THE INFLUENCE OF FIGURE-GROUND RELATIONSHIPS
ON BINOCULAR RIVALRY

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by

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CHAPTER I.

INTRODUCTION

The invention of the stereoscope by Wheatstone in 1838 made available to investigators an instrument by the use of which the conditions of normal binocular vision could be simulated in the laboratory and the factors which determine visual space perception could be varied systematically and examined. In normal vision the binocular fields overlap but the images which each eye receives are different. Yet the images are fused and objects are seen singly. Moreover, it has been proven that the perception of depth depends upon just this dissimilarity of the unocular images.

The work of the early physiologists and of Sherrington has demonstrated that the phenomenon of single vision can be ascribed to the mere fact that, with each eye, a seen object is normally projected to the same place in the environment. The depth effect can be explained by assuming that the dissimilar images are reorganized at the cortical level and that, as a result of this reorganization, unitary interpretation and the perception of depth emerges as a new factor.

However, when corresponding areas of the two retinas are each stimulated simultaneously by different colors or

by figures which differ sufficiently that the response to them cannot be one of unitary interpretation, then one of three things may occur: the fields may fuse, one may dominate the other, or they may alternate. Thus, if slightly different plane projections of a solid object are presented stereoscopically to corresponding areas of each eye, the two images will fuse, with correspondingly vivid depth effects. But, if one of the fields contains a figure of some sort while the other is homogeneous, the figure will be seen continuously; as if the eye to which the unstructured field is presented were closed.

Between these conditions are fields that alternate. If each half of a stereogram is composed of a number of parallel lines and if the two systems of lines are perpendicular to each other, the fields will rival. Rivalry can be observed in two forms: successive, in which case the alternation is complete and the two fields supercede each other completely; and simultaneous, or patchy, where both fields are seen at the same time but where one or the other of the fields is alone visible at any one place. In normal observation of the phenomenon either or both of these types may occur.

In his discussion of the relation of rivalry to dominance and fusion Kuroda (Helson, 19) has concluded "that dominance and rivalry appear only when there is a sufficient amount of difference between the two stimuli. But rivalry

appears when the difference between the stimuli is not too great. Rivalry is a half-way stage between mixture and dominance."

It is possible to obtain rivalry between fields on each of which there is only one line. Helmholtz (18, vol. III, pp. 495-497) used a stereogram of this type (called the "Helmholtz cross") on which the figures are black oblongs, approximately five times as long as wide. When viewed stereoscopically, the lines appear as a cross. Distinct alternation can be seen at the place where they intersect.

Helmholtz made a thorough and systematic investigation of the conditions under which rivalry may be observed, on the basis of which he came to the conclusion that rivalry is a "psychic" act, completely controllable by attention. He reported that by fixing his attention upon one of the fields he could stop alternation and retain that field indefinitely in "consciousness". (18, III, pp. 496-499)

Both Hering and Panum (Meenes, 26) agree with Helmholtz as to the general requisite conditions for producing rivalry. Hering says "only when a contour on one retina crosses a contour on the other does a rivalry between the contours occur at the crossing place". However, they disagree with Helmholtz as to the cause of the alternation; both basing their explanation solely upon the operation of physiological mechanisms. The question of a mutually exclusive physio-

logical vs. psychological explanation of any phenomena of this type is a spurious dichotomy based on a dualism which has not persisted in later investigation.

Wundt (Titchener, 31) explains rivalry in terms of eye movements. "... that image is always preferred whose contours run in the same direction as the (accidental or purposed) movement of regard." Breese (2) was able to show that all efforts on the part of his observers to influence rivalry were accompanied by eye movements (in the same direction as the movement of regard), but that when eye movements were prevented, all sense of "will" disappeared. And Peckham (27) proved that there was no relation at all between eye movements and rivalry.

Guilford (15) showed conclusively that rivalry and the related phenomenon of alternation of perspective in ambiguous perspective figures had nothing to do with attention. A number of physiological conditions are involved, among which are local retinal adaptation, eye movements, and local central fatigue and inhibition. MacDougall (25) thought rivalry could be explained by this last factor alone.

The relevancy of local retinal adaptation as a causal factor would have to be based upon the assumptions that the retinal elements function as discrete units and that a decrease in sensitivity, through previous stimulation, of any portion of the retina is determined entirely by the refrac-

tory phase of the neural elements distributed in that area.

Helmholtz said exactly that. He noted that after light has acted upon the eye, the sensitivity to new stimuli is lowered and concluded that this is due to a condition of fatigue of the retina (18, II, p. 235).

However, in the light of more recent investigations, this state of decreased sensitivity may be explained in terms of adaptation or fatigue effects at higher neural levels. Dunlap (11) has reported that when a point on one retina is stimulated, there is a decreased sensitivity of a corresponding point on the other retina. Guilford (15) demonstrated essentially the same effect and Crook (7) in a more recent experiment, has presented further corroborative evidence. Crook attributes these findings to some state of "central inhibition or fatigue."

In the most recent and definitive work on the visual mechanisms, Polyak has accumulated enough data to show that the retina and the higher neural processes can only be regarded as a single functional system, the various units of which do not operate independently. (29, pp. 369-386)

Further evidence of the central origin of rivalry can be demonstrated by a simple experiment. After observing the alternation of two fields of sufficient intensity and then shifting the gaze to an appropriate surface, there is distinct alternation of the after-images.

Breese (2) has shown that the rate of fluctuation of rivalry decreases as the illumination of the fields is lowered. Further (3), that if one of the fields is more highly illuminated than the other, the phase length of the brighter is lengthened, although there is no change in the rate of fluctuation. DeVries and Washburn (10) have corroborated these findings.

Breese also reported that if the interval between observations is great enough, there is no practice effect.

Washburn (32) has advanced the hypothesis that rivalry between the visual fields is normal and necessary for the perception of depth. She was able to demonstrate that rivalry could be observed, without the use of a stereoscope, while viewing a solid object (33). It follows that if alternation were prevented or interfered with in some way, perception in three dimensions would be restricted to secondary cues. This is certainly the case in monocular vision.

We will be concerned here primarily with a problem involving the rivalry of contours. However, there are some conclusions which we may draw from previous studies on the mixture and rivalry of colors which will have an important bearing on the present investigation.

Creed (6) cites DuFour as being the first to observe the binocular fusion of different colors. Since then there has been little or no agreement as to which colors can be

fused; and some investigators have denied the possibility of color mixture under any conditions. Dove (Dawson, 9) reported that binocular mixture can be obtained when different colors of the prismatic spectrum are used. Prismatic colors are highly saturated.

Helmholtz insisted that he was unable to combine two colors, and that, when different colors are viewed stereoscopically, rivalry always results. Failure to observe rivalry he attributes to faulty observation. (18, III, p. 503).

Panum, Hering, and Wundt (Titchener, 31) all report observing color mixture, and in 1901 it was demonstrated conclusively by Sterling. In the last edition of the *Physiological Optics*, Von Kries admits that, under special conditions, there is a possibility of mixing colors binocularly, and attributes Helmholtz' inability to individual "idiosyncrasy". (18, III, p. 529)

Sterling (28) conceived the idea of combining fields of different colors but of similar design. He used postage stamps which, being of different colors and having all the engraving of the King's head, are perfectly suited to this purpose. Dawson (8) investigated the whole problem of color mixture and color rivalry, carefully controlling hue, saturation, and brightness factors. He found that alternation always occurs between colored fields of unequal brightness. The alternating colors were seldom as pure as the unocular

components and, as observation proceeded, there was a further gradual reduction in saturation. His subjects also reported that the rate of alternation increased when the eyes were fixated throughout the trial period.

Johannsen (21) presented fields composed of contourless, monochromatic colors and found that only those hues which lie close together in the spectrum would fuse. A greater degree of fusion was obtained if the colors were of equal brightness although there was some degree of alternation in all of her combinations. The number of alternations which occurred in a definite unit of time was found to be some direct function of the difference in wavelength, measured in milli-microns, between the colors.

However, Hecht (17) developed a method of presentation by which, he says, anyone can achieve binocular color mixture. He had his subjects fixate a brightly illuminated white surface on a black background. A red filter was placed before one eye and a green filter before the other. When the two colors were fused, most of his subjects reported a patch of red on one side of the binocular field and a patch of green on the other, while between these was a patch of yellow. Observers who failed to report this effect were subsequently shown to be color-blind. Creed (6) repeated Dawson's experiment and got essentially the same results. By extending his investigation further, he found evidence that when two fields are combined binocularly,

various differences of hue, brightness, texture, and contours may behave independently of one another in their effect upon the resulting combination. He says:

"The various attributes of the unocular percepts may be, to some extent, dissociated from one another, so that they contribute relatively different proportions to the combined binocular percept. The content of each visual field does always enter consciousness as a whole: the form of one may appear with the color of the other or with a binocular mixture of color or of brightness."

"In binocular rivalry prevalence of a form does not necessarily involve simultaneous prevalence of the color with which that form is objectively associated."

From these investigations we may conclude the following:

1. When two fields differ sufficiently that a unified response cannot be made to them both, rivalry occurs;
2. The rate of fluctuation is increased by increased illumination and by a greater brightness difference between the two fields;
3. These latter factors influence the rate of fluctuation independently and may be summative in their effect;
4. Rivalry rate cannot be voluntarily controlled;
5. Rivalry is not related to eye movements;
6. Rivalry is a central rather than a peripheral phenomenon.

CHAPTER II.

THEORETICAL BACKGROUND OF THE PROBLEM

The purpose of science is to discover and describe the relationships that exist among all natural events; relationships which depend upon the occurrence of these events within functional systems. It is perhaps the ultimate goal of science to determine the relationships between all systems and partial systems, to the most inclusive of all -- the universe.

A system, as Humphrey (20) has pointed out, is not a mere mosaic of elements or events, but is a dynamic unity, the function of whose parts is determined by the forces which operate as intrinsic characteristics of the whole organization.

This concept of dynamic organization has been applied to problems in all the sciences, with fruitful results. The theory of electro-magnetic fields, introduced by Faraday, revolutionized physics; Einstein's demonstration of gravitational fields eliminated Newtonian astronomy. And the holistic approach is represented in biology by the organismic theory and by the principles of field dynamics advanced by Child (4), Coghill (5), and Weiss (34). "A field is the condition to which a living system owes its typical organization and its specific activities." "None of its

parts is independent and the condition of each is determined by the characteristics of the whole." (34, pp. 291, 111). Thus a field itself is a kind of system.

The essential characteristic of a field is organization "from above." A field is organized by vector forces operating within it, but, at some point, an aggregation of these forces results in a dominant locus of activity from which a gradient throughout the field is set up. The structure and function of other parts of the field are determined by their relation to this gradient.

It is the aim of the Gestalt school to apply to Psychology these same principles of field dynamics in an attempt to explain behavior in its causal connection with the psychophysical field. (22, p. 67).

In this case, the psychophysical field refers to the physiological processes and their relation to physical energy changes in the environment. Kohler (Ellis, 12, pp. 17-54) was able to show that physical gestalten do exist; that there are structured energy distributions.

But, since the physiological processes which underlie behavior are physical processes, describable in terms of physico-chemical activity, may we not postulate that they too are molar phenomena? Wertheimer (Ellis, 12, p. 12-16) has introduced the hypothesis of isomorphism to describe the function of these physiological processes. They are not a sum or combination of independent local nerve processes, but

nervous processes in extension such that each local process depends on all the other local processes within the molar distribution. (22, p. 59).

The investigations of Von Kries (Koffka, 22, p. 54), of Lashley (24) on the equipotentiality of cortical areas, of Bartley (1) and Perkins (28) on action currents in the cortex, of Polyak (29) on the action of nerve currents in the retina and optic tracts all add conclusive evidence to the acceptability of this hypothesis. Bartley concludes that "in accordance with the facts and suggestions that have preceded, a field theory of the nervous system is demanded, if its activities are to become intelligible. (1, p. 54).

There is a common frame of reference within which we may now describe behavior and its underlying physiological correlates as they are affected by energy distributions in the environment. If the eyes are stimulated by a non-homogeneous visual field, unequal electro-chemical reactions would be set up in different parts of the neural field such that, between two differently stimulated areas, there would be a difference in electrostatic potential. Thus a certain energy distribution, or gestalt, in the external visual field is represented in the optical field by leaps of potential along the constituent borders of inhomogeneously stimulated regions. Perception of the visual field is determined by these physiological electrical phenomena.

Energy distributions occur in the visual perceptual field as constellations of stimuli which are organized according to definite laws into a series of configurations or gestalten. The whole perceptual field is made up of these groupings and sub-groupings. "When we are presented with a number of stimuli we do not as a rule experience 'a number' of individual things, this one and that and that. Instead, larger wholes, separate from and related to one another, are given in experience; their arrangement and division are concrete and definite." (Ellis, 12, p. 72).

The most fundamental characteristic of the organization of a perceptual field is its differentiation into two phenomenal parts. These parts, which have different characteristic properties, were called by Rubin, (Hartmann, 16, p. 25), "figure" and "ground".

A figure is a locus of energy produced and maintained by the action of cohesive forces within the field. A contour, which segregates the figure from the remainder of the field, i.e., the ground, is formed at the boundary of this energy aggregate. The contour is part of the figure but not of the ground, although it separates the two.

The figure is held together by stronger forces than the ground and so, is more resistant to distortion. However, if the energy processes which resulted in the formation of the figure are continued too long without reinforcement, they become self-extinct. There is a redistribu-

tion of forces within the field, a recession of the figure into the ground, and the consequent emergence of a new figure at the next strongest locus of energy aggregation. Rubin called this process figural extinction.

Redistribution of field forces will explain such phenomena as the reversal of the "Rubin Cross", the reversal of ambiguous perspective figures, and may well be used to explain binocular alternation. Graham (13) has investigated the nature of these forces, as has Granit (14), and they have been discussed at length by Koffka (22, pp. 177-210).

Wever (35) has described the stages which occur in the emergence of a figure from a ground and found that, with simple figures, the process may be completed in a period as short as 10 milliseconds.

At first, there appears a degree of heterogeneity in the visual field such that two separate, homogeneous regions, which are different in brightness, are perceived. As this brightness difference increases, there appears a region of separation between the two units, which eventually narrows down to become the contour. Shape or form appears before the contour becomes definite. Further stages, designated "depth localization of the figures", "texture, color, and brightness difference between figure and ground," and "halo experience" all appeared with an exposure time of approximately 11 milliseconds. With longer exposures (up to 2 minutes) all observers reported figure ground reversals.

An interesting and significant fact is revealed in some of the protocols. One statement, which is representative of all the subjects, was, "The only way that I can hold the figure is to make the figure mean something" (35, p. 220). That is, when object-meaning is present, the fields may be less liable to reversal; and when object-meaning is present, alternation is accompanied by changes in object meaning.

Thus we find a dynamic relationship between meaning, and alternations of figure and ground. If an object in the visual field acquires meaning, i.e., then it is named, it is then reacted upon in a different and distinct manner, thus rearranging the forces in the larger field which includes both the visual stimulus and the organism.

Kohler and Wallach (23) have completed a series of studies concerning the effects on the perception of figures in the visual field after previous inspection of other figures. They found that by fixating one figure for some time and then replacing it by another, distortions of color and of depth, and certain spatial displacements can be observed in the latter figure.

The authors have offered a theory of cortical satiation to explain these figural after-effects and, more important, to explain in concrete terms the molar processes in the nervous system which are the correlates of visual perception. The theory is based upon the assumption that

the brain is a volume conductor in which electrical current flow is subject to the same laws that govern the flow of currents in non-living electrolytic systems.

It is a characteristic of such systems that currents which flow in them produce polarizing effects; tend to resist further current flow; and distort the flow of other test currents which may be induced therein. When electric currents flow in nerve tissue the phenomenon of electrotonus is observed, the early stages of which resemble the polarization effects in non-living matter. However, with a prolonged flow of current, there occur certain changes in the permeability and conductivity of the cell membrane which increase the resistance of the nerve tissue. (23, pp. 320-322).

If the visual field is structured, there will be an unequal pattern of stimulation on the retina. More nerve impulses will travel to the visual cortex in fibers which issue from the more strongly stimulated areas. In the cortex these impulses alter the chemical condition in the tissue fluid which surrounds the cells so that strongly stimulated retinal areas are connected to cortical areas of heightened chemical activity.

In the visual field, non-homogeneous adjacent areas, i.e., a figure on a ground, are represented by adjacent areas on the retina and by adjacent areas of different electro-chemical potential in the visual cortex. Currents

will be initiated along the boundaries of such areas.

Thus, figures in the visual field are represented in the cortical field by "figure currents" which originate in the region of the contour and spread out in three dimensions. These currents produce a state of satiation, or electrotonus, in the neural substrate which will alter and distort any subsequent figure currents in that area. (23, pp. 327-332).

This theory is certainly adequate to explain the after-effects which are described in the first part of the Kohler-Wallach paper (23, pp. 269-315) and, according to its implications, may also explain binocular rivalry.

If we assume that one figure in a split-stereogram produces a state of satiation in a certain area of the cortex, this state will inhibit a further flow of the current which results from this figure. At this point the figure will recede into the ground and another figure in the field will emerge. The fields of the two split-stereograms are fused in a stereoscope and are projected to the same area of the cortex. The only figure which remains to take the place of the former figure is that on the other half of the stereogram. This new figure will now produce its own figure current and the whole process will be repeated.

The intensity of figure currents depends upon the strength of the figures in the visual field. The stronger

the figure, the more intense will be the cortical figure currents and the more quickly will satiation, and reversal take place.

CHAPTER III.

STATEMENT OF THE PROBLEM

If rivalry results from mutual inhibition of non-combinable cortical processes, and, if the rate of alternation is due to the strength of figures in the visual field, then by varying the strength of these figures, there should be a change in the rivalry rate.

All figures have certain characteristic attributes which differentiate them from their background and cause them to behave differently. Strong figures possess these attributes to a greater degree.

A figure is produced when field forces aggregate at a certain locus. The sequence of stages which occur in the gradual emergence of a figure from the rest of the field has been described by Wever (33). The primary stage is a brightness differentiation in the field; the first evidence of heterogeneity. As this brightness difference increases, a more distinct surface of separation appears between the two areas. As the figure becomes stronger, this boundary narrows down to become the contour which separates the figure from the ground.

However, the contour belongs only to the figure and does not affect the ground. Since it is the contour which gives the figure its form, its quality as an object, the figure appears to possess "thing" properties, whereas the

ground can only be described as "stuff-like". This has been demonstrated by Rubin (22, pp. 181-184).

A figure is a distinctive unity and, since it is the result of an aggregation of forces, is more articulate and more resistant to distortion than is the ground. The figure appears to stand out in front of the ground which extends behind it. It has a hard surface color which is resistant to penetration, whereas the color of the ground is soft and filmy. If a color is part of the figure it will be more saturated than if it were part of the ground (22, pp. 187-190).

However, figural properties are not independent of the ground. Both figure and ground are part of one field and, as such, are functionally interrelated. The ground acts as a framework on which the figure is located and any change in the former will result in a change in the latter. Thus, the strength of a figure may be increased if the size of the enclosing ground is increased. This was quantitatively proved by Graham (13). He systematically varied the size of the white and black segments of the Rubin cross to determine which of these appeared as figure and which as ground. He showed that if the organization of the field is such as to produce a larger and a smaller unit, the smaller will be seen as a figure. As Rubin (Koffka, 22, p. 183) demonstrated, if the black and white segments are equal in area, first one and then the other will appear as figure: a

situation similar to rivalry.

As was shown by Hartmann (Koffka, 22, p. 184), the spatial orientation of the ground will determine the shape of a figure which it encloses and the work of Gottschaldt (Ellis, 12, pp. 109-122) certainly demonstrates that the very important "thing" quality of a figure, which enables it to be perceived and recognized as a separate entity, can be changed by "imbedding" it in a different ground.

Brightness difference between a figure and its ground and figure contour are two figure characteristics which can be easily varied and which can be represented by plane drawings on a stereogram. Thus, the rivalry rate of a stereogram which has a strong figure can be compared with one which has a weak figure.

Will there be any variation in the rate of alternation in binocular rivalry between fields which have strong figures and fields which have weak figures?

It is the purpose of this investigation to present such fields, according to the method to be described in the next chapter, and to determine the effect upon rivalry that results.

CHAPTER IV.

METHOD, APPARATUS AND OBSERVERS

All observations were made using the Renshaw Stereo-Disparator and were recorded on a polygraph tape driven by a synchronous motor. The room in which observations were made was dimly illuminated, the main light source being a ten-watt frosted bulb on the Disparator. The polygraph was in a separate room to reduce any distracting noises to a minimum. The experimental set-up is shown in Figure 1.

All the stereograms were drawn with Higgins Black Waterproof ink and, except Stereogram No. 2, were drawn on white drawing paper with a reflectance factor of 0.70. Stereogram No. 2 was drawn on grey paper with a reflectance factor of 0.10: No. 27 in the Hering-Zimmermann series.

The left member of all the stereograms consisted of four parallel vertical bars, 2mm. wide and 25 to 39 mm. long. The right member consisted of four parallel horizontal bars of similar dimensions. The bars were drawn as if they were circumscribed by a circle at the center of which was drawn a small cross which served as a fixation point. Figure 2 is a photograph of the four stereograms used.

The stereograms were selected to represent two attri-

Figure 1 - Experimental apparatus

STEREOGRAM No. 1

STEREOGRAM No. 2

STEREOGRAM No. 3

STEREOGRAM No. 4

FIGURE 2 - THE STEREOGRAMS USED TO DEMONSTRATE THE EFFECT ON BINOCULAR RIVALRY OF DIFFERENT FIGURE-GROUND RELATIONSHIPS.

butes of figure-ground structuring: brightness difference between figure and ground, and contour. Stereogram No. 1 shows approximately seven times more contrast between the bars and their background than does No. 2; Stereograms No. 3 and No. 4 illustrate complete and broken contours.

According to the hypothesis outlined above, since No. 1 has a stronger figure than No. 2, its rate of alternations should be greater. Similarly, No. 3 should rival faster than No. 4.

The stereograms were viewed at "far point" on the Disparator, a distance of 200 mm. from the centers of the lenses. At this point, all the observers but one could comfortably fuse the targets when they were separated by the orthophoric separation of 95 mm. Subject M. F. could only attain fusion with an 80 mm. separation; indicative of a 7.5 diopter esophoria.

When the subjects reported for the first time, they were given the following instructions to read:

When you look into the eye-pieces, you will see a series of vertical lines and a series of horizontal lines. In the center of the field there will be a cross. You will have three or four minutes to become acquainted with the experimental situation and to familiarize yourself with the phenomenon of binocular rivalry.

After a while you will notice that the vertical lines and the horizontal lines are not seen superimposed, as a lattice, but that they appear and disappear alternately, in cycles.

Fixate the cross in the center of the field and report, by pressing and releasing the key, when the cross appears between vertical lines. This, together with any change from

the vertical condition, constitutes one cycle. A return of the vertical lines marks the beginning of the next cycle. It is the vertical phase of these cycles which you are to report.

It may be that the whole field will not alternate as a unit. Use as your criterion the region surrounding the cross.

They were then seated comfortably in a chair, with an arm rest on which was clamped a telegraph key. They were allowed to observe the rivalry using the four stereograms for about one minute each under complete experimental conditions. Recorded observations began the following day.

Each session consisted of a three minute observation of one stereogram. The first minute was regarded as a warm-up period and was not counted, although the subjects were not aware of this. The number of alternations in the next two minutes were averaged and the results obtained constituted the score for that session.

The next session was conducted in the same manner, using another stereogram. There were never fewer than four hours between any two sessions.

The stereograms were always presented in the same order: No. 1; No. 2; No. 3; No. 4; No. 1; etc., and each one was observed eleven times. The first session with each of the four stereograms was regarded as a pre-experimental period during which the subjects were supposed to become fully acquainted with the equipment, with the phenomenon of rivalry, and with the experimental situation in general.

The experiment proper, then, consisted of 10 three-

minute observations of each of the four stereograms by five observers; a total of 40 sessions for each subject.

The observers were: Mr. Chester Pheiffer, C.P., Graduate Assistant in Psychology; Mr. Robert Maurer, R.M., Graduate Assistant in Psychology; Mrs. Madeleine Feil, M.F., Graduate Student in Psychology; Mr. James Trump, J.T., fourth year undergraduate in Psychology and assistant in the Experimental Laboratory; and Miss Helen Holcomb, H.H., fourth year undergraduate and assistant in the Experimental Laboratory. Mr. Pheiffer, Mr. Trump, and Miss Holcomb had had at least one year of previous training in psychological laboratory observation, while Mr. Maurer and Mrs. Feil had had none.

CHAPTER V.

RESULTS

At the end of each session, the subjects were asked to make comments about what they had observed. Each one reported that during most of the three minutes there was simultaneous rivalry, in which only that part of the field about the fixation point was seen to alternate. Occasionally, one figure would disappear entirely. All the subjects said that when both fields were seen simultaneously, they appeared to be in different planes, one behind the other. No one complained of eye strain nor of any other kind of fatigue. Of some interest is the fact that there was very little variation in the number of alternations among any one of three minutes of observation during a session.

The data for each subject are charted in Figures 3 to 7. Each curve represents the rivalry rate for one stereogram obtained during ten trials. Figure 3, the graph showing the results obtained from Subject R. M., is representative. It can be seen that the rate of Stereogram No. 1 is approximately one and one-half times as great as the rate of Stereogram No. 2. The same relation holds between Stereogram No. 3 and Stereogram No. 4. Except for inter-trial fluctuations, the curves maintain a fairly constant level throughout.

FIGURE 3 - BINOCULAR RIVALRY WITH DIFFERENT STEREOGRAMS. SUBJECT R.M.

FIGURE 4- BINOCULAR RIVALRY WITH DIFFERENT
STEREOGRAMS. SUBJECT J.T.

FIGURE 5 - BINOCULAR RIVALRY WITH DIFFERENT STEREOGRAMS. SUBJECT H.H.

FIGURE 6 - BINOCULAR RIVALRY WITH DIFFERENT STEREOGRAMS. SUBJECT M.F.

FIGURE 7 - BINOCULAR RIVALRY WITH DIFFERENT
STEREOGRAMS. SUBJECT C.P.

On some of the charts, the displacement of one point in any one of the curves may give the impression that there is no difference among them. Such is the case in Figure 4, Subject J. T., and in Figure 7, Subject C. P. It will be noticed that all such inversions occur at the beginning of the experiment, among the first few trials. This indicates that the subject may have not fully understood the instructions or that his criteria of observation was changing. This explanation, however, cannot account for the inversions of the curves for Stereograms No. 3 and No. 4 in the later trials of Figure 5.

The curves of Stereograms No. 1 and No. 2 show the effect on rivalry of fields having different figure-ground brightness relationships, while a comparison of the curves of Stereograms No. 3 and No. 4 show the effect of a completed contour. In all cases, except Subject M. F., there is a clear difference between No. 1 and No. 2 and between No. 3 and No. 4.

The rivalry rate of the "strong" figures, i.e., No. 1 and No. 3, is higher than that of the "weak" figures and the relative position of the four curves is fairly constant. However, there is no uniformity as regards the absolute number of alternations per minute among the subjects.

The highest rate shown by Subject R. M. (Figure 3) is 17.5 alternations per minute, in trial 7. The lowest rate

for this subject is for Stereogram No. 4, in trial 10: 4 alterations per minute. Contrast this with Subject C. P. (Figure 7). Only in a few trials with Stereogram No. 4 does his rate go below 25 alternations per minute. These two cases are extreme. The average range is between 10 and 20 alternations per minute.

An analysis of these charts seems to indicate that rivalry rate is an individualized function, somewhat analogous to form fields or visual perceptual skills. Therefore, any attempt to total the results of all the subjects on each stereogram, in an effort to derive representative averages, would be meaningless. Rivalry is an individual reaction to a certain type of visual field and any comparisons among different persons must be on a relative basis.

The data has been collected and certain statistics have been computed. These are shown in Tables I to V. In these tables the mean rivalry rate of Stereograms No. 1 and No. 2 are compared and similarly, a comparison of the mean rates of No. 3 and No. 4 are made. The range indicates the spread of the rivalry rate for each stereogram during the ten trials. In all cases, except Subject M. F., the differences between the compared means are significant far above the 1% level. This indicates that the chances that such a difference would occur again if the experiment were to be repeated is less than one in one hundred.

The results shown by Subject M. F. represent the only

TABLE I

A COMPARISON OF THE DISTRIBUTION OF THE BINOCULAR
RIVALRY RATES OF FOUR DIFFERENT STEREOGRAMS OVER
TEN TRIALS. FIGURES INDICATE NUMBER OF ALTERNATIONS
PER MINUTE. SUBJECT R.M.

Stereogram	1	2	3	4
Range	11-16.5	5-7.5	10-17.5	4-8.5
Mean	13.60	6.15	13.90	6.45
S.D.	1.74	.87	2.35	1.67
S.E. M	.58	.29	.78	.56
Diff. M		7.45		7.45
S.E. diff.		.65		.96
Diff./S.E. diff.		11.50		7.76
P		< 0.0000		< 0.0000

TABLE II

A COMPARISON OF THE DISTRIBUTION OF THE BINOCULAR RIVALRY RATES OF FOUR DIFFERENT STEREOGRAMS OVER TEN TRIALS. FIGURES INDICATE NUMBER OF ALTERNATIONS PER MINUTE. SUBJECT J.T.

Stereogram	1	2	3	4
Range	12-22.5	9.5-16.5	11.5-20.5	5-13
Mean	18.20	13.05	15.30	10.30
S.D.	2.97	2.35	2.39	1.79
S.E. M	.99	.78	.80	.60
Diff. M		5.15		5.00
S.E. diff.		1.59		1.00
Diff./S.E. diff.		3.24		5.00
P		0.0025		0.0000

TABLE III

A COMPARISON OF THE DISTRIBUTION OF THE BINOCULAR RIVALRY RATES OF FOUR DIFFERENT STEREOGRAMS OVER TEN TRIALS. FIGURES INDICATE NUMBER OF ALTERNATIONS PER MINUTE. SUBJECT H.H.

Stereogram	1	2	3	4
Range	17.5-21	10.5-15.5	13-22	10.5-16.5
Mean	19.15	13.85	17.45	12.70
S.D.	1.12	1.45	3.00	1.65
S.E. M	.37	.48	1.00	.55
Diff. M		5.30		4.75
S.E. diff.		.61		1.14
Diff./S.E. diff.		8.69		4.17
P	< 0.0000		0.0003	

TABLE IV

A COMPARISON OF THE DISTRIBUTION OF THE BINOCULAR RIVALRY RATES OF FOUR DIFFERENT STEREOGRAMS OVER TEN TRIALS. FIGURES INDICATE NUMBER OF ALTERNATIONS PER MINUTE. SUBJECT C.P.

Stereogram	1	2	3	4
Range	31-45	27-36.5	29.5-42	17.5-29
Mean	38.15	31.65	35.25	22.50
S.D.	3.81	2.69	4.15	3.77
S.E. M	1.27	.90	1.38	1.26
Diff. M		6.50		12.75
S.E. diff.		1.56		1.87
Diff./S.E. diff.		4.17		6.82
P		0.0003		< 0.0000

TABLE V

A COMPARISON OF THE DISTRIBUTION OF THE BINOCULAR RIVALRY RATES OF FOUR DIFFERENT STEREOGRAMS OVER TEN TRIALS. FIGURES INDICATE NUMBER OF ALTERNATIONS PER MINUTE. SUBJECT M.F.

Stereograms	1	2	3	4
Range	16.5-36.5	8-33	10.5-34	5.5-31
Mean	25.90	16.10	20.90	15.75
S.D.	6.90	8.74	8.89	9.08
S.E. M	2.23	2.91	2.96	3.03
Diff. M		9.80		5.15
S.E. diff.		3.67		4.24
Diff./S.E. diff.		2.67		1.21
P		0.0073		0.1128

deviation from the pattern set by the other observers. A glance at Figure 6 will show that for the first six trials, the curves correspond to the general standard, but, from the 7th to the 10th trial, there is extreme variation and complete inconsistency with any of the previous data.

The 7th trial of each of the four stereograms occurred at about the same time. The subject could not recall any outside experience which may be related to this change in performance. However, since at that time she was engaged in some other visual observation in the laboratory it may be inferred that these conditions are causally related in some way.

It is interesting to note that if her first six trials only are counted, the ratio of the mean difference to the standard error of the difference between the rates of Stereograms No. 1 and No. 2 is 5.57; and the ratio between No. 3 and No. 4 is 3.40.

In testing the hypothesis that two means are from different populations, it is customary to accept a critical ratio of 3 or better as being indicative of a significant difference. Actually such a ratio indicates a probability of 0.0038 that the difference between the means is due to a sampling error ($n = 18$). The critical ratios obtained in this experiment range from 3.24 to 11.50, except in the case of Subject M. F., which is discussed above.

In general, the results show that when viewed stereo-

scopically, fields which include strong figures rival at a rate which is significantly greater than fields with weak figures. There has been no attempt to express figural strengths in quantitative terms.

The results obtained apply only to plane figures viewed in a stereoscope. Any generalization regarding normal vision would have to be based upon Washburn's hypothesis. Thus, if rivalry is constantly going on, the rate of alternation should be an important factor in visual perception; which is the emergence of a figure from a ground. Also, there must be an optimal rate of alternation at which perceptual organization is most efficient.

CHAPTER VI.

DISCUSSION

The present investigation was conducted in an effort to test some implications of the Kohler-Wallach theory of cortical satiation. Certain periodic visual phenomena which resemble rivalry may all be separate but related instances of a more general psycho-physical condition such as is postulated in this theory. The phi-effect, the reversals of ambiguous perspective figures, the examples of field reorganization such as the Rubin cross or the shift from two to three dimensional perception of plane drawings, and rivalry itself, may all be explained by reference to the realignment of electrical potentials in the brain.

The theory states that a figure in the visual field is represented in the cortex by areas of different potential across which a current flows. In the course of its existence this current produces a state of electrotonus, or satiation, in the neural substrate which offers progressively greater resistance to the continued flows of the figure current as well as to the flow of any other currents which may be induced in the same area.

The assumption was made that a figure in one of the fields of a stereogram will set up such a state of satiation, and, in the course of time, the resistance will

build up sufficiently to halt further flow of the current. At that point the figure will disappear, the other half of the stereogram will take its place, and the whole process will then be repeated.

It was further assumed that the rate of alternation depends upon the strength of the stereogram figures, since a stronger figure will be represented by a stronger figure current which will produce a state of satiation more rapidly. The results have demonstrated that these assumptions are highly probable.

Woodworth (36, p. 574) has said that any theory explaining binocular rivalry must answer these questions:

(1) why is response made to only one of the "retinal fields" at a time?; (2) why does the stronger, clearer, or more interesting field have the advantage?; and (3) why does the advantage shift?

This study has been concerned with stereograms on which the two "retinal fields" are equal in "strength, clearness, and interest", and the effect on rivalry of changing the strength of these figures (on different stereograms) has been demonstrated. But, rivalry under the conditions set by Woodworth, in which the two halves of one stereogram are unequal in strength, can be accounted for by the same underlying theory.

Many previous investigators have shown that the stronger of two such fields will be seen for a greater

length of time, but none have mentioned what happens to the rate of alternation in these instances. Some data on this problem can be found in the work of Breese (3). He showed that if two fields are unequally illuminated, there will be an increase in the phase length of the brighter field but the rate of alternation will remain constant. In other words, if the illumination of one of the fields is increased, the amount of time that field will be seen will also increase, but the amount of time the weaker field will be seen is correspondingly decreased.

Breese, however used fields upon which there were figures of equal strength. The only difference between the fields was the amount of illumination upon them. Since, as was demonstrated in this experiment, the rate of alternation does not change unless some aspect of the figure-ground relationship is changed, we should not expect any variation in the rate merely with an increase in the illumination of one of the fields.

How then may we account for the increase in phase length of the brighter field? Such an increase in illumination means that the retina will be more strongly stimulated and an increased number of fibers will fire. Consequently, a state of satiation will be produced in the cortex more quickly. However, a reversal of field, i.e., an alternation, can only occur when the processes of extinction have proceeded long enough that the figural current (of the

brighter field) is reduced to a level below that of the current produced by the weaker field. When the weaker field predominates, its phase will be shorter because the amount of satiation necessary to cause another reversal does not have to be so great.

When the two fields of a stereogram have figures of equal strength, the rate of alternation will depend upon the figure-ground relationship. Only a change in this relationship will result in a change in the rate of alternation. Any factors which cause the two fields to appear different, e.g., brightness, texture, will produce a change in the relative phase ratios and, as Creed (6) showed, the effects of these factors act independently of each other.

In order to answer Woodworth's first question, it is necessary to relate rivalry to binocular fusion. Most investigators agree that response is made only to one of the fields at a time because no other meaningful response can be made. Two dissimilar fields which can be combined, will be combined, with the consequent perception of depth. Alternation of response is merely a compromise.

All the subjects in this experiment reported that when the two fields were seen in simultaneous rivalry, they appeared to be in different planes. This indicates that cortical figure currents exist in three dimensions and may indicate an explanation of the emergence of depth perception when dissimilar retinal images are combined. It certainly

shows that rivalry is not a different kind of phenomenon from binocular fusion, but merely that they are two points on a single continuum.

In this light we may discuss Washburn's hypothesis (32). If rivalry is the normal process in binocular vision, why is it not noticed? We have made the assumption that the emergence of the new factor of depth in binocular vision is the result of a combination and reorganization of two part processes: the figure currents arising from disparate images on both retinas. This emergent whole constitutes a unity which is stronger than the individual parts that compose it. Furthermore, it is something more than a mere summation of these parts. The forces which maintain this unity are strong enough to resist distortion. Where rivalry occurs, however, there is no strong unitary response, but two antagonistic part processes vying for ascendancy.

It was found that during any one session, the rate of alternation does not vary significantly from minute to minute. Consequently, if the subjects are familiar with the phenomenon of rivalry and are reasonably trained in experimental observation, it would not be necessary to extend any trial beyond one minute. Or, if greater precision is desired, an average of the rate over a period of two minutes will eliminate any errors which may result from instrument variation or faulty timing. It would be interest-

ing to determine the effect on rivalry of longer sessions. If observation were continued as long as ten minutes, would there be a gradual decline in the rate?

The order of presentation of the stereograms was not varied from subject to subject because only one stereogram was presented at each session, and there was an elapsed time of at least four hours between sessions. If each session included three minutes of observation of all four stereograms, any progressive errors which may have resulted from the effect of one stereogram upon a subsequent one, could have had to be corrected for. Further study on the relation between the inter-session time interval and rivalry rate seems indicated here.

Kohler and Wallach (23) have stressed the fact that cortical figure currents must be regarded as unitary processes. Selection of the figures for this experiment was based upon consideration of this fact. If the stereograms were made with single bars, as the "Hemholtz cross", rivalry would have occurred only at the place of intersection where the satiation produced by one figure current could affect the other figure current. The satiation effects produced by the figures on the stereograms used here covered a wider area and so affected the entire field. It would be interesting to determine the effect on rivalry of bars of different width at various distances apart.

The Kohler-Wallach study showed that the medium in

which visual figure processes occur is anisotropic in the vertical dimension and that figural after-effects are stronger in the lower half of the field (23, p. 281). Comments by some of the observers in this experiment show that this anisotropy affects rivalry as well. They reported that the figure in the lower half of the field disappeared completely more often than in the upper half.

The results obtained with Subject M. F. are very interesting. Of all the subjects, she alone showed an anomalous space projection. Although this was the only outside factor measured, her performance indicates that there must be some close connection between rivalry and other visual skills.

Various investigations in this laboratory have shown that rivalry rate is quite useful as a probe body to indicate the presence of certain visual anomalies and as a measure of progress in orthoptic training. It has been shown that there is an important connection between rivalry rate and the stereoscopic threshold. When the rate is too far above or below a certain optimal level, there is a significant decrease in the ability to perceive depth or to localize in the third dimension. Evidently, it is important to determine how rivalry is related to visual skills in general, and to discover what part it plays in efficient organization of the perceptual field.

This experiment was intended merely as an exploratory

study and was designed to investigate the effect on rivalry of the simplest figure-ground relationships. In the judgement of the writer, many new problems have presented themselves for future exploration. There were only ten trials in this experiment, each of a certain duration, and each separated by a certain minimum time interval. All these factors should be varied in order to test the basic hypothesis presented here.

The results indicate that further study should be directed toward determining the relation between rivalry rate and all phases of figure-ground structuring.

CHAPTER VII.

SUMMARY AND CONCLUSIONS

Four stereograms, which represented different degrees of figural strength, were presented stereoscopically to five subjects. A comparison was made between these stereograms which had strong and weak figures.

On the basis of the results we may conclude the following:

1. Binocular rivalry rate is determined by figure-ground relationships.
2. Strong figures alternate faster than weak figures.
3. Rivalry is one of a number of visual skills and, as such, is determined by individual perceptual characteristics.
4. Over a period of ten trials, some of the subjects show evidence of an increasing practice effect.

Certain tentative conclusions may also be drawn:

1. The theory of cortical satiation is strengthened by these results.
2. There is evidence which indicates that rivalry is related to certain other periodic visual phenomena.
3. Deviations of rivalry rate from a certain optimal level is associated with poor depth perception and anomalous space localization.

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