, triangles and *U* patterns in horizontal and ver-

FIGURE 65   FIGURE 66   FIGURE 67

FIGURE 68   FIGURE 69   FIGURE 70

tical reversal. The learning scores for the four groups were the following; the averages based only on cases which reached the criterion in 150 trials or less.

	Trials	Errors	No. failed
Triangles, vertical reversal (Figure 65)	42.0	10.3	0
Triangles, horizontal reversal (Figure 66)	33.0	7.4	0
U-figures, vertical reversal (Figure 67)	70.5	14.3	2
U-figures, horizontal reversal (Figure 68)	119.4	32.6	5

The learning scores with the symmetrical figures do not significant-
ly exceed those for non-symmetrical pairs of figures of the same order
of complexity, as listed in Table 2. The difference in difficulty
between triangles and U-figures is greater than the difference of
horizontal and vertical symmetry.

The greater difficulty of the horizontally reversed U-figures is
significant and may indicate a confusion introduced by the sym-
metry. It is more probably due to the identity of base-line of these
particular figures.

2. Five animals were trained on each of the N- and S-designs
shown in Figures 69 and 70: five others on each pair rotated 90
degrees. None of the 20 animals discriminated these figures in 150
trials.

3. Two animals were trained on a clockwise vs. a counterclock-
wise involute of a circle. Neither made better than chance scores
after 300 trials.

The figures in Experiments 2 and 3 lack conspicuous identifying
elements, other than relative position of parts which are remote from
the frame of reference provided by the edges of the cards. Sym-
metry was probably of less importance than lack of distinct identify-
ing features in determining the failure to differentiate these pairs.
In general, there is no clear evidence that the normal animal
confuses mirror-image figures.

Complexity of Figure and Situation. The term complexity is very
freely and loosely used in current psychological literature. It most
often refers to the number of items which the experimenter can dis-
cover and enumerate in the situation, but frequently the only basis
for the judgment of complexity is the apparent psychological diffi-
culty of the task. Viewed as a whole, which is the more complex,
Figure 21 or Figure 24, Figure 57 or Figure 64? In each case
one of the figures contains more lines, and more recognizable part
figures than the other but these are arranged in a repetitive pattern.
If complexity is defined as number of elements, then the regular
figures are the more complex. But if lack of conformity to a con-
ceptual plan containing few elements is taken as the criterion, then
the irregular figures are the more complex. It is in the latter sense
that most judgments of complexity are actually made.

There is little evidence that the number of items influences the
identifiability to any great extent. The reduplicated lines of Figure

25 rank with triangle vs. square in ease of learning for the rat and are significantly easier than *H* vs. 5-pointed star (Table 2). Where increase in items seems effective, as in the difference between cross vs. circle (30 trials, 11 errors) and cross plus triangle vs. circle plus triangle (140 trials, 49 errors) the difference may be ascribed to other causes—the fact in this case that the figure nearest the center bar of the apparatus was alternately significant and nonsignificant. Where the pattern contains many items, the animal solves the problem by disregarding most and reacting to a part-figure.

Number of variables in the total situation does apparently increase its difficulty. Thus cross vs. circle in the 2-card apparatus requires 30 trials with 11 errors, whereas cross vs. 2 circles, in the 3-card apparatus requires 150 trials with 49 errors, and size discrimination with 3 circles requires 4 times as much practice as with 2 circles. These results are the opposite of those reported by Fields (13, '35) who found that apparatus presenting 5 cards gave more rapid learning than the 2-card apparatus. Our apparatus and methods of training are so different that it is impossible to interpret this contradiction. The results are in agreement with those of Grether and Wolfle (24, '36), who report a progressive increase in learning time in a brightness discrimination experiment with increase in number of stimulus cards from two to five.

Conformity with a Frame of Reference. Next to presence vs. absence of a figure, the horizontal and vertical striations of Figure 8 have been most readily learned by all animals. Other figures in which conspicuous lines differ clearly in direction are also easily learned. A certain correspondence of these directions to the vertical and horizontal axes is important. Thus Figure 8 is learned very quickly but, if the lines are sloped 45 degrees in opposite directions, the difficulty is increased, and the contrast is still more pronounced, if circular frames like those of Figure 11 are introduced.

In experiments with horizontal vs. vertical striations more than half of the animals studied have reached the criterion of 20 consecutive jumps to the horizontal lines without once jumping to the vertical. With training positive to the vertical no animal has ever made better than chance scores in the first ten trials.

In training experiments to establish reactions to numerical relations where several variable figures were displayed on each card the animals most readily learned to react to the direction of the black

spaces between the figures, whenever these had a determinate direction.

Next to direction, distance from the dividing partition between the doors of the apparatus seems most readily identified, and is likely to provide the cue to discrimination. When marked differences in size or surface area of the figures exists, the animals are likely to disregard form entirely and transfer to any figures which differ similarly in size (see the analysis of "size" on p. 167). When the figures contain many elements, the animal either disregards the elements when they conform to a regular geometrical plan, as in the case of Figure 43, or reacts to some limited part, as with Figure 57.

Although the evidence is very sketchy, it all seems to point in the same direction. The identifying feature is conformity to a more general frame of reference, either spacial orientation or position in a linear quantitative series. We have seen that with very complex or interrupted figures a regularity of geometrical arrangement facilitates learning, and this regularity also introduces dominance of direction or other means of relating the figure to some frame of reference. With very complex irregular figures, the basis of discrimination is a part-figure; the response is to some limited cue and the remainder of the figure is ignored. The part selected seems to be determined by its relation to the boundaries of the stimulus card, again a dominance of direction and distance. Thus recognition seems never to be specific but always the identification of some property of the figure with a more general reaction tendency.

C. Primitive Forms of Abstraction

An organism may give the same reaction to various objects because it lacks sensory or integrative capacity to distinguish between them. This may give rise to a false appearance of generalization, if to the human observer the objects differ widely except for a single common attribute. The orientation of Euglena may be determined by the relative intensities of two lights, because, in spiral course the avoiding reaction to shading orients it to a direction in which the least change in intensity of light on the eyespot is brought about by its spiral course (Mast and Johnson, 60, '32). The insect may react more readily to radiating flower patterns (Hertz, 34-35, '29, '35), not because the flower forms are generalized as biologically signifi-

cant objects, but because the facet eye is maximally stimulated by the flicker produced by involved contours (Wolf, 101-102, '33, '35). Reaction to a single stimulus in otherwise nonstimulating situations requires only a simple reflex mechanism, and does not raise the problem of generalization or abstraction as it appears in human behavior.

When, however, an organism is variously stimulated by constellations of forces in two situations and reacts only to those forces which are common to the two, some mechanism in addition to a simple sensory-motor connection must be postulated. There is selective reaction to the common properties of the two situations and an inhibition of reaction to other properties determined by the internal organization of the reacting system. In the conditioned reflex experiment on differentiation of the stimulus this internal organization is developed by a series of combined stimulations in which reaction to the stimulus or attribute to be differentiated is reinforced and that to others subjected to experimental extinction. In the discrimination experiment much the same thing seems to happen. Presented with a pair of stimuli, the animal reacts to first one, then another attribute. There is reinforcement of reaction to one, inhibition of reaction to others by punishment, until the significant character is isolated from the total complex of stimuli. But perceptual organization and discrimination must always have occurred before the differential training can be effective. Once such a reaction has been established the animal will identify the familiar attribute among a group of unfamiliar stimuli.

A review of the experimental literature on abstraction and the formation of concepts reveals that these expressions are used to designate just such a process as this. In his study of the "evolution of concepts" Hull (37, '20) required his subjects to discover the identical element in a series of Chinese characters and applied the term "generalizing abstraction" to the recognition of the identical element. In his "simple to complex" method the procedure was essentially the same as in our tests with Figures 15 to 27. Other investigators have sought to exclude the recognition of identical elements from the concepts of generalization and abstraction and to limit the terms to cases in which the common element is relational or propositional. Thus the stress which has been laid upon the animal's ability to develop a "generalized conception of form" seems

to derive from the notion that this particular sort of generalization marks a sharp inflection in the evolution of intelligence.

In contrast to such a view, I wish to emphasize that the sort of generalization implied in Bingham's definition of form is only a particular instance in continuous series of generalized abstractions. It is more difficult for the animal than the recognition of direction but less difficult than the discovery of the common attribute of size, when the brightness relations of figure and ground are reversed.   The fundamental process, the identification of the common properties in two or more constellations of elements, seems to be almost universal among animals, appearing wherever a differential reaction is established.   In the course of evolution this basic process of isolating and identifying common properties of objects has changed little, if at all. By both rat and man, a variety of properties of objects are immediately perceived and behavior is associated with those found by trial and error to have functional significance.   The problem of the evolution of the capacity for generalization is really a question of the kinds of properties or of relations between objects with which animals at different evolutionary levels can deal.

Identical reaction to the identical existential elements in different situations is logically the simplest form of generalized reaction. That it is physiologically the simplest or most primitive is doubtful, but that question may be ignored for the present. Plenty of evidence has been presented to prove that the rat can give a consistent reaction to a constant figure on a varied ground.   It has also been shown in equivalence tests that the basis of reaction is not the identical existential element but the presence of some more abstract common property.

What kinds of relations can the animal perceive and what is their comparative difficulty? For the rat, after presence vs. absence of object, direction seems the most easily distinguished of all properties and to be the one which dominates reaction when situations differ in several respects.   Next in order of difficulty seems to be the relative position in a linear, directional series. Relative size, brightness, or distance seem to form the basis for a very primitive reaction. In view of the recent controversy concerning the problem of transposition and the directional nature of quantitative differences (Warden and Rowley, 95, '29; Perkins and Wheeler, 76, '30) the following experiments are significant.

Relative versus Absolute Factors in the Discrimination of Size.
Transposition in reaction to stimuli forming a linear series has been
demonstrated in a great variety of animals and under ordinary con-
ditions of training seems to dominate reaction to the absolute prop-
erties of the stimuli. Under other conditions the animal may respond
to the absolute properties of the stimuli rather than to the relative.
The psychological problem, as Warden has pointed out, is to deter-
mine the conditions under which each of these types of reaction is
dominant.

Neurologically there is a more fundamental problem concerning
the mechanisms of stimulation involved. In the writings of many
reflexologists there is implicit or expressed the theory that the basic
response is to the absolute properties and that only by the formation
of a vast number of specific reactions is the generalization concerning
the relative properties of the stimuli built up. An alternative
hypothesis assumes that the primitive mechanism of reaction is one
which determines response to ratios of excitation, the absolute re-
sponse being derived secondarily by limitation of this mechanism. A
third alternative is, of course, that the neural mechanisms involved
in the two types of response are independent.

As a means of testing the dominance of the relative or absolute
aspects of the stimuli I have attempted to devise a situation where
neither aspect is emphasized. The animals were confronted with
three doors bearing white circles on a black ground. The ratios of
area of the circles was 1:2:4 (Figure 72). Three groups of four
rats each were used. For one group the largest circle, for a second
group the intermediate, and for the third group the smallest circle
was made positive, the other doors being blocked. The training
records are presented in Figure 71, plotted as percentage correct in
groups of 20 consecutive trials. There was a slight initial prefer-
ence for the larger circles, quickly overcome by the group trained
to the smallest. The groups trained to the smallest and largest
circles learned rapidly and reached the criterion of 20 consecutive
errorless trials after 120 and 160 trials respectively. The group
trained to the intermediate circle, on the contrary, gave no evidence
of improvement above chance scores within 200 trials. Two of the
animals of this group were then trained to leap to the largest and
the other two to the smallest circle. Their combined scores are shown
at the right (1. or s.) in the figure. They attained the criterion
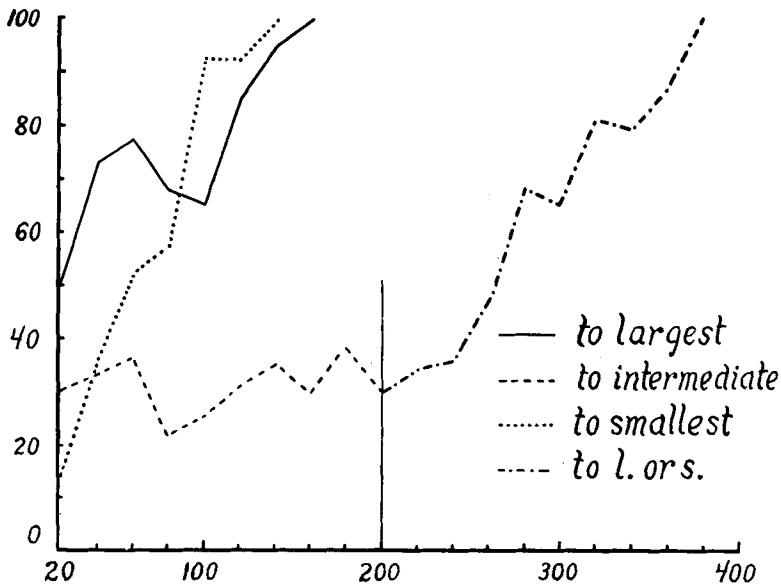
FIGURE 71

TRAINING SCORES, EXPRESSED AS AVERAGE PER CENT OF CORRECT RESPONSES IN
SUCCESSIVE GROUPS OF 20 TRIALS, FOR THREE GROUPS OF ANIMALS
TRAINED RESPECTIVELY TO THE LARGEST, THE INTERMEDIATE,
AND THE SMALLEST OF THREE CIRCULAR FIGURES OF
UNEQUAL SIZE PRESENTED SIMULTANEOUSLY

After 200 trials the animals of the "intermediate" group were trained to
the extremes, with averages shown beyond the vertical line.

after 180 trials. Their failure with the intermediate circle was there-
fore not due to inferiority of the group, but to the nature of the
situation to which they were at first required to respond.

In this experiment, where the opportunity was equal for reaction
upon an absolute or a relational basis, only the latter was effective.
The animals were quite unable to learn the problem of "intermediate
size." On an absolute basis this should have been no more difficult
than reaction to the largest or smallest.

Wolfle (103, '36) has succeeded in establishing a discriminative
reaction to the intermediate of three intensities of light in the rat,
using the technique of Warden and Rowley and relatively enormous
differences in intensity. The behavior of extremes in a linear series

has not been systematically investigated but many facts indicate that large intervals in the scale radically alter the situation. A pinhead and a cartwheel are less obviously different in size than a dime and a quarter; they just do not belong in the same series. In order that a series have direction there must be not only difference but also similarity between the elements. The contradictory results of Taylor (91, '32) and Lewis (58, '30) on transposition for brightness series with the chick may be ascribed to this fact. Taylor used a series consisting of black, gray, and white with negative results. Whether black and white are truly members of the gray series has been frequently discussed in other connections and this problem seems as genuine for the chick as for man.

In Wolfle's experiment, as in those of Warden and Rowley and Warden and Winslow the training was such as to break down any association based upon relational properties. Even so, McCulloch (61, '35) concluded that when the animal is selecting the intermediate of three stimuli he reacts at least in part on the basis of membership of the positive stimulus within the lineal series.

In all tests reported with brightness or size, where relational reaction has not been opposed by the conditions of training, transposition has been obtained. Gulliksen (27, '36) has shown that accuracy of transposition increases in proportion to the accuracy of discrimination with the training series; that continued training confirms the relational behavior and does not tend to establish reactions to absolute properties. Hebb (31, '37) has found that without previous visual experience the rat reacts both to brightness and size on a relational basis and that the same type of reaction dominates in animals lacking the striate areas of the visual cortex We are therefore compelled to recognize that the most available and probably also the most primitive mechanism of response to a quantitative series is a relational one.

For an explanation in neurological terms the problem of response to a quantitative series on an absolute basis offers fully as great difficulties as a relative response. Differential response to two separate receptors may be dealt with in terms of two independent arcs and presumably this conceptually simple situation accounts for the feeling that the reflex explanation is always the simplest. But in a differential response to brightness the same receptors are stimulated at different intensities. The spinal reflex, stimulated at different

intensities, shows a continuous relationship between intensity of stimulation and intensity of response. The only case where this is not true have been ascribed to Wedensky inhibition, where reaction follows weak stimulation and inhibition is brought about by stronger stimulation through interference of impulses at higher frequencies. Such a mechanism might give differential reactions to two intensities with a "zone of uncertainty" between them. To account for the discrimination of several intensities of light and for building up new reactions by training it would be necessary, however, to postulate some additional mechanism capable of changing the position of the "zone of uncertainty" and for establishing several reversed shifts from excitation to inhibition, in case several intensities of light are discriminated. I am not concerned to develop such a theory, since it seems too improbable to justify the effort, but merely suggest it to emphasize that differential reaction on an absolute basis is not the obviously simple process that it is sometimes held to be.

The Basis of Reaction to "Size." Objects differing in size, as the term is commonly applied, actually differ in linear dimensions, in surface area, in the total amount of light reflected, and in their position with respect to the frame of reference. A series of tests was carried out to determine which of these variables formed the basis of discrimination.

Three solid white circles were presented (Figure 72). The ratio of areas of the figures was approximately 1:2:4. Two animals were trained to choose the largest, two the smallest of the three. After training, tests for transposition were given with positive results except where reaction to a very small circle was required. Next the series of patterns shown in Figures 73 to 79 were presented in critical trials, with 20 retraining trials between the tests with each pair of figures. The characteristics of the figures were the following:

Figure 73. Triangles: form and distance from frame altered, relative surface area and linear dimensions unchanged.

Figure 74. Outlines: Surface areas equated, linear dimensions unchanged.

Figure 75. Gray circles of equal area with surface brightness in the ratio 1:2:4. Dimensions and area altered, total reflected light unchanged.

Figure 76.   Gray circles with areas of 1:2:4, equated in total light reflected.

Figure 77.   Black circles of same ratio on white ground.

Figure 78.   Vertical striations of unequal width: areas equated, ratio of widths 1:2:4.

Figure 79.   White circles of equal diameter with central black discs of unequal size.

FIGURE 72

FIGURE 73

FIGURE 74

FIGURE 75

FIGURE 76

FIGURE 77

FIGURE 78

FIGURE 79
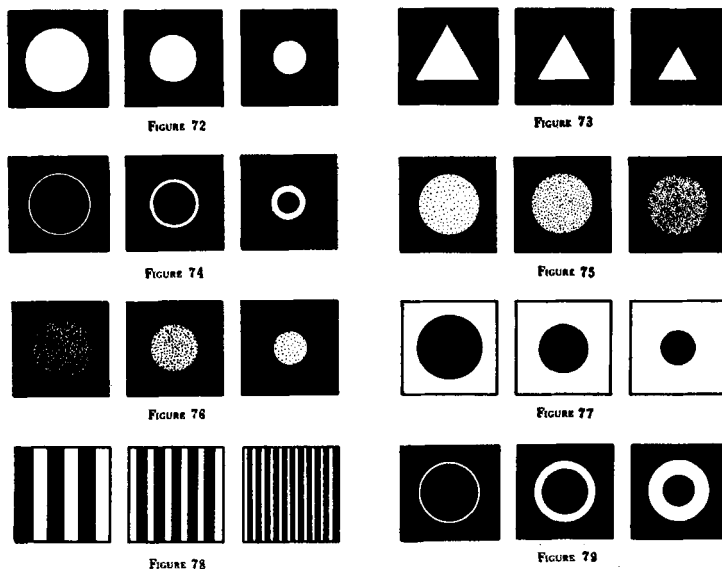
The records of the animals are shown in Table 3.   Rat No. 4 failed to show a preference with the gray circles of equal area and Nos. 3 and 4 failed with the vertical striations.   All other tests exhibited a consistent and significant preference.   The average score in the intervening critical trials with the training figures was 90.5 per cent to the largest circle (based on 640 critical trials).

Alteration of the shape of the figures did not destroy the reaction (Figure 73).   Equation of surface areas was somewhat disturbing but all of the animals chose the appropriate figure in the majority of trials (Figure 74).   When areas were equated three of the four animals chose on the basis of surface brightness or total luminosity (Figure 75).   With the same difference in surface brightness but

TABLE 3

RECORDS OF CRITICAL TRIALS FOR FACTORS INVOLVED IN DISCRIMINATION OF
"SIZE"

The numbers represent the number of times that each of the three stimulus
cards was chosen in 20 critical trials. The cards of each set are desig-
nated *a, b, c,* reading from left to right in the figures.

| | Positive to largest | | | | | | Positive to smallest | | | | | |
| | Rat No. 1 | | | Rat No. 2 | | | Rat No. 3 | | | Rat No.4 | | |
Figure	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
73	20	0	0	20	0	0	0	3	17	0	2	18
74	12	8	0	14	4	2	0	1	19	2	4	14
75	8	10	2	12	8	0	4	4	12	6	8	6
76	8	12	0	14	6	0	0	0	20	0	10	10
77	0	6	14	0	7	13	10	6	4	12	6	2
78	18	2	0	14	2	4	8	2	10	6	8	6
79	0	6	14	2	8	10	8	6	6	12	4	4

with the difference in size restored the animals again reacted on
the basis of dimensions (Figure 76). When the brightness relations
of figure and ground were reversed (Figures 77 and 79) the animals
showed a preference for the greater area of white ground, in 7 of
the 8 tests. Both animals trained to the largest circle unmistakably
chose the broadest of the three sets of striations. Animals trained
to the smallest circle failed to transfer (Figure 78).

This experiment shows that during initial training with "size"
at least some of the animals acquired the capacity to react inde-
pendently to linear dimensions, to surface area, and to total reflected
light. Rats can be trained quite readily to distinguish between any
of the figures which were equivalent in this series of critical stimuli,
as between circle and triangle or white and gray circles. From their
hesitant behavior and less than perfect scores it is clear that they
recognized some differences between the training circles and the test
objects. Nevertheless they were able to identify the properties com-
mon to the different figures. During initial training with objects
differing in "size," at least some of the animals acquired reactions
to linear dimensions, to surface area, and to the total amount of
reflected light and were able to recognize these attributes when
presented separately.

That some function was involved other than reaction to objec-
tively identical elements in the different situations is shown by
failure in other experiments to obtain transfer in the opposite direc-
tion. Groups of animals were given initial training on circles of

equal size and different surface brightness (Figure 75) and on the vertical striations of different widths (Figure 78). They were then given critical trials with white circles of unequal size and with the other test objects of the above series. The animals trained on surface brightness transferred to Figure 76. No animal made better than chance scores with any of the other figures. If the equivalence of stimuli in the first experiment had been due to recognition of identical elements in the figures, transfer should have been equally easy in either direction. The fact that it was not shows that the common attributes were abstractions from "size" differences and that generalization from different figures is not equally easy.

Chang (8, '36) has reported experiments in which rats were trained on figures combining differences in both size and form, then were tested to determine to which of these variables they were responding. Animals trained to the larger figure reacted on the basis of size, those to the smaller figure, on the basis of form. Chang correlates this with the facts that it is more difficult to train animals to jump to the smaller than to the larger of two figures and that the different forms which he used are learned at an intermediate rate. The basic reason for the difference in difficulty of learning is not revealed by his study, but it shows, as do my own experiments, that the effective cue is determined by internal conditions of organization.

Reactions to other Linear Series. Gulliksen (26-27, '32, '36) and Hebb (31, '37) have reported transposition with objects differing in brightness or size in experiments with the rat, and others have obtained it with every vertebrate tested. It is not obtained with all series which appear continuous to man; it is limited at the extreme limits of series; is rarely 100 per cent accurate. But without specific opposed training, such as used by Warden and Rowley (95, '29), reaction on an absolute basis has not been demonstrated. With unidimensional series the alternative to a relational reaction is a chance score.

There are some definite, and probably many as yet undetermined, limits to this type of reaction. Obviously with very large circles which cannot be seen all at once discrimination cannot be based on "size" but must depend upon appreciation of the relative curvature of an arc. With wave-length of light transposition occurs within the limits of certain of the primary colors—one light is more redish than another—and probably occurs with animals as well as man

(Lashley, 50, '16), but it is limited by development of receptors having differential sensitivity and a limited range.

In tests with the rat for transposition with objects of different sizes it is more difficult to get selection of the smallest object and transposition in the direction of smaller size than in the reverse direction. In the jumping apparatus the untrained rat tends to choose the larger of two white objects, as is evident from Figure 71. It is almost impossible to train him to jump to a single figure of less than 2 cm. diameter, although no difficulty is encountered, if two or three such figures are scattered on the stimulus card. Hebb found the same thing true of animals which had had no previous visual experience. This great reluctance to jump to small figures is unexplained. Such figures are well above threshold value and their total surface area may exceed that of the outline of a larger figure to which the animal readily jumps. Much of the behavior of the rat with the jumping apparatus suggests that the figure is not a symbol indicating the correct card but is an object upon which he jumps. With solid figures most animals strike the center of the figure or claw at its upper margin and the refusal to jump to small figures may be a result of this identification of the figure with the landing place.

Whatever the explanation of the behavior, it indicates that reaction on a relational basis in one part of a linear series does not assure that the same property will be effective throughout its extent.

No transposition has been obtained with directional series other than those of brightness and over-all dimensions of the test objects.

1. Four animals were trained to choose the widest of three sets of vertical striations (Figure 78), of 5, 10, and 15 mm. width. Three of the four learned this, though slowly. They were then presented with cards ruled with 10, 15, and 25 mm. striations. No animal made better than chance scores in these critical trials. There was no preference either for the widest stripes or for the originally positive 15 mm. ones.

2. Several tests with numerical series have been carried out. In typical experiments animals were trained to choose 3 vs. 2 rectangles (Figure 80) and given critical trials with 4 vs. 3, with the external dimensions of the figures held constant. Other animals were trained on 3 spots vs. a number varied from 2 to 7 (Figure 81), then tested with different arrangements of spots, lines, or larger

FIGURE 80   FIGURE 81

figures. All such experiments gave negative results. The animals could learn particular pairs of figures but either failed to transfer to other figures of the series or, if they did transfer, proved to be reacting on the basis of some common spacial arrangement of the objects. Dr. Yum has since extended this study in an elaborate series of tests with intensive training and with essentially similar results.

In contrast to the ease with which transposition up or down a linear scale may be obtained is the difficulty of developing a reaction to "intermediate," found in the experiment on relative vs. absolute discrimination. This generalization, involving as it does the combination of two directional tendencies, exceeds the ability of the rat under the conditions of this experiment.

Absolute Properties in Successive Comparison. The inaccuracies of response in the equivalence tests with three stimulus cards generally involve the pair of figures most like the positive one of the training series. Thus with the circles equated in total light reflected (Figure 76) rats Nos. 1 and 2 confused the larger pair and rat No. 4 the smaller. No animal chose the figure least like the positive training figure in a total of 80 trials. This confusion cannot be ascribed to liminal differences, since it occurs at opposite ends of the scale, depending upon the previous direction of training of the animal. The mistakes are generally made when the two objects most like the positive training object are placed in the lateral positions with the least similar object between them. In this situation the rat usually sways back and forth, pointing his nose at each card many times before making a decision. When he does not make such a protracted comparison, errors are made.

Movements of the head indicate that the rat's field of clear vision is relatively small. With groups of figures (Figure 20) very definite movements of fixation are made toward each of the objects on the same card. With the three-card apparatus it is certain that the animal cannot see clearly the two lateral cards at the same time. He must therefore make a successive comparison of the objects

displayed on these cards and must remember the absolute size of one long enough for comparison with the other. He can do this when the situation is familiar through long training, but not when the situation is radically changed in the equivalence tests.

Generalized "Concepts" of Form. The series of experiments with Figures 15 to 28 (pp. 139-141) show that once an animal has learned a differential reaction to a pair of figures he is able to recognize them in spite of alterations in size, in continuity of surface, or of outline, and is able to discover the figure in various combinations with irrelevant lines. In this there must be some primitive generalization of form which goes beyond the recognition of identical elements. The reaction is independent of any characteristics of the patterns except those contained in the internal proportions of the figure.

Fields found that, without special training, the rat is unable to identify a triangular figure when it is rotated more than 10 degrees from the position in which it had been learned. Only after long training with triangles in many positions did his animals learn to identify a triangle irrespective of its orientation.

Failure to recognize figures rotated through 90 degrees has been confirmed in several experiments, as with the cross and triangle of Figure 26 and the Thorndike figures of Figure 57. However, with very unlike figures the opposite result has been obtained.

Two animals were trained to choose a large *H* (positive) and avoid an *X* of equal surface area and length of major axes (Figure 82). The cards were then rotated through 90 degrees (Figure 83)

Figure 82   Figure 83

and 20 critical trials given. One animal chose the rotated *H* in 18, the other in 20 of the 20 trials. Control tests with fresh cards and with cards bearing other designs assured that the reaction was to the visual properties of the figures. Beyond this no attempt was made to analyze the basis of the reaction.

Gellerman (18, '33a) has listed 6 requirements for proof that the

animal can discriminate form "per se." These, formulated for triangularity, are:

1. A subject must be able to learn to discriminate a triangle from other forms.

2. He must be able to maintain the discrimination throughout *rotation* of the triangle.

3. His discrimination must be independent of absolute or relative size.

4. He must be able to respond to *all types* of triangles, as well as to the particular one upon which he was trained.

5. He must be able to respond to *outlined* triangles as well as to solid figures.

6. His discrimination of the triangle from other forms must be independent of the particular *backgrounds* in which the forms appeared.

In one or another test reported in the foregoing sections the rats have met every one of these criteria. We may therefore conclude with Fields that the rat has a conception of form *per se*. The importance of this particular test of ability to generalize has, however, been considerably exaggerated, as if there were only one kind of generalization which must be either present or absent. Actually there seems to be no difference in principle between the abstraction of *size* and of *form per se*. Both involve the discovery of relational properties common to several stimulating situations. Transposition in a brightness series is easier for the rat than is the recognition of a rotated figure, but the latter is easier than is transposition for width of striations (Figure 78) or in a numerical series. The rat can find the common difference in the figures on page 141, but he would never find the identical elements in Hull's Chinese ideographs. We are not justified in assuming that abstraction or the formation of concepts appears as a sudden advance or unique trait in the evolutionary scale. It appears rather that the fundamental process of generalization is involved in all discrimination and that evolutionary development has been concerned chiefly with the application of the process to particular kinds of material or of relations.

Generalizations of a Second Order. In all of the tests reported it has been possible to vary the stimulus figures through a fairly wide range without disturbing the reactions. The adequate stimulus

seems always to be some relational property of direction, distance, size, proportions, or the like. In generalizations at this level the rat is not markedly inferior to higher mammals. When, however, the problem requires a reaction to a combination of properties the limits of his capacity are approached. Difficulty arises when two variables must be reacted to simultaneously or when one variable determines the reaction to another.

Reaction to the "intermediate" of three figures in a directional series seems to require simultaneous reaction to both "larger than" and "smaller than." I have failed to obtain this. The experiment of Wolfle (103, '36) may have involved it, though the reactions in that case were more probably on an absolute basis.

Borovski (4-5, '30a and b) has reported experiments in which the reactions to one property of the stimulus were determined by another. He succeeded in training rats concurrently to choose the larger of two circles and the smaller of two triangles. In this case the form of the figure presumably determined the sign of the reaction to size. He also attempted to train animals to choose, of a triangle and circle, the triangle when on a white ground, the circle when on a black. In this task the animals failed.

Borovski's experiment was not well controlled, as Munn (69, '33) points out. His apparatus allowed the animals to crawl through holes, forming the figures to be tested, and he did not demonstrate that the reaction was visual. He did not show that the reactions were to size rather than to the position of the lower edge of the openings. In the experiment with black and white grounds the figures occupied a constant position and the animals failed to make the discrimination. This confirms the suspicion that in the successful experiment the animals were not reacting to the visual properties of the figures. We cannot, therefore, accept his experiments as conclusive.

The generalization required in Borovski's experiment was conditional, of the order, if a, then b. Two other methods have been tried to establish generalizations of this type at a still higher level of complexity. In the first of these the animal was required to compare the stimuli with a separate model and to choose the one like the model.

1. The three-door apparatus was arranged so that the middle door was always locked and the animals were trained to jump to the lateral doors. The cross and circle, figures easily discriminated

by the rat, were chosen for the experiment. These two figures were irregularly alternated between the lateral frames. A similar cross or circle was exposed at each trial in the middle frame. The animal was required to choose the one of the two lateral figures which was like that in the middle frame.

The animals readily learned to jump only to the lateral frames. Their training records for 200 trials are summarized in Table 4.

The reduction in number of false jumps during the tests is due to elimination of the tendency to jump more than once to the wrong figure in any single trial. The slight improvement in percentage correct choice resulted from an increased tendency to alternate be-

TABLE 4
TRAINING SCORES OF ANIMALS REQUIRED TO SELECT THE ONE OF TWO FIGURES
LIKE A THIRD

Trials	No. 1		No. 2	
	Per cent correct	False jumps	Per cent correct	False jumps
1-50	44	54	38	45
51-100	38	42	38	36
101-150	46	30	52	27
151-200	48	30	54	25

tween the doors which, with the order of shifting cards used in this experiment, gives a slightly better score than does a position habit prevailing in the first hundred trials. The data give no indication that the animals could solve the problem.

In other experiments the comparison figure was located above or below the dividing panel of the two-card apparatus, but in all cases the results were the same. In the first trials the animals jumped to the comparison figure as well as to the stimulus cards but, after a few falls resulting from this, they confined their reactions to the stimulus cards and did not again make movements of fixation toward the comparison card.

2. Animals were trained in an attempt to establish the generalized reaction described by the clause, *that one of any three figures is correct which is different from the other two.* Klüver (45, '33) has observed spontaneous selection of the different figure by the monkey and Robinson (81, '33) has established a similar consistent

reaction by training. With apparatus presenting three stimulus cards different groups of animals were trained in the following ways:

(*a*). To choose 1 cross vs. 2 circles (Figure 84). Next to

Figure 84   Figure 85

choose 1 circle vs. 2 crosses (Figure 85). Alternate training was continued in the hope that the animals might eventually come to choose whichever figure was presented singly. Instead, after the third to fifth reversal all animals became confused and either refused to jump or jumped persistently to one figure in spite of scores of bumps and falls.

(*b*). To choose a cross and avoid two triangles, to choose a circle and avoid two crosses, to choose a striated card and avoid two circles, and so on through a series of different pairs of figures. Some animals learned as many as 10 such pairs, but never showed any tendency to choose the single figure of a new pair, either when it was opposed to formerly positive figures, as above, or when both figures presented were entirely new.

(*c*). With apparatus presenting two stimulus cards a card bearing two circles was opposed to one bearing circle and triangle. Training was continued with a number of like combinations of figures in the hope that the animals might ultimately learn to choose any card bearing two unlike figures. All animals failed.

Limits of Generalization. The experiments reported in this section form a very incomplete analysis of the rat's capacity to deal with complex visual situations. They do indicate an upper limit of generalization beyond which the rat cannot go and which is relatively easy for the lower monkey. They suggest some types of generalization of which the rat is capable. The experiments have been incidental to other work and the chief excuse for reporting them is their suggestiveness for a more systematic analysis and classification of possible types of generalization.

The conception of generalization is a broad category which does not designate a unitary psychological process but rather a certain class of logical relations. As Heidbreder (33, '24) has said, ". . . most of the words used in describing thinking are merely collective terms and . . . do not refer to processes, but only to results produced." There is no satisfactory analysis and classification of the processes by which different kinds of generalizations are reached, nor is there an adequate classification of the end products.

The discovery of identical elements in a series of figures was designated by Hull (37, '20) as "generalizing abstraction." In the study of Fisher (15, '16) the characters generalized were sometimes relations among the parts of the figures. Heidbreder (33, '24) required generalization of a conditional relation, *if a, then b*. These by no means exhaust the possible types of abstraction, nor can we say how many diverse integrative processes may be involved in them. The whole problem is closely tied up with that of perceptual organization, and limits of capacity are set by the latter as well as by the types of organization which are described in formal logic. The rat can discover a triangle as the common element in a series of patterns. He certainly could not discover any of the identical symbols in Hull's series of Chinese ideographs. The result, the discovery of the identical element, can be described by the same logical formula, but evidently a greater complexity of perceptual organization is required for the solution of Hull's figures.

What determines the relative difficulty of such tasks? We speak of complexity but usually find ourselves involved in a circle in which complexity is really only a synonym for psychological difficulty. To what extent is ability a continuous function, varying with the amount of "neural energy" available, as interpreted by Spearman? To what extent an aggregation of qualitatively diverse functions (capacities for specific insights) as implied by Gestalt psychologists? Is each "insight" a unique event or is there a limited number of types of insight each mediated by a particular kind of nervous organization? No conclusive answers can be given to these questions at present and only a comprehensive analysis of the nature of the adequate stimuli in a great variety of situations will provide decisive evidence.

V. Peculiarities of the Rat's Visual Reactions

Throughout the work the experimenter has been on the alert to detect any behavior which might indicate a different type of visual organization from that of man. In general, as emphasized above, no evidence for any fundamental difference in organization has been found. But certain phases of the animal's behavior are difficult to interpret except in term of a lack of dominance of vision among the senses.

In earlier studies with the Yerkes box great difficulty was encountered in demonstrating visual reactions to patterns. Only when methods of directing reactions to the stimulus cards were devised (Lashley 51, '30; Munn 68, '31) was it possible to get consistent use of detail vision. In the jumping apparatus the rat usually makes a careful visual inspection of the cards before jumping, turning back and forth from one to the other and at times seeming almost to trace the outlines of the figures by movements of the head. If the discrimination required is very difficult however the whole pattern of behavior may change. He may jump at random, not to the stimulus cards but to the sides or against the glass top of the enclosing box, apparently without the slightest regard for any visual cues.

The first form of jumping apparatus devised consisted of a flat screen, 3 by 5 feet with openings for the cards cut in the midde. After some failures and falls the animals would throw themselves violently against the screen, several inches above the stimulus cards and once this behavior became established, it was practically impossible to retrain the animals to jump to the cards. Only by adding a sloping deflector to throw them through the doors when they jumped too high could discrimination, even between a single white card and a black ground be established again.

These facts suggest that the rat may have a different order of dominance of sensory modalities from that familiar to us as primates. The waking man or monkey is apparently almost continuously visually alert. Adaptation to olfactory, cutaneous, and auditory stimuli may occur but the visual system dominates attention almost continuously. The same condition seems to prevail among the birds in which vision is also highly developed.

With the rat it is as if negative adaptation to visual stimuli occurs

as readily as does negative cutaneous adaptation in man. Only with forced attention is the effectiveness of visual stimuli maintained for considerable periods. The earlier experiments with dogs (Johnson, 41, '16; Szymanski, 89, '18) which failed to demonstrate detail vision in the discrimination box with stimuli which have since been found effective with other techniques (Rizzolo, 80, '32; Karn and Munn, 42, '32) indicate that the peculiarities of vision shown by the rat may be common to other macrosmatic animals.

I have discussed above the difficulty in getting rats to jump to figures of less than 15 mm. diameter. In the jumping apparatus there is an initial preference for the larger of two objects, as Yoshioka 105, '30) has found also in food selection. There is also an initial preference for the horizontal lines of Figure 8 in animals trained to jump through the open doors of the apparatus. The significance of these observations is not clear, but they probably indicate no more than transfer of previous habits.

A more significant peculiarity of the rat's visual behavior is an apparent dominance of remote over local visual cues. This first became evident in an earlier study of depth perception. Animals were trained to jump from one small platform to another in a situation where the direction of jumping was away from the source of light. They showed ability to adjust the force of the jump accurately to the distance, thus giving evidence of visual reaction to the platform. The landing platform could be moved to either side through about 20 degrees without disturbing the reaction. If this arc were exceeded however the animals would jump to the floor in the initial direction of the platform and with some it was impossible to change the direction of jumping through more than 45 degrees, even by long training with a gradual shift of the platform.

With the enclosed apparatus of Figure 1 the influence of remote cues is not entirely eliminated. Often after rotation of the apparatus through 45 degrees to the right an animal will persistently jump only to the left stimulus card, even when he has previously made more than 100 errorless trials with the pair of stimulus cards presented. Hebb (32) has made a comprehensive study of this partial dominance of remote cues and has confirmed it in "free-field" situations.

Considered with the suppression of reactions to visual detail these facts suggest that the conditions of visual attention must be quite

different in the rat from those in man. The rat has no macula, only a uniformly decreasing number of ganglion cells from the fixation point to the periphery of the retina, with a corresponding lack of differentiation of a macular region in the central visual nuclei. Whether the visual behavior is related to these anatomical conditions remains to be determined by further comparative studies.

VI. The Nature of the Rat's Visual Organization

Aside from any interpretation of the experiments reported here, one must be impressed by the similarity of the rat's discriminative behavior to the perceptual impressions of the human observer. If a series of patterns is ranked in order of the conspicuousness of the figures for the human eye, that order will have a high predictive value for the rate at which the rat can learn the figures. Stimuli to which the rat transfers in equivalence tests are those obviously similar for man. Figure-ground relations seem to be determined in much the same way for both. Both distinguish complex figures by discovering limited part-figures as cues.

I do not believe that this result is an artifact arising from the design of the experiments by *Homo* rather than by *Mus*. In addition to those reported I have run equivalence tests with scores of figures, often quite at random, to see if the rat might find similarities which were not evident to the experimenter. In only one instance did this seem to occur. Two rats insisted for 40 trials each that Figure 63*a* is a circle and 63*b* a triangle. Repetition of this test with other animals gave negative results and in every other case where two figures were equivalent for the rats they were obviously similar for the experimenter. In no case has there been any indication that the rat perceives relations which are not obvious to the human observer. Even though we are not able to define the organizing forces satisfactorily, it seems clear that they are essentially the same in the rat and in man.

Whenever the attempt has been made to discover to what characteristics of the stimulus pattern the rat is reacting, by eliminating parts of the pattern or by testing for equivalence with new patterns, the adequate stimulus has been found to be some rather simple perceptual relation within the pattern. The animal never responds to pattern as defined by Hunter or shape as defined by Bingham, nor to an exact form which must be a replica of the training figure, but

always to some more general property which differentiates the positive from the negative training figure.

The range of these general properties revealed by equivalence tests seems quite limited. Presence or absence of a figure, direction, relative distance, relative brightness or size, and geometrically simple proportions probably exhaust the range. Yet by using these and by isolating part-figures the animal is able to identify configurations of almost any degree of irregularity and numerical complexity of elements. Perhaps man employs no greater range of abstractions in his visual perception.

Figures which the rat fails to differentiate, aside from those presenting only liminal differences, are the ones in which differentiating features are subordinate to general similarities of form, such as the symmetrical *S*'s of Figure 70.

The basis for more generalized recognition of form is still obscure. I have found immediate transfer to *H*- and *X*-figures on 90 degree rotation but not to triangle and cross. Fields has shown that with long training this can be acquired. Evidently success in such tests depends not only on the capacity for generalization but on the particular forms as well. We can identify a white with a black triangle in any orientation, but how many people can identify a negative portrait, or even an inverted one? At present we can only specify what the rat can do in two particular situations and neither from these nor from human data of a similar nature can we infer what factors set a limit to such generalization.

The experiments reported stress the tendency of the rat to base his reactions upon such relations as distance, or direction, where a human subject identifies a total geometrical figure. It must be borne in mind that the jumping apparatus emphasizes the relation of the figure to the frame of the card and that this may determine the property to which the animal reacts. A ski jumper is more likely to note the distance of a spectator from the slide than the shape of his hat. Nevertheless, the care with which the animals inspect the figures before jumping, and the readiness with which such properties as brightness are perceived, which do not involve relation to the frame, argue for the validity of the data.

Observations of the rat in the maze and free-field have suggested that the chief function of vision in the animal's adaptive reactions is for general orientation, with little or no visual identification of

specific objects. This is consistent with the dominance of distance and direction in the discrimination of figures. The contrast between the rat, on the one hand, and the cat and monkey with respect to the readiness of transfer to rotated figures, as revealed by the experiments of Fields (12, '32), Smith (86, '36), and Gellerman (18-19, '33*a, b*) also shows a correlation between this behavior and the use of vision in daily life. Finally the behavior which I have interpreted as a suppression of vision, the importance of remote cues, especially the direction of the source of light, for orientation, and the accuracy of perception of depth in the visual field, all point to a visual system primarily organized for adjustment in space rather than for identification of objects.

So long as the problem is the discovery of differences or resemblances between specific figures which can be generalized in terms of spacial relations the rat is able to solve it readily. When, however, the problem requires a combination of such generalizations or when one generalization is conditional upon .another, the limits of his capacity are approached. The experiments with size indicate that the animal is able to generalize simultaneously several properties which are later differentiated, but such a generalization as "intermediate" has proved impossible. Borovski's experiment, which is not adequately controlled, has given positive evidence of a conditional generalization, but other tests involving the same principle have given only negative results. The variety of tests carried out at this level is too limited to justify the conclusion that they are beyond the rat's capacity, but the failure to learn to choose the one of three figures which is different from the others definitely distinguishes between the rat and monkey.

VII. THEORETICAL CONSIDERATIONS

The discrimination experiment presents the animals with a definite situation, then with another having different characteristics, and ultimately establishes a different reaction to each situation. What is the basis for this differential reaction? For a stimulus-response psychology the one situation is associated with approach, the other with withdrawal: $S_a \rightarrow R_a : S_w \rightarrow R_w$: all simple and neat. Unfortunately this formula does not include the essential feature of discrimination, the fact that the efficacy of each stimulus is dependent upon the character of the other; $S_a = FS_w$. The moment we ex-

amine the concept of stimulus critically, the inadequacy of such general formulations becomes apparent.

The Nature of the Adequate Stimulus.   Analysis of the differential response reveals the following facts concerning the character of the effective stimulus:

1.   The positive or negative reaction is determined by some fraction of the total visual situation.   In every case the total situation may be broken down into an effective part, the figure, and an indifferent part, the ground.

2.   The effective fraction of each situation is always some character which differentiates the negative from the positive stimulus. The animal trained to the larger of two circles chooses the larger of other figures, but not a circle from other forms of equal area.

3.   The differentiating characters are always abstractions of general relationships subsisting between figures and cannot be described in terms of any concrete objective elements of the stimulating situations.

4.   In isolating these characters the animal itself is an important factor, since in identical situations no two animals may react on the basis of the same properties.

These conclusions, which are amply supported by the experimental evidence, show that the description of discrimination as a mere combination of a positive and a negative reaction misses the essential features of the process, which are the isolation of figure, the discovery of differences, and the generalizing character of the response.   These are prior to and not a result of the training.

The Fractioning of the Visual Field.   Physically, visual stimulation of the rat consists of the excitation of some 28 millions of structurally independent rhabdomes with various intensities of light. The light rays reaching the individual rhabdomes are the elements of the stimulus.   Any functional relations of pattern or form must be determined by the interaction of impulses from the rhabdomes at some central level.   Studies of figure-ground relations show that there are certain general principles of organization applicable to the isolation not only of familiar but of new figures.   The general effectiveness of continuity of figure, contrast, or conformation to a regular geometrical arrangement in determining the structure of figure cannot be accounted for in terms of trial-and-error learning except by the postulation of some capacity for generalization which

begs the question at issue between nativistic and habit-system theories. The experiments of Turner (93, '35), Lashley and Russell (57, '34) and Hebb (30-32, '37a, b) and the data on the congenitally blind with restored vision (Senden, 84, '32) all point to the conclusion that the isolation of figure occurs at the first moment of visual stimulation. The fractioning of the visual field into coherent units must then be recognized as an immediate product of organic structure and an indicator of the character of the integrative mechanism.

The Generalization of Attributes. In equivalence tests the properties of the figure may be varied through a wide range, so as to destroy any physical identity with the training figure without destroying the reaction (McKinney, 62, '32). This does not mean, as Pavlov (74, '32) has asserted, that "at first only the most general features of the situation act and only later, gradually, under the influence of special conditions, a further analysis takes place and the more special components of the stimuli begin to act." There is evidence that on the first presentation of a figure the animal may be stimulated by any or all of the special components to which he will ever react. If an animal is trained on horizontal vs. vertical striations, next on triangle and circle, and is then given critical trials with the figures superimposed on the striations, the latter are likely to dominate his reactions. But if both grounds are striated horizontally or both vertically, his reactions are determined by the triangle and circle. We cannot assume that in one case he is stimulated by the striations and not in the other, but must conclude that the reaction is selective among effective stimuli. In the transfer from a solid figure to an outline of the same, the animal's time for jumping may be increased from half a second to five minutes, yet he finally jumps with 100 per cent accuracy. It is not failure to see the difference which leads to transfer, but the identification of the common characteristic of the two otherwise diverse situations. Differentiation of the conditioned reflex is not the development of differential sensitivity to the stimulus, as Pavlov implies, but the definition for the animal of the properties to which he must react. We must recognize that any discrimination of a difference is prior to the association of that difference with a new reaction.

Identical Elements or Abstract Relations. For many years the doctrine has been urged upon psychologists that a recognition of iden-

tical existential elements in different situations is the most primitive and simple of reactions and therefore to be preferred among alternative explanations of similarity. During the controversies concerning the value of formal discipline the theory of transfer of training through the presence of identical elements reached the height of its vogue and won a practical victory, even though its proponents finally admitted that identity after all is not identity and elements are relations.

The assumption that reaction to identical elements is physiologically a simple process is a consequence of the connectionist or telephone theory of integration. If cerebral integration occurs by the interaction of dynamic fields (Köhler, 46, '24), then reaction to abstract relations should be the most immediate and direct form of response, whereas the recognition of the identity of existential elements should require the combined recognition of all of the common properties of the situations. It is time that we realize that the doctrine of transfer through identical elements has no greater a priori claim to explanatory value or simplicity than has any relational or organismal theory.

Equivalence tests show that so long as the abstract property which differentiates the positive figure from the negative is preserved, differential reaction persists. No physical identity of stimuli is necessary for transfer nor is there any evidence that even in successive identifications of the same figure, physical identity is the determining factor.

The Limits of Abstraction. The relational properties which form the basis of the rat's reactions seem to be quite limited in number and to be chiefly those arising from the relation of the figure to the animal's orientation in space. Relative distance is quickly learned, relative number not at all; direction far more easily than specific pattern. What determines this limitation of the rat's capacity in comparison with the cat, monkey, or man? Is it past experience or structural organization? Is the predilection to see certain relations a result of the rat's mode of life, or is the mode of life determined by such limitation of capacity? Questions of this kind are of fundamental importance for understanding the evolution of behavior. There is no decisive evidence upon which an answer can be based, but both comparative and clinical material is consistent with the view that the relational framework within which

generalization occurs is determined by innate structural or physio-ogical organization.

I must take sharp issue with the view of Smith (86, '36, p. 51) that such speculations concerning constitutional determiners of activity do not further our knowledge of behavior. They do not, of course, provide any immediate explanation but they do formulate a definite problem which offers a meaningful alternative to a theory of redinte-gration, such as he proposes, and which is capable of solution by experimental means.

Perhaps the most significant result of this study is the indication that the development of ability for generalization or abstraction does not present a few well marked and easily defined steps, such as a capacity to abstract relations, a capacity to generalize form, or a capacity for education of relations, but rather that material and process cannot be sharply separated. The education of a size re-lationship differs in difficulty according to the figures used and differs also from education of a number relation. The processes involved may have only logical, not physiological similarity. Once we recog-nize this, stop trying to fit the animal's behavior into a few a priori logical categories, and turn to detailed analysis of relational behavior and of the conditions limiting abstraction and generalization the way is opened for an adequate account of the evolution of intelligence.

VIII. SUMMARY

This study has been concerned with an analysis of the properties of the stimulating situation which form the basis for discrimination of visual objects. After estimation of differential thresholds for the chief variables with which later work is concerned, experiments were directed to determine the characteristics of stimulus objects which are effective for discrimination. Evidence was obtained that the figure-ground relation exists in the animal's visual field and that the segregation of figure is determined by at least some of the same factors which are effective in human vision. Discrimination was found to be based upon the abstraction of certain general properties of the figure which are then recognized in non-identical figures. Ease of discrimination depends upon the presence of certain relational properties, such as predominant direction, in the figures.

Differences in the ease of discrimination and recognition of dif-ferent figures indicate that the rat's visual system functions most

efficiently in spacial orientation—the recognition of relative distance and direction—and that the identification of objects or forms, though possible, is secondary to a system of space coordinates.

The bearing of the observations upon the general problem of the nature and evolution of intelligence is discussed.

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