BINOCULAR INTERACTION IN GEOMETRIC ILLUSIONS

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The purpose of this study is to examine the characteristics of geometric illusions under stereoscopic viewing, that is, how the illusory effects under stereoscopic viewing become smaller than under monocular viewing and how the effects vary according to the size and angle of the stimulus figures.

A Mueller-Lyer figure and concentric circular figures were selected as a stereogram (see Fig. 2, 3 and 8). Four subjects were asked to observe these stereograms under stereoscopic and monocular conditions.

The apparent length of a test line in the angular figures, and the apparent size of the inner circle (test circle) of the concentric figures were measured by the method of limits. A third experiment was performed to examine the effect of two introversive angular figures upon the inner field of vision.

The results of the three experiments are summarized as follows: (1) the illusory effects produced under stereoscopic viewing were clearly observed, (2) these effects were smaller than those obtained under monocular viewing, (3) the magnitudes of the effects were a half or more of those obtained under monocular viewing, (4) comparatively great individual differences were recognized among the subjects.

From these facts it may be assumed that the same effect as that perceived in a monocular projection field also exists in a binocular projection field, though there is some difference in magnitude between the two effects.

Recently a new hypothesis which takes into consideration the binocular projection field has been proposed as a powerful model concerning the mechanism producing binocular depth perception. This hypothesis may be sufficient for explaining the occurrence of depth perception owing to binocular disparity, but seems inadequate for answering the following questions : why does apparent depth vary in accordance with the size of a stimulus object, with its intensity, or with the constellation of several stimull; how can be explained depth perception which occurs, as E. Lau (1922. 1925) and others discovered in their studies, owing to apparent disparity?

Depth perception due to apparent disparity may be understood if we assume that Lau's illusory effect is first produced in the monocular projection field, and the effect then appears as a disparity in the binocular projection field. Such an illusory effect has been seen to extend from one eye to the other eye, as is evident in the studies of Day (1961), Schiller & Wiener (1962), and Ichikawa (1972, 1979). Day's and Schiller-Wiener's studies showed that geometricai illusory effects are seen when the inducing element and the test element of the figure are presented stereoscopically. In the study of Ichikawa, two desparate vertical lines were presented, one to each eye, so that they are projected on to non-corresponding positions of the retinae. The results showed that the desparate lines appear to approach each other under stereoscopic viewing, and the extent of approach varies accord-

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ing to that of the non-correspondence on the left and right retinae. Maximum approach is observed at a distance. The function which causes variations in apparent positions and apparent contraction or expansion of interval distances is explained as "field induction effect." The appearance of illusory effects under stereoscopic viewing means that some effects of the induction field occur not only in the "monocular projection field" but also in the "binocular projection field" where binocular interaction takes place.

From these facts I would hypothesize that the variation of binocular depth perception due to stimulus constellation is attributable to that of binocular disparity which is caused by the following two processes. The first process is the variation of binocular disparity which is caused by the induction effect in the monocular projection field and the second is the variation of binocular disparity which is caused by the binocular interaction, that is, the induction effect in the binocular projection field. I think that further detailed studies of functions of the projection field are essential to elucidate the mechanism of stereopsis.

The purpose of this study is to clarify the characteristics of phenomenon caused by binocular interaction on such a hypothesis. For this purpose, the geometrical illusory effects under stereoscopic viewing are to be examined.

EXPERIMENT I

The aim of this experiment is to examine fully how the illusory effects under stereoscopic viewing become smaller than under monocular viewing, and how much the degree of effects varies as the size and the angle of geometrical figures change. The same measurement method as we measured illusory effects under monocular and binocular viewing is used here, and the results under stereoscopic viewing are to be compared with those under monocular viewing.

METHOD

Subjects

Four paid volunteer subjects who have all visual acuity of 1.0 or more for both eyes.

Apparatus and Materials

The Ishihara's stereoscope, as shown in Fig. 1, was employed. In the experiment Mueller-Lyer geometrical illusory figures were used as stereogram, because these figures are comparatively effective in producing illusion. Two types of introversive and extroversive figures were used (see Fig. 2, 3). They were drawn in black ink on white card board. Two angular figures (I) presented to the right eye in stereoscopic presentation were inducing element. A horizontal line (T) of the same length with the interval distance between two vertexes of the figures was presented to the left eye at the position corresponding to the main line of Mueller-Lyer figure under stereoscopic viewing. That is, we can perceive Mueller-Lyer illusory figures under stereoscopic viewing.

The line T is the test element of stereogram. The wings of the two angular figures are 8mm long, and the interval distance between two vertexes is 20mm, two different wing angles of 60° and 120° were employed as the inducing figures ; so a test line is held constant, i. e. 20mm long. To measure the illusory effects by angular figures on a test line, the other line as a comparing stimulus is presented horizontally sideward below the test line (see Figure 2). The length of a comparing line is varied from 12.5mm to 26.0mm in 0.5mm steps for each figure.

The measurement of illusory effects under stereoscopic and monocular viewing is made by means of the method of limits. The over-all number of repetitions in both the ascending and the descending series

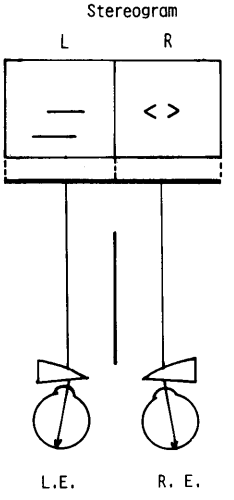

Fig. 1 Ishihara's stereoscope used in the study.

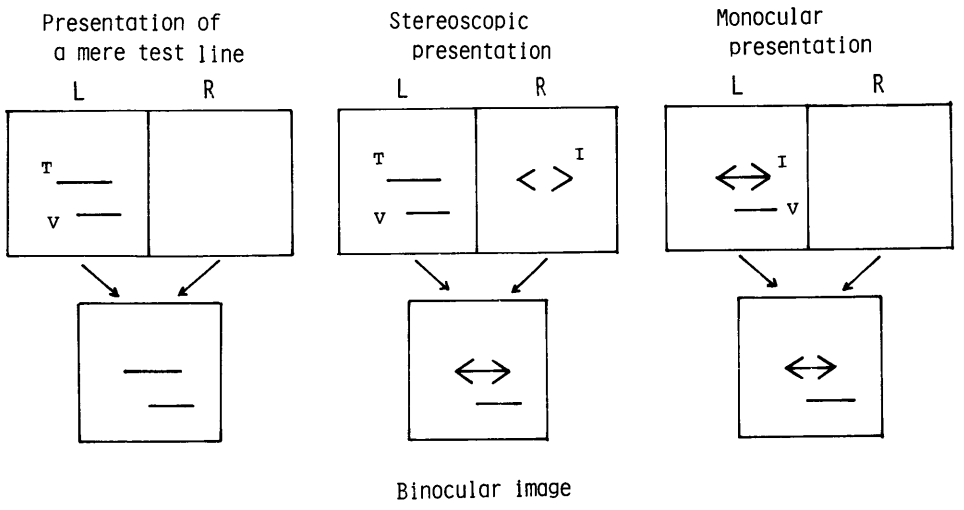

Fig. 2 The stereograms of an introversive angular figure used in Exp. I. The relative size of the back ground of stereograms to the figures and lines is actually larger than that of Fig. 2.
T : Test line, I : Inducing figure, V : Varing lines (comparison stimuli), L : Left eye, R : Right eye.

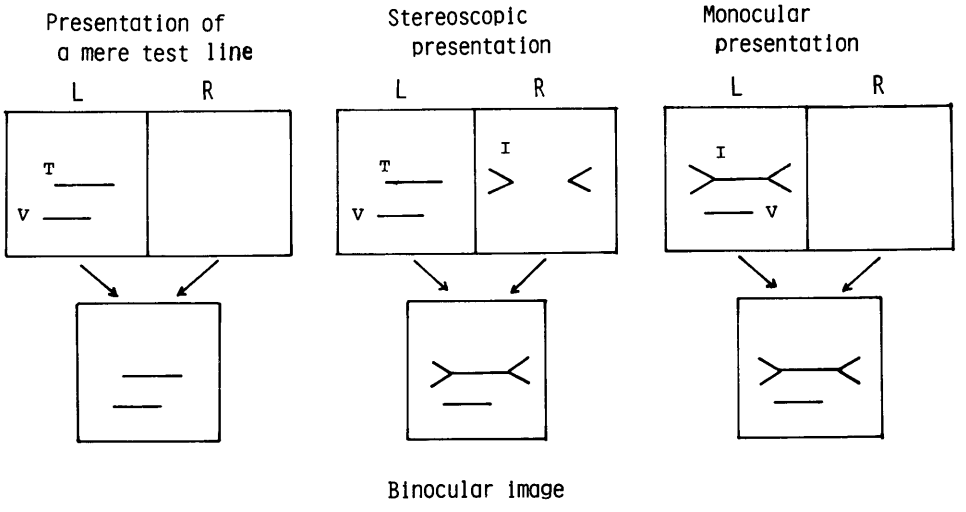

Fig. 3 The stereograms of an extroversive angular figure used in Exp. I

for a figure was 12.

Procedure

The problem of stereoscopic presentation is that it is difficult to fuse the centers of the test stimulus and inducing stimulus presented seperately to the left and right eye, so that they may be projected onto the identical point on the retinae.

In this experiment, a test line was required to meet the two vertexes of an angular figure. Before the experiments begin, the subjects were requested to do the following practices.

From the Ishihara's stereograms, four picture cards in which many animals and trees with different apparent depth are depicted were chosen. The subjects observed the cards with stereoscope and decided the position where the images of these cards can be clearly seen and where the difference of depth can be clearly perceived. Then, the stereograms employed in the experiment were presented in that position. When a test line (test stimulus) and an angular figure

(inducing stimulus) were completely met, the measurement was made. If the two stimuli should be seen more or less differently, the L and R cards were moved slightly left- or rightwards. After such an adjustment, the measurement was made.

The results of the above mentioned observation by Ishihara's stereograms are not only essential to the experiment but also are conducive to examining the abnormality of stereopsis and strabismus of subjects. All of the four subjects in our experiment proved to be normal.

In this experiment, the measurement was made not only under stereoscopic viewing but also under monocular viewing and the presentation of the mere test line. In the monocular viewing, Mueller-Lyer illusory figures are presented only to the left eye, as is shown in Figure 2, 3. This is done to compare them with results under stereoscopic viewing. By such a comparison we can make clearer the illusory effects under stereoscopic viewing.

A test line is presested only to the left eye and measured. Even the perception of a test line itself also is differed among observers, day after day and due to repetitions of the measurement. These influences are to be independently measured and they are to be eliminated from the results in the case of presentation of inducing stimulus figures. Thus these measurement values are to be regarded as the values representing individual differenses. The magnitude of illusory effect thus obtained indicates the effect of an inducing stimulus. The graphs of the results show the values eliminating the values of the subjects individuals respectively. The method of monocular viewing and measurement of the values are quite the same as in the case of stereoscopic viewing. The concrete measurement procedures are as follows. The lines as a comparison stimulus are presented horizontally sometimes right downward, at another time left downward a test line. According to the method of limits, the lines are shown from a shorter one to a longer one, or, conversely, from a longer one to a shorter one. The subjects were then asked to judge whether the apparent length of all the comparison lines relative to the test line is longer, equal (or uncertain), or shorter.

RESULTS

The results are shown in Figures 4,5,6,7. In Fig. 4 the result of the experiment employing the introversive figures with $\angle$ 60° and their mean value (illusion magnitude) of four subjects are shown.
Fig. 5 is the result of introversive figures with $\angle$ 120°. Fig. 6 and 7 are similar results as to extroversive figures. The height of bar graphs indicates the magnitudes of illusory effect (the differences relative to the standard values of the mere line), and S in the Figures represents the results under stereoscopic viewing, M the results under monocular viewing.

1. The results of introversive figures

The common facts revealed both in the figures

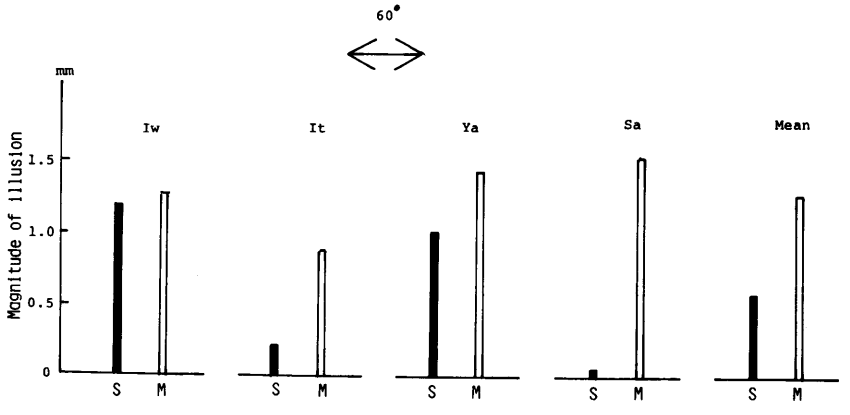

Fig. 4 The result of the introversive angular figures with angle 60°. The height of bar-graphs indicates the magnitude of the illusory effect of the figures. These magnitudes are the values eliminating the values of the subjects individuals respectively.
S : Stereoscopic presentation, M : Monocular presentation, IW, IT, YA, SA : Subjects.

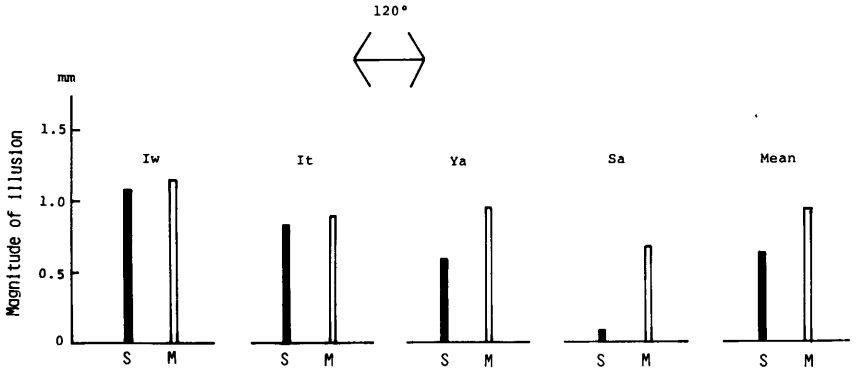

Fig. 5 The result of the introversive angular figures with 120° angle.

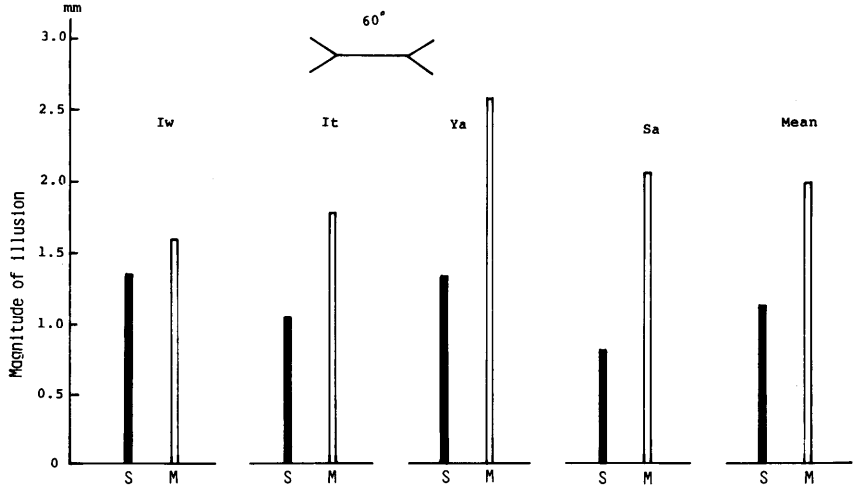

Fig. 6 The result of the extroversive angular figures with 60° angle.

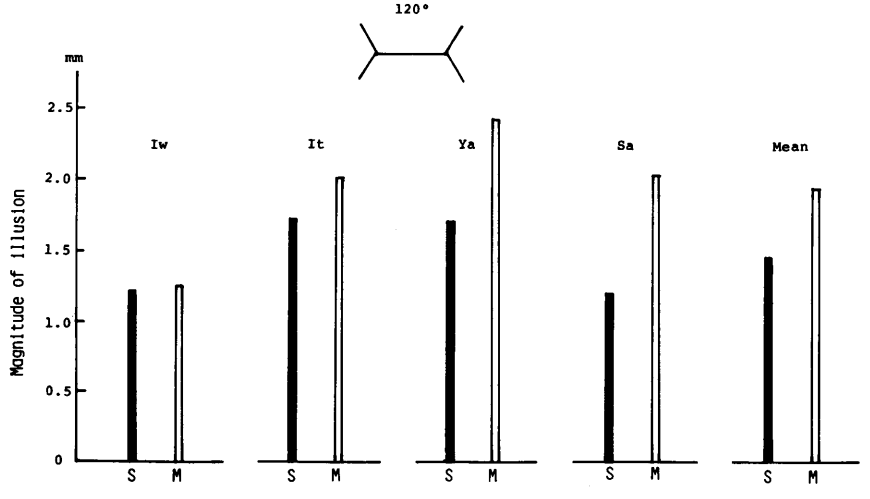

Fig. 7 The result of the extroversive angular figures with 120° angle.

with ∠60° and ∠120° were : (1) even under stereoscopic viewing the shortening of the test line was evidently observed, (2) its effect was smaller than under monocular viewing, (3) there were comparatively great differences among the subject individuals, (4) in terms of the mean value, the magndtude of illusory effect was nearly a half or more, as compared with that of monocular viewing, (5) the illusory effects in the figures with ∠60°, both under stereoscopic viewing and monocular viewing were greater than that of ∠120°.

2. The results of extroversive figures

In the cases of extroversive figures, the results were : (1) the test line appeared to be lengthened both under stereoscopic viewing and under monocular viewing, (2) the lengthening effect was smaller under stereoscopic viewing than under monocular viewing, (3) though the magnitude of illusory effect was differed according to the subjects, the mean value was a little more than half the value (magnitude under monocular viewing).

EXPERIMENT II

The aim of this second experiment is to examine the illusory effect of concentric circular figures under stereoscopic viewing.

METHOD

Subjects

The same subjects are selected as in the Experiment I.

Materials

The Ishihara's stereoscope was used.

The stereograms of concentric circle illusion employed in this experiment are shown in Fig. 8. The upper row shows the stereograms, while the lower row the apparent constellation (i. e. concentric circular figure) under stereoscopic viewing. The circular figure presented in the stereogram R is the inducing stimulus, and the smaller circle presented in L is the test stimulus. The two larger circles with the diameters of 21.0mm and 30.0mm were employed as the inducing stimuli, while the smaller circle as the test stimulus has the constant diameter of 14.0mm. The fixation point is drawn at the center of R and L circles respectively, so that the fixation points of R and L may be adjusted to coincide under stereoscopic viewing ; this is necessary for making the constellation of concentric circles. To measure the magnitude of illusory effect of the inner circle (test circle), the other circle was presented as a comparison stimulus on the right side of the test circle (i. e. the smaller

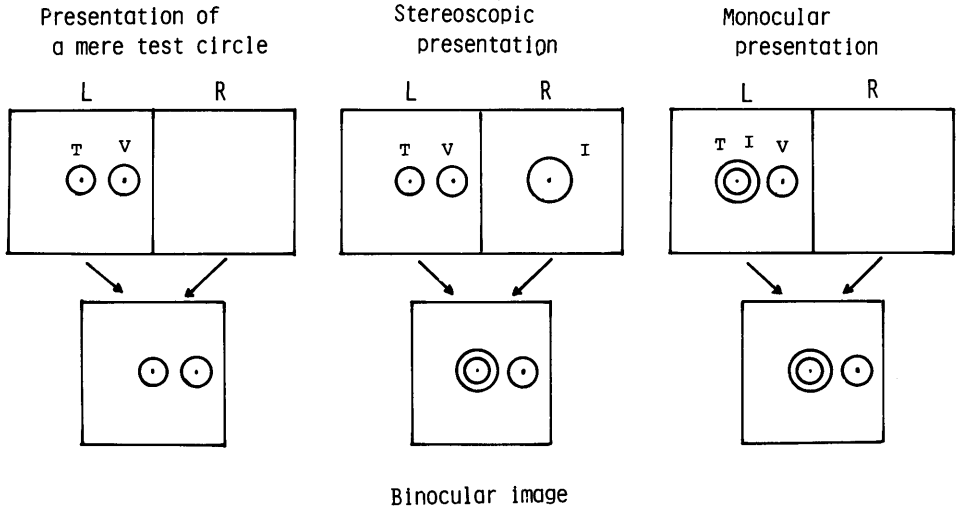

Fig. 8 The stereograms of concentric circles used in Exp. II.
T : Test circle, I : Inducing circle, V : Varing circles (comparison stimuli).

circle).

In this measurement, several circles ranging from 10.5mm to 20.0mm of diameter in 0.5mm steps were presented in accordance with the method of limits, and the comparison in size was made between the left smaller (inner) circle and these varying circles.

Procedure

As described in the Experiment I, it is difficult to fuse the centers of the stimulus figures presented separately to the left and right eye, so that they are projected onto the identical points on the retinae.

For the above reason, also in this experiment, a very short line (like as a small point) with 1mm length is set at the center of both test and inducing circles. The line is to make coinside the center of the test circle with that of the inducing circles, and the point is a fixation point.

Before the experiments, the preparatory observation of the Ishihara's four picture cards is made.

In the experiment, the test circle and inducing circle were presented to the left and right eyes separately under stereoscopic viewing. In monocular viewing the test and inducing circles are presented as a concentric figure to the left eye only.

Further more, to measure the values of the subject individuals, the mere test circle is presented to the left eye. The bar graphs of the results show the values eliminating the values of the subject individuals. These values are the magnitudes of the illusory effects.

In the above three stimulus conditions, the experiments were made. The subjects were asked to judge the apparent size of all the comparison circles relative to the test circle. In accordance with the method of limits, twelve measurements were made both in the ascending and the descending series. The detailed procedures are all the same as those of Experiment I.

RESULTS

The results are shown in Fig. 9 and 10.

Fig. 9 shows the result that the diameter ratio of the inner circle to the outer circle is 2 : 3, and Fig. 10 shows that the ratio is 1 : 2. The results show : (1) the overestimation of inner circle occurs under stereoscopic viewing just as well as under monocular viewing except only one subject to whom a slight under estimation occurred, (2) the magnitude of overestimation is smaller under stereoscopic viewing than under monocular viewing. The magnitude differs amog observers (subjects). In view of the average value, the illusory effect of the concentric circle with

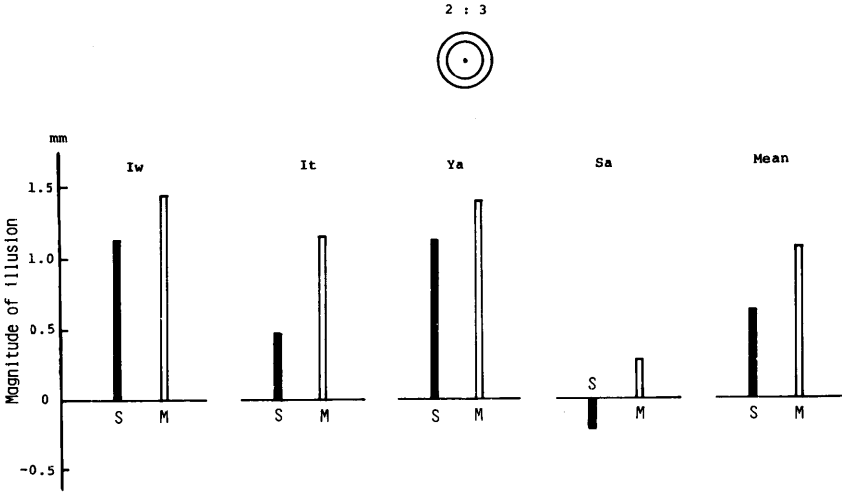

Fig. 9 The result of concentric circles that the diameter ratio of the inner and outer circles is 2 : 3. The bar-graphs show the magnitudes of illusory effects of four subjects and their mean valuue. Those magnitude are the values eliminating the values of the subjects individuals respectively.
Plus value indicates the overestimation of inner circle, and minus indicates underestimation.

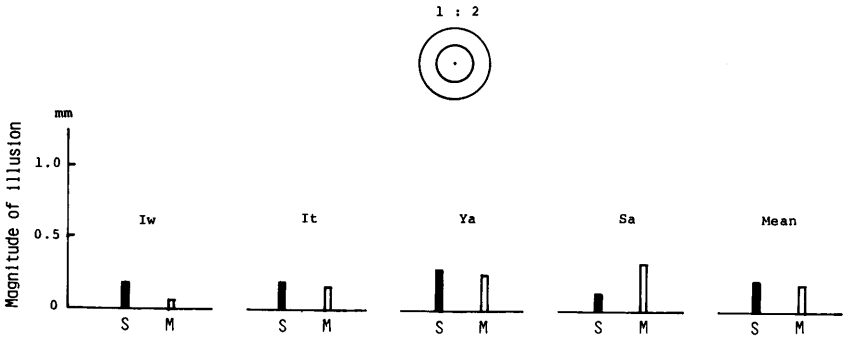

Fig. 10 The result of concentric circles that the diameter ratio of the inner and outer circles is 1 : 2.

the ratio of 2 : 3 shows the magnitude slightly greater than the half of the value (magnitude) under monocular viewing. But, in the constellation of the concentric circle with the ratio of 1 : 2, the overestimation of inner circle was extremely small both under stereoscopic viewing and monocular viewing, and the difference between both viewings was scarecely observable. From the results of geometrical illusions in Experiment I and II, it will be pointed out that the presence of illusory effects was confirmed also under stereoscopic viewing as in the experiments by Day and others, and that the way of appearance of illusory effects was the same as the results hitherto showed in the experiments under binocular and monocular viewing, with the proviso that the magnitude of the effects is smaller under stereoscopic viewing in the two cases above.

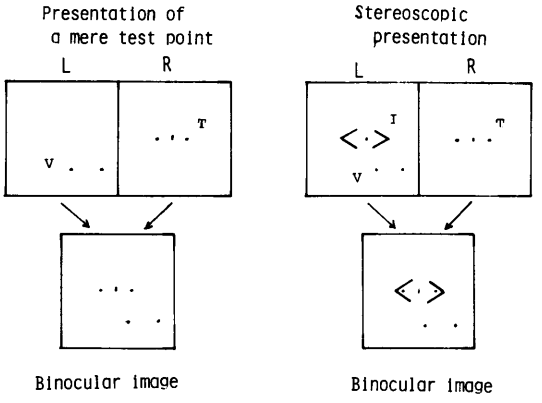

Fig. 11 The stereograms used in Exp. III.
I : Inducing figure, T : Two test points, V : Conparison points changed the interval distance, Fixation point : the very short line.

EXPERIMENT III

The aim of this experiment is to examine the displacement effects of angular figures upon their inner visual field under stereoscopic viewing. As is shown in the stereogram of Fig. 11, two points are presented on a imaginary line between two vertexes of angular figures, and the changes of the apparent distance between the two points in accordance with the width of the two angular figures are measured. Here the displacemest effect means the fact that a small point or two points are apparently displaced by the effects of angular figures as in W. Köhler's after effect (1940).

METHOD

Subjects

Two are selected from the four subjects in the Experiment 1.

Apparatus

The Ishihara's stereoscope is employed as in Experiment 1.

Stimulus Conditions (Materials)

Two introversive angular figures which face to each other were presented to the left eye L. These figures are inducing stimulus. To the right eye R only two test points with the interval distance of 16mm were presented on a imaginary line between the two vertexes. The distance between the two test points

was held constant. The distances between the two vertexes are 18, 20, 22mm and 24mm respectively. These conditions were employed to examine the effect by the width of the visual field surrounded by the two angular figures. A vertical short line of the length of 1mm was drawn to the angular figures and to the center of the two points (see Fig. 11). This mark (short line) is the fixation point to make fixed the position of the two test points within the angular figures.

Procedure

The procedure of the measurement is performed according to the method of limits. The two comparison points with different intervals are presented horizontally right or left downside to the test points. These are indicated in the stereogram L of Fig. 11.

The distances between the two points presented as the comparison stimuli were changed from 12 mm to 24 mm in the step of 0.5 mm, and they were presented in order, sometimes from the longer ones to the shorter ones, or, conversely, from the shorter to the longer ones, and the judgements of the distances were asked to be made. The order of presentation and the analysis of the results are based upon the method of limits. Besides, in order to obtain the value of subjects individuals its apparent interval distance was also measured under the same conditions and method above.

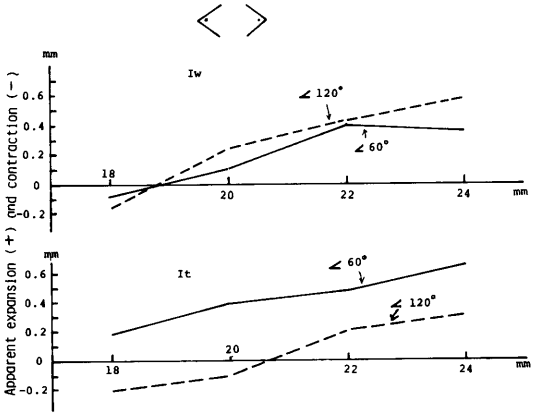

Fig. 12 The result of Exp. III.
Plus value indicates the apparent expansion of inteval distance between two test points and minus the apparent contraction. Two graphs show the results of subjects separatly.

The solid line represents the result of the figures with 60° angle and the dotted line that of 120° angle.

RESULTS

The result is shown in Fig. 12. The abscissa of the graph shows the distance between vertexes, and the ordinate indicates the values eliminating the values of subjdct individuals of the apparent interval distance between the two test points under stereoscopic viewing. The results are : the perceived distance between the two test points becomes shorter when the inner visual field within the introversive angular figures is narrower, and the former becomes longer when the latter is wider. The larger its field is, the more enlarge the perceived distance is.

As for the above constellation, Morinaga (1941) had already reported the results concerning the perceived distance between the two test points under binocular viewing. Based on the results, he indicated the apparent displacement of a point at each distance by an arrow sign. According to him, the perceived distance between the two test points appears to be displaced toward shortening when the points are near the inside of the vertexes, and, conversely, becomes lengthened when they apart from the vertexes. In this experiments nearly the same tendency is observed when the apparent displacement of the points is represented as a function of the distances from the vertexes.

DISCUSSION

In this study, the writer has examined the quantitative properties of the illusory effects concerning Mueller-Lyer figures and concentric circles under stereoscopic viewing. The reason is that Day and Schiller-Wiener have already discovered the effects of illusory figures under stereoscopic viewing. In view of Day's results, while all the ten subjects reported Mueller-Lyer illusory effects under stereoscopic viewing, six out of the ten subjects recognized the Delboeuf effects corresponding to concentric illusion and four denied them. Thus, under stereoscopic presentation, there are not always evident illusory effects in some illusory figures.

In view of our experiments, the illusory effects of the two geometrical figures under stereoscopic viewing were recognized in all the subjects. Their magnitudes, however, were smaller than under monocular viewing, and showed the value (magnitude) a little greater than one-half on the average. This points out the fact that the effects become weaker under stereoscopic viewing, that is, when to the one eye is presented an influencing stimulus and to the other eye the influenced stimulus. In other words, illusory effects become smaller under binocular interaction. This fact has already been pointed out by Day, Schiller and Wiener, and was also confirmed quantitatively in our experiments. In the case of stereoscopic viewing of concentric illusions. the effect was smaller than under monocular viewing. The appearance of the effects is the same as under monocular viewing, that is, the overestimation of inner circle occurs to a greater extent in the narrower interval (2 : 3) than in the wider interval (1 : 2).

The occurrence of depth perception under binocular viewing is considered as resulting from the interaction, in the binocular projection field, of left and right retinal stimuli which are in binocular non-corresponding relation. Our experiments offer a useful information about this interaction, along with the facts discovered by Lau, Day, Schiller, Wiener and Ichikawa.

Concerning the difference of depth effects due to stimulus constellation, the occurrence of those caused by apparent binocular disparity (by Lau), and the phenomena of binocular depth contrast discovered by Werner, the writer would like to propose the following explanatory hypothesis of these facts from both of the facts about "field induction effect" and of the results of our experiments. The non-corresponding different stimuli which are given to both the retinae firstly cause a process in the respective monocular projection field. They are then sent to the binocular projection field and cause the second process in the field.

In other words, the differences of apparent depth due to the stimulus constellation are occured depending upon the following effects in the two-step processes above described. In the first step, the degree of non-correspondence on the retinae is changed through the displacement effect of the "induction field" in the monocular projection field, and in the second step the changed degree is more varied through the displacement effect in the binocular projection field. The former effect is due to the stimulus constellation but the latter to the binocular interaction.

This means that the depth effect does not occur in proportion to the magnitude of binocular disparity because the difference of effects of stimulus constellation changes further the degree of non-correspondence of left and right retinal stimuli which were first given. The three dimensional figure effects which the writer (1961, 1966) has already reported support this explanation. The above is my hypothesis concerning the function within the projection field as regards the binocular depth perception. This hypothesis perhaps needs more examination in other cases.

There may remain questions whether the two seperate stimulus figures under stereoscopic viewing can be observed at the fixed position and whether some part of the figures may disappear. The observation reports of the subjects in these experiments show that the fusion could be secured because of the preparatory adjustment for fusion and the setting up a fixation point. As regards the problem of disappearing parts of the figures, the test line which is very near the inside vertexes was reported to disappear sometimes in the figure with the angle of 30 degrees. So the figure with 30-degree angle is excluded from the experiments. In the case of the figures with 60-and 120-degree angles the disappearance did not occur.

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