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THE ILLUSION OF THE KINDERGARTEN PATTERNS.

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Every one that has had occasion to examine attentively a collection of patterns designed for the Kindergarten occupation of mat-weaving, and of course every one practically engaged in

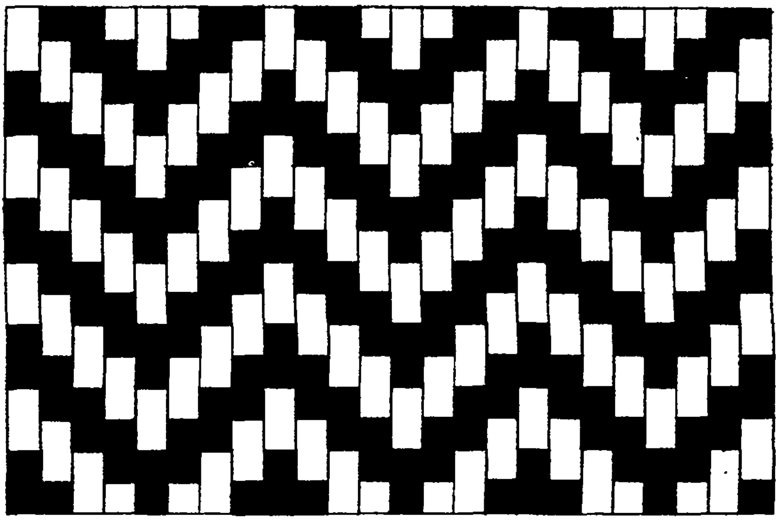

FIG. 1.

this work itself, must frequently have noticed the peculiar irregular appearance presented by the numerous patterns of which the above is a typical representative. Nor does this irregularity escape the notice of the children. A slight examination, however, suffices to convince one that the irregularity of the vertical lines is only apparent, the seeming departure from rectangular perfection being due wholly to an optical illusion. While casting about for an explanation of this illusion the writer's attention was called to the articles of Heymans[1] and Münsterberg,[2] in which the elementary form of the illusion is figured and discussed. Fig. 2 represents this elementary form as first published by Professor Münsterberg in the Milton Bradley collection of optical illusions.[3] In this collection no name is attached to the illusion, but in the German article it is called 'Die verschobene Schachbrettfigur,' for which 'The Shifted Checkerboard-Figure' may be a sufficiently exact, though perhaps less expressive, equivalent in English. The explanations given by the above mentioned authors are widely at variance, Münsterberg appealing to *irradiation* as the chief factor in the matter, while Heymans rejects this and forthwith places this illusion in the same category with those of Zöllner and Loeb, to be explained as a phenomenon of *contrast*. Neither writer gives a sufficiently detailed discussion of the matter to enable the reader to decide definitely between the rival claims. Then, too, while presenting strong arguments in favor of irradiation as the explanatory principle, Münsterberg acknowledges that other factors *may* possibly coöperate to produce the illusion—factors, namely, of contrast, or whatever they may be, which are commonly appealed to in explanation of those illusions of which the Zöllner pattern is a type. In view, then, of the somewhat un-

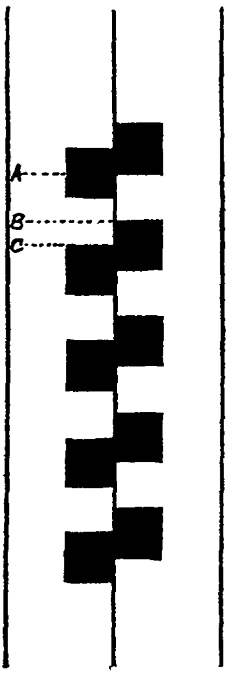

FIG. 2.

[1] Zeitsch. f. Psych., XIV., 118.

[2] Ibid., XV., 184.

[3] Bradley: Pseudoptics, B 5.—According to the description given by its discoverer in the article above referred to, the complete figure from which this element was taken must have been much like the Kindergarten pattern above figured, squares however taking the place of the rectangles.

settled state of the question, and in view too of the interesting character of the illusion itself, it seemed not amiss to enter upon a qualitative and quantitative examination, the illusion being subjected to as many of its possible variations as seemed likely to throw light upon the problem. It may be stated at once that the general conclusion arrived at as a result of the experiments to be described is that *irradiation* alone seems to be an adequate explanatory principle.

The exact nature of this irradiation must be made clear at the outset. This Professor Münsterberg does admirably in the article referred to, pointing out, at the same time, that it was the failure to rightly apprehend this that led Heymans to his sweeping denunciation and rejection of this explanation. The irradiation-effect here, namely, is not of that simple sort where dark areas surrounded by light are contracted uniformly in such wise that the apparent contours remain everywhere parallel to the actual outlines. For here, in consequence of the form of the figure, there is a point of maximum effect, the result of which is to give the whole line an oblique appearance. In Fig. 2, *e.g.*, consider the portion *AB* of the middle line. It is not true here that the upper half of this section has been seemingly shifted to the left in a direction parallel to itself, while the lower half remains unchanged. The fact is rather that at the upper end of the line *AB* the white square on the right has, as it were, *bored into* the black area, giving the angle at that point the appearance of being no longer a right but rather an *acute* angle,[1] so that the upper half of *AB* seems to slope obliquely downwards from left to right. Similarly *BC* slopes in the same direction. And the lower half of *AB*, influenced by the sloping sections above and below, seems to join with them and assume likewise an oblique position. Similarly for each section of the whole middle line. Accordingly, the irradiation that is effective in producing the illusion is that which occurs in the *corners* of the several pairs of squares. This is Professor Münsterberg's explanation of the matter, and its great plausibility is at once evident from an examination of the figure.

[1] How great this boring effect is can be readily appreciated if the attempt be made to fill out the appropriate corners of Fig. 2 sufficiently to destroy the illusion.

With this brief introduction let us enter upon the experimental examination of the illusion.

A. Qualitative.

Strong presumptive evidence in favor of the supposition that one is here in the presence of irradiation-effects is given at once by the fact that the inclination of the middle line (see Fig. 2) appears greatest when the figure is viewed with imperfectly

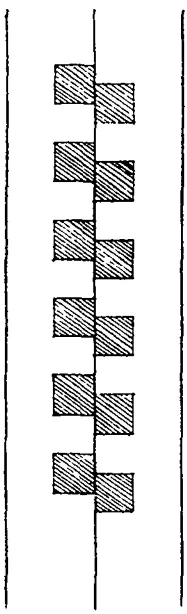

Fig. 3.

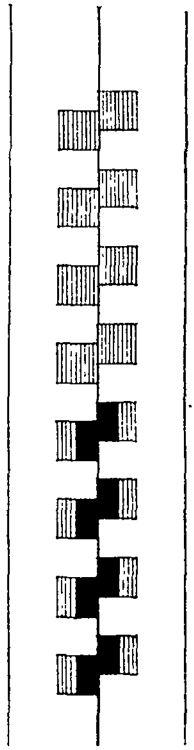

Fig. 4.

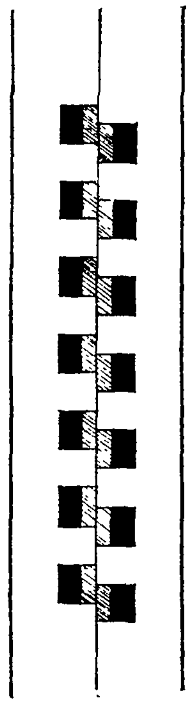

Fig. 5.

accommodated eyes—a condition well recognized as most favorable for the appearance of such effects.[1] But above all, the presence of irradiation is shown by the entire disappearance of the illusion when the figure is held in the full glare of a bright light and viewed at a distance of six or eight inches from the eyes. If the paper upon which the figure is drawn be semi-

[1] See Helmholtz, Physiologische Optik, 2d Ed , p. 395.

transparent, the same disappearance of the illusion may be accomplished by holding the figure between the bright light and the eyes.

But may not the alternating and contrasted position of the squares be also influential, wholly aside from the effect of irradiation? Before entering upon a quantitative investigation of the problem, the effort was made to gain an answer to this question. To this end several figures were prepared, the object of each of which was to exclude the possibility of irradiation while retaining the other operative factors, if such exist. In these figures the form of Fig. 2 was adopted, but the squares, instead of

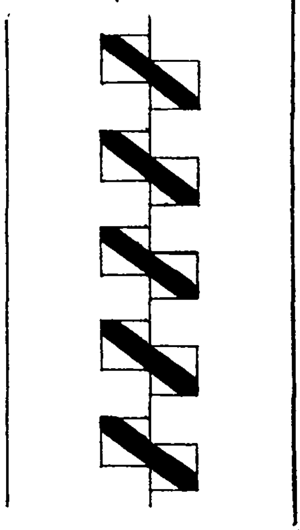

FIG. 6.

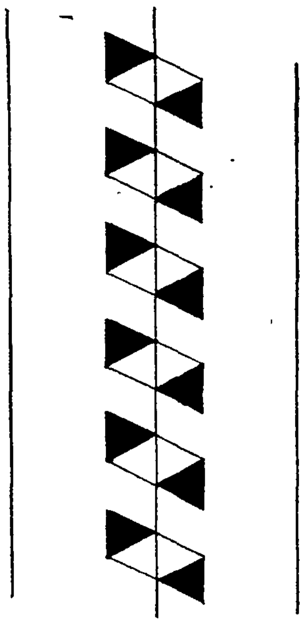

FIG. 7.

being filled with a uniform black, were variously treated with vertical or oblique lines, etc., as shown in the adjoining cuts, 3, 4 and 5. Here the full effect of contrasted squares is present, but no illusion is produced, except in the lower half of Fig. 4, where irradiation becomes possible. Alternately covering either half of Fig. 4 with a piece of blank paper will serve to render clear the difference between the two halves.

Figs. 6 and 7, also, would seem to offer as much 'contrast' as even Heymans would demand, but it is evident that no illusion is produced.

Still more interesting, however, are figures 8 and 9. In Fig. 8 the black squares are brought to within $\frac{1}{48}$ inch of

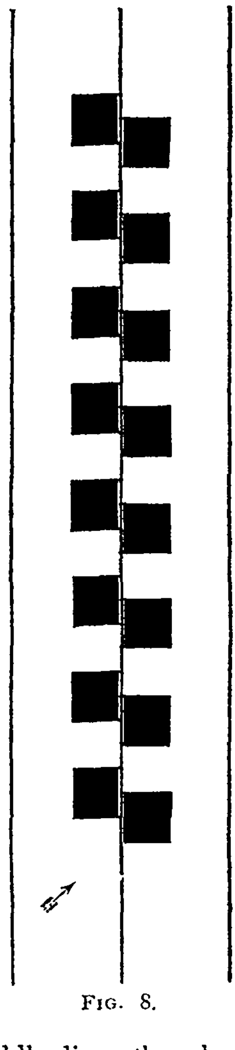

FIG. 8.

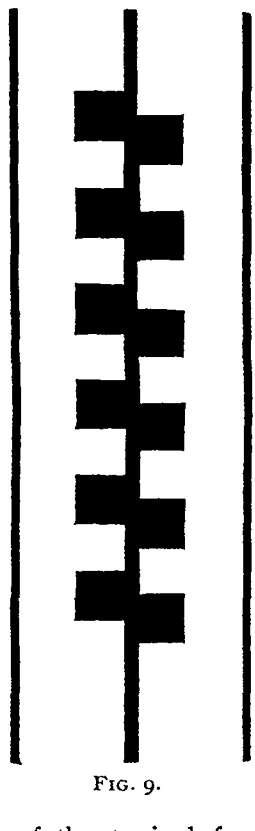

FIG. 9.

the middle line, the characteristics of the typical form being thus retained to the greatest possible extent. If the figure be looked at directly, irradiation is excluded and the middle line is not deflected. If, however, it be viewed somewhat obliquely as indicated by the arrow, at a distance of 18 inches or more from the eyes, and with the plane of the paper at an angle of 30°–45° to the line of vision, irradiation can become effective to a limited extent and the illusion reappears in proportionate degree.

Fig. 9, on the other hand, offers every opportunity for the working of irradiation, but the heavy middle line precludes that particular direction of its effectiveness which is requisite for the production of the illusion. That is to say, the 'boring' effect in the corners formed by the several pairs of squares is no longer able to produce the tilted appearance of the middle line. For here not only the inner corners formed by each pair of squares, but each and every corner along the middle line offers a boring point for the action of irradiation. Consequently, in so far as the middle line is concerned, these effects neutralize one another, leaving this line unaffected, while instead the white areas at either side seem to have been dovetailed into the black, so tightly do the white squares appear to fit into the inner corners. If one recall in this connection that the original Zöllner pattern was constructed with heavy lines, the non-appearance of linear deflection in the case before us becomes all the more instructive.

That irradiation does produce a maximum effect in the corners of dark areas, so that a right angle is thus made to appear acute, may be readily seen by drawing a square (with an edge, say, of two inches), three-fourths of which shall be black and the remaining fourth white, as in Fig. 10. Here the inner corner of the white square is seemingly the vertex of an angle slightly less than 90°. In fact, by an application of this principle to a variation of the typical figure an illusion of an en-

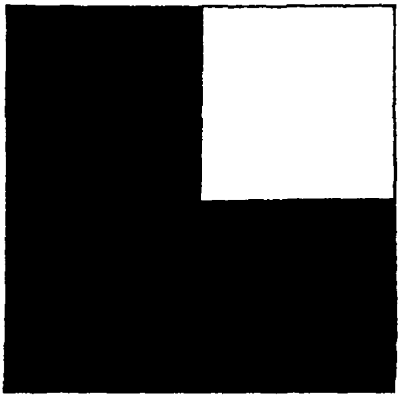

FIG. 10.

tirely new form may be brought about, as shown in Fig. 11. Here the central line is no longer tilted, for the place of maximum irradiation has been transferred from the outer corners to the centres of the squares. What now occurs is this: The horizontal cross lines, which bound above and below the successive pairs of tiny white squares, receive each a slight deflection in the direction of the full black portion of the larger squares. The upper cross-line is deflected upwards from right to left, and the lower downwards from left to right. At the same time the vertical boundary lines on the right and left receive deflections downwards to the right and upwards to the left, respectively. The result is, as Fig. 11 shows, that each pair of adjacent white squares (which may be apperceived as a single white bar crossing the central line), seems to slope slightly downwards from left to right. By diminished illumination this becomes still more apparent. In fact all these illusions due to irradiation come out very clearly when viewed under reduced illumination, as, *e. g.*, when drawn upon semi-transparent paper and viewed from the back, the blank side, that is, being towards the face.

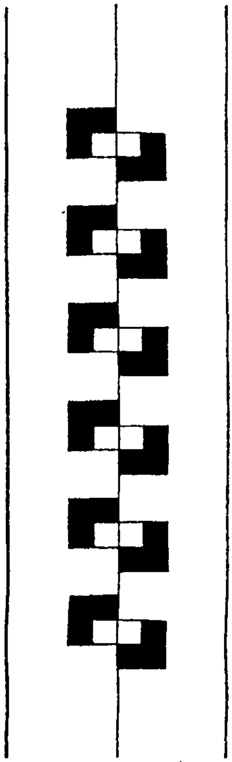

FIG. 11.

Of still greater interest in certain respects is Fig. 12, which grew out of the attempt to exclude irradiation by presenting one line of squares only to each eye, the two being united into a single figure by ordinary stereoscopic methods. Of course, the union into the desired figure is impossible unless certain well marked portions of the original figure be retained and presented to each eye. Otherwise the two vertical lines of squares would simply coalesce. Fig. 12 represents the adopted form which fulfills the required conditions very satisfactorily. Hold a paper-cutter, or similar object, between the figure and the eyes in such a way that each eye receives only its appropriate image. Converge the eyes for some distant object and the single compounded figure will appear. At first this will present the appearance of Fig. 8, a stripe of white running down between the squares, but if the illumination be reduced by shading the diagram from the source of light, or by allowing the illumination to pass through several thicknesses of transparent paper, after a little the wished-for figure will appear wholly in black and exactly like the typical form, but *with no trace of the illusion*. To be sure, on account of retinal rivalry, the white stripes will frequently reappear, but if the illumination be properly adjusted and the white parts be darkened by rubbing lightly with a hard lead pencil the compounded figure can be made to retain its desired state long enough for a thorough and satisfactory examination.

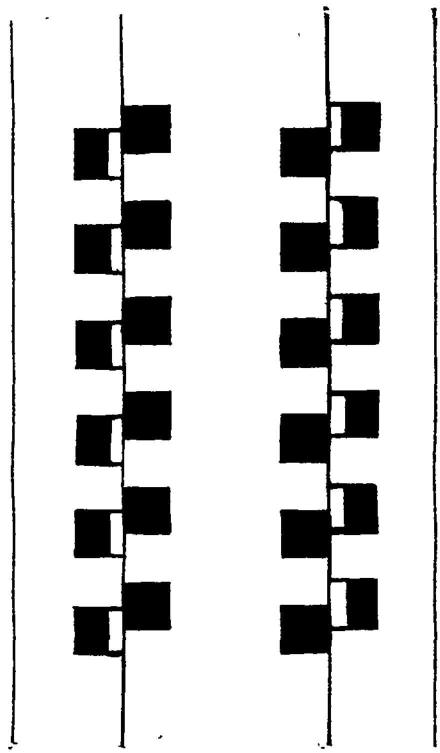

FIG. 12.

Of course, I am far from claiming that in this experiment irradiation alone has been excluded while all three factors, such, *e. g.*, as that of 'contrast,' have been retained in full force. Although, perhaps, we have most closely approximated the desired form of the experiment that shall possess these latter qualifications, we can by no means draw any absolute conclusion. For, while in the compounded figure every possible condition of *geometrical* form and contrast is present, it would be evidently unwarrantable to conclude from the absence of the illusion that therefore the factor of 'contrast,' or what not, is without influence in this particular illusion. For, if what is meant by 'contrast' here be a physiological matter, as it presumably is to a greater or less extent, its effectiveness in this case must be diminished, in some measure at least, since neither eye receives the full contrast-effect as from the typical figure seen by both eyes alike. And yet one must acknowledge that, owing to the manner of constructing the parts of Fig. 12, the greater portion at least of all contrast possibilities has been preserved in each of the two parts. Still, all that the experiment can be made to prove with absolute decisiveness is that, when irradiation in corners is rendered impossible, the illusion under discussion fails to appear. And, as a means of demonstrating this, the above seems to be a convenient and effective method.

There has now been established, it seems to me, a rather strong presumption in favor of irradiation as the only necessary explanatory principle for the Münsterberg illusion. That this presumption becomes overwhelmingly strong will be seen when the supplementary evidence derived from the quantitative investigation has been considered. For, as the subsequent text will endeavor to show, all conditions that in any way alter the character and amount of irradiation alter in the same degree the amount of apparent angular displacement undergone by the middle line. Let us turn therefore to the quantitative portion of our task.

B. Quantitative.

The purpose of the quantitative investigation was to ascertain as far as possible the influence of various factors in determining the amount of the illusion. Such factors are, *e. g.*, the *vertical distance* between the squares on either side; the length of the *free edge* along the middle line; the *color* of the background and of the squares; the character of the *illumination* as changed by interposing colored media between the eyes and the figure, or as conditioned by causing the figure to be viewed through a pinhole, or under the momentary flash of the electric spark; etc., etc.

The apparatus employed throughout was of the most simple character. Numerous cards were prepared, all being furnished with half-inch squares at varying vertical distances, arranged along the inner edge of each card, much as in the case of the Bradley model, so that the desired amount of overlapping edge could be readily adjusted. These cards were brought together in appropriate fashion along the middle line *on* of the board *FH* (Fig. 13). Parallel to the actual middle line were stretched threads *am* and *bs*, fastened below to the board itself but above to a sliding rod *KL*. This rod, being attached to a car travelling upon a firm support, could be moved to any amount and in either direction by means of a thumb-screw not indicated in the figure. By this means the vertical threads could be brought to a position of parallelism with the apparently deflected middle line *on*, assuming, *e. g.*, the positions indicated in the figure by the dotted lines *cm* and *ds*. A scale was attached to one end of the rod *KL*, and the amount *ac* (= *bd*) of horizontal movement could be read micrometrically to the hundredth of a millimeter. Then the angular displacement *a*, which stands for the amount of the illusion, could be calculated from the simple formula $\tan a = \frac{ac}{am}$.

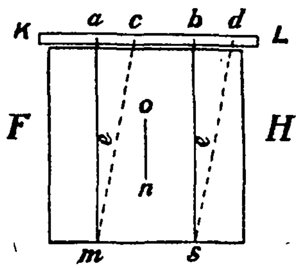

FIG. 13.

The entire apparatus was hidden behind a screen of black cardboard, a window in which disclosed the central part of the prepared cards and the parallel threads. This window was 17 cm. in width and varied in height from 16–20 cm., as the particular experiment demanded. In general, six pairs of squares were used, exceptions to this being in the experiments described in Tables I. and VI., where eight and five pairs respectively were used. The parallel threads were two inches apart and equidistant from the middle line. The illumination, except in the single case where the electric spark was used, was diffused daylight. The eyes of the observer were at a distance of 70–80 cm. from the cards, this range of movement being deemed advisable in order to allow free access to the thumb-screw and in order to prevent fatigue arising from the attempt to maintain a fixed position. The plane of the cards formed an angle of 90° with the line of vision. The observer himself set the threads in the desired position, and as much time and as much shifting were allowed as were necessary to bring the threads into satisfactory parallelism with the middle line. In any series of experiments parallelism was established alternately from the left and from the right. The usual regulations as to practice, fatigue, etc., were carefully regarded.

In proceeding with the experiments it soon became evident that only a trained observer could give reliable and utilizable results. For the illusion is of such a character that a certain method of procedure must be acquired by each observer before a satisfactory parallelism between the three lines can be established. As Münsterberg has pointed out,[1] the middle line does not always appear to be deflected *as a whole*. The fact is rather that each portion of the middle line that unites the pairs of squares seems to be deflected by itself, and these partial deflections must be apperceived together before the illusion can extend to the whole line. From this consideration it will be seen how difficult it is in many cases to decide upon a position of parallelism, and how necessary a sufficient training and the adoption of a particular method are in the production of reliable and comparable results. In general, the method employed was to allow the eyes to move freely, the gaze being directed principally to the *middle* portions of the figure and *both* threads being considered in the judgment of parallelism. In the attempt to carry out this method there arose, of course, slight individual differences of observation. These, however, were unessential, the only point to be insisted upon being that such individual peculiarities should remain constant throughout the experiments. In view of the difficulties just noted, the tables given below contain the records of only three observers, C., E. and P., each of whom possessed the requisite amount of preliminary experience.

In the following tables the letters of the first column designate the observers. Series 1, Series 2, etc., at the heads of columns signify that the amount of the *free* inner edge of the overlapping squares was respectively one-fourth, two-fourths, three-fourths

[1] Loc. cit , p. 187.

and four-fourths of the length of the edge itself. This edge was in every case a half inch in length. The numbers in these columns indicate the apparent angular displacement, or in other words the amount of the illusion under the given conditions. Column N shows the number of observations, and the adjacent column gives the mean variation of the single judgments to the nearest minute of arc.

TABLE I.—V. D. (VERTICAL DISTANCE BETWEEN SQUARES) = ¼ IN.

Observer.	Series 1.	N	M.V.
C.	8°23'.1	3	62'
E.	10°48'.6	5	30'
P.	10°49'.3	5	78'
Av. and Tot.	10°0'.3	13	

TABLE II.—V. D. = ⅜ IN.

Observer.	Series 1.	N.	M.V.	Series 2.	N.	M.V.	Series 3.	N.	M.V.
C.	11°21'.2	3	66'	9°42'.3	3	71'	0°40'.5	4	6'
E.	11°19'.2	3	40'	9°31'	3	28'	2°40'.4	3	40'
P.	13° 4'.4	4	6'	11° 5'.6	4	42'	1°14'.1	3	26'
Av. and Tot.	11°54'.9	10		10° 6'.3	10		1°31'.6	10	

TABLE III.—(NORMAL.) V. D. = ½ IN.

Observer.	Series 1.	N.	M.V.	Series 2.	N.	M.V.	Series 3.	N.	M.V.
C.	12°13'.3	4	49'	**12°51'**	6	16'	8°47'	5	71'
E.	11° 0'.5	4	44'	**11°56'.4**	4	71'	9°23'	5	38'
P.	16°10'.3	4	66'	**17°19'**	4	43'	8°16'.8	7	42'
Av. and Tot.	13° 8'	12		**14° 2'.1**	14		8°48'.9	17	

TABLE IV.—V. D. = 5/8 IN.

Observer.	Series 1.	N.	M.V	Series 2.	N.	M.V.	Series 3.	N.	M.V.	Series 4	N.	M.V.
C	8°40′	4	46′	10°31′.5	4	52′	8°48′.7	4	55′	5°52′.5	4	34′
E.	9°26′.5	3	28′	11°25′.8	3	49′	10°36′	3	45′	6°52′.4	3	11′
P.	10°14′.5	3	59′	11°21′.7	4	54′	10°45′.8	4	84′	6°49′.5	4	55′
Av. and Tot.	9°27′	10		11°6′.3	11		10°3′.5	11		6°31′.5	11	

TABLE V.—V. D. = 3/4 IN.

Observer.	Series 1.	N.	M.V.	Series 2.	N.	M.V.	Series 3	N.	M.V.	Series 4.	N.	M.V.
C.	6°47′.4	2	39′	7°23′.9	2	23′	6°21′.3	2	13′	5°22′.3	3	33′
E.	7°41′.6	3	13′	8° 7′.2	3	44	7°43′.	3	35′	3°39′.6	3	30′
P.	7°20′ 4	4	49′	7°48′.2	4	45′	6° 2′.1	4	32′	3°59′.6	4	25′
Av and Tot.	7°16′.5	9		7°46′.4	9		6°42′ 1	9		4°20′.5	10	

TABLE VI.—V. D. = 1 IN.

Observer.	Series 1.	N.	M.V.	Series 2.	N	M.V.	Series 3.	N.	M.V.	Series 4.	N.	M.V.
C.	5°23′.7	3	66′	7°24′.3	3	31′	5°31′.8	3	16′	3°56′.	3	47′
E.	4°55′.7	3	19′	5°29′.3	3	35′	5°22′.3	3	48′	3°26′.5	3	48′
P.	6°14′.7	3	45′	7° 3′.4	3	69′	5°13′.2	3	16′	5°11′.8	3	49′
Av. and Tot.	5°31′.4	9		6°39′	9		5°22′.4	9		4°11′.4	9	

The following observation may be made on these tables. Taking a downward glance through the tables and comparing the corresponding series reveals the fact that increase of vertical distance between the squares is attended, first, by increase and then by decrease in the amount of the illusion. The maximum in each case is reached in Table III., where V. D. and edge of squares are equal. Table III. may be said to represent the *normal* form. Tables IV., V. and VI. show by series 4 that the illusion still persists where there is no overlapping but merely a touching of the corners.

A horizontal glance discloses the fact that, with the exception of Table II., the maximum illusion is reached in series 2, where free edge and overlapping edge are equal. In Table II., series 1 shows the largest results, but, as great subjective difficulty was felt here, as also in the experiments of Table I., because of the zigzag character of the line, no importance is attached to this fact. The *maximum illusion* is then in series 2 of Table III. That is, what we have previously called the *typical* form (Fig. 2) presents the illusion under its most favorable conditions.

TABLE VII.—NORMAL FORM. MIDDLE LINE HEAVIER.

Observer.	Series 2	N.	M.V.	Normal.[1]	N.	M.V.
C.	8°44′.3	4	36′	10°12′.8	4	49′
E.	9°38′.8	3	43′	11°41′	3	43′
P.	11°48′.7	4	17′	17°10′.2	4	2′
Av. and Tot.	10° 3′.9	11		13° 1′ 3	11	

The facts noted in connection with Fig. 9 suggested measuring the illusion in its normal form but with the middle line emphasized by introducing between the edges of the cards a piece of No. 50 black cotton thread. The left-hand columns give the results. A 'normal' was measured at the same time, the results being given in the right-hand columns. It will be seen that a heavier middle line considerably reduces the illusion.

TABLE VIII.—NORMAL: VIEWED THROUGH PINHOLE.

Observer.	Series 2.	N.	M.V.	Normal.	N.	M.V.
C.	4°33′.8	4	78′	9°32′ 5	4	29′
E.	9°40′.9	4	68′	11°56′.4	4	71′
P.	14° 3′.7	4	85′	15°52′.5	4	39′
Av. and Tot.	9°26′.1	12		12°27′.1	12	

Fick[2] has prettily shown that the amount of irradiation varies with the width of the pupil of the eye. A 'normal' form was accordingly viewed through a pinhole whose diameter was ap-

[1] In this and the following tables, 'Normal' refers to the form of Table III., Series 2.

[2] Fick, Archiv für Ophthalmologie, II., 2 (1856): 70–76.

proximately 1 mm., and records without the use of the pinhole were taken at the same time for comparison. The results are shown in the respective columns of Table VIII. The illusion is seen to be diminished. So far as I can judge, the illusion of the Zöllner patterns is not thus diminished when viewed in this way.[1]

TABLE IX.—NORMAL: ELECTRIC SPARK.

Observer.	Series 2.	N.	M V	Normal.	N.	M V.
C.	9°33′.4	2	92′	10°36′.6	2	48′
E.	7°11′.8	2	169′	12°20′	2	49′
P.	8°57′.3	2	66′	16° 8′.6	40[1]	
Av. and Tot.	8°34′ 2	6		13° 1′.7		

Here, again, the diminution of the illusion under changed conditions of illumination is very apparent.

TABLE X.—WHITE SQUARES ON BLACK. V. D. = ½ IN.

Observer.	Series 1.	N.	M.V	Series 2	N.	M.V	Series 3.	N.	M.V.
C.	8°23′.6	4	51′	8° 3′.8	4	6′	6°17′.8	4	42′
E	8°59′.7	4	25′	10°24′.7	4	34′	8°52′.1	4	39′
P.	11° 0′.5	4	67′	14°41′.8	4	49′	9°20′.3	4	92′
Av. and Tot.	9°27′.9	12		11° 3′.4	12		8°10′	12	

N. B. *White* threads were used.

TABLE XI.—BLUE SQUARES ON YELLOW. V. D. = ½ IN.

Observer.	Series 1.	N.	M.V.	Series 2.	N.	M.V.	Series 3.	N.	M.V.
C.	8°41′.8	3	49′	8°33′.5	3	30′	4°36′.4	4	99′
E.	6°57′.	4	11′	5°57′.2	3	78′	4° 4′.2	4	13′
P.	7° 8′.7	4	43′	6°59′.7	4	44′	2°30′.7	4	44′
Av. and Tot	7°35′.8	11		7°10′.1	10		3°43′.8	12	

TABLE XII.—RED SQUARES ON GREEN. V. D. = ½ In.

Observer.	Series 1.	N	M.V.	Series 2.	N.	M.V.	Series 3.	N.	M.V.
C.	3°56′.	3	71′	5°38′.8	3	47′	3°31′.5	3	23′
E.	1°56′.4	3	18′	2°49′.3	3	35′	2°37′	3	10′
P.	4°16′.2	4	36′	4°39′.9	4	43′	4°10′.1	4	67′
Av. and Tot.	3°22′.8	10		4°22′.6	10		3°26′.2	10	

[1] The angle here given is the average of all normal observations. See Table XX.

Table XIII.—Colored Media.

Observer.	Normal Series 2.	N.	M.V.	Red.	N	M.V.	Yellow.	N.	M.V.	Blue	N.	M.V.	Green	N.	M.V.	Smoked Glass.	N.	M.V.
C.	12°51′	6	16′	11°49′.6	3	37′	11°17′.8	3	65′									
E.	12°16′.7	4	18′	13°45′.4	4	49′	12°10′.6	4	31′	15°22′	4	78′	12°18′.3	4	29′			
P.	16°50′	4	31′	13°44′.4	4	50′	15°11′.4	4	32′	15°42′.8	4	46′	15°59′.6	4	50′	9°23′	4	86′
Av. and Tot.	13°59′.2	14		13° 6′.5	11		12°53′.3	11		15°32′.4	8		14° 8′.9	8				

Table XIV.—Normal. Varying Inclination to Line of Vision.

Observer.	30°	N.	M.V.	45°	N.	M.V.	60°	N.	M.V.	90° Normal.	N.	M.V.
E.	5° 8′	2	16′	4°41′.7	4	99′	8°52′.1	2	18′	13°17′.1	4	27′
P.	11°37′.8	2	20′	12°25′.8	4	68′	13° 7′	2	4′	17°10′.2	4	2′
Av. and Tot.	8°22′.9	4		8°33′.7	8		10°59′.5	4		15°13′.6	8	

Tables X., XI. and XII. present interesting variations of color. In Tables X. and XII. the various series show in general the same direction of increase and decrease as did Tables II.–VI. above. In Table XI., series 2 is slightly less than series 1. But the point to be noticed is the universal decrease in the amount of the illusion, especially in Tables XI. and XII., where colors are used. Many interesting color combinations suggest themselves for similar experiments, but these were deemed sufficient to make clear the great changes produced by the introduction of colors without alteration of geometrical form.

Table XII. gives the records obtained by viewing the 'normal' form through variously colored gelatine papers. A comparison series taken at the same time is given at the left. The table shows nothing decisively. There is a general tendency towards a diminution of the illusion, especially in the one case where smoked glass was used. Observer E., however, shows a constant tendency to see the illusion increased. Careful questioning at the time failed to elicit any reason for this, but I suspect that E. was influenced by the greater ease of measurement here. For under these conditions the deflection of the line seems to be more constant and to extend more to the line as a whole.

Table XIV. shows that the illusion is greatest for two observers when its plane is perpendicular to the line of vision.

TABLE XV.

Observer	Fig. 14, *a*.	N.	M V.	Normal.	N.	M.V.
E.	10°24′.7	4	41′	13°17′.2	4	27′
P.	11°31′	4	69′	17°10′.2	4	2′
Av. and Tot.	10°57′.8	8		15°13′.7	8	

TABLE XVI.

Observer.	Fig. 14, *b*.	N.	M.V.	Normal.	N.	M.V.
E.	11°41′.2	4	31′	13°17′.2	4	27′
P.	15°47′.5	4	23′	17°10′.2	4	2′
Av. and Tot.	13°44′.3	8		15°13′.7	8	

TABLE XVII.

Observer.	Fig. 14, *c*.	N.	M.V.	Normal	N.	M.V.
E.	8°43′.5	4	38′	13°17′.2	4	27′
P.	13° 0′.3	4	44′	17°10′.2	4	2′
Av. and Tot.	10°51′.9	8		15°13′.7	8	

TABLE XVIII.

Observer.	Fig. 14, *d*.	N.	M.V.	Normal.	N.	M.V.
E.	4° 7′.7	3	28′	13°17′.2	4	27′
P.	3°57′.2	3	27′	17°10′.2	4	2′
Av. and Tot.	4° 2′.5	6		15°13′.7	8	

N. B. Threads 3 in. apart.

From Fig. 14 it will be seen that various geometrical shapes may be used to produce the illusion, the 'wriggling' character of which in this case is due to the reversal of the figures at *b*, the lower being here upon the left. Tables XV.–XVIII. refer to experiments made upon figures composed each of six pairs, in the form respectively of *a*, *b*, *c* and *d*. The comparison column of 'normals' was taken at the same time and with all conditions identical except that of form.

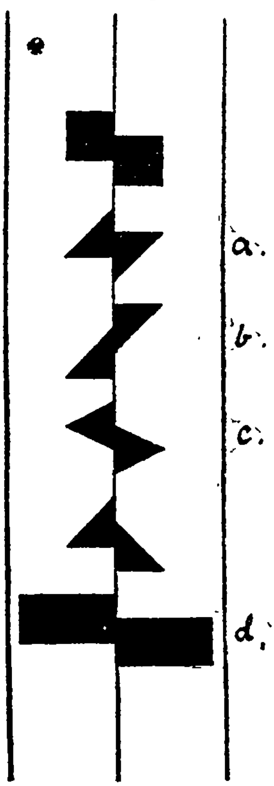

FIG. 14.

In Figs. 14 *b* and 14 *c* the 'irradiation angles' are respectively 135° and 116°+. It is interesting to note that these odd forms give a weakened illusion; also that the particular distribution of black in Fig. 14 *b* gives an illusion greater than that in Fig. 14 *c*, although its 'irradiation angle' is greater. A lateral increase of dark area strikingly reduces the illusion, the records of Table XVIII. being the smallest that we have anywhere encountered.

TABLE XIX.—COMPARISON TABLE OF 'NORMAL' FORMS.

Character of Figure.	Observer. C.	E.	P.	Averages.
Typical form. Fig. 2	**12°51′**	**11°56′.4**	**17°19′**	**14° 2′.1**
White squares on black	8° 3′.8	10°24′.7	14°41′.8	11° 3′.4
Blue squares on yellow	8°33′.5	5°57′.2	6°59′.7	7°10′.1
Red squares on green	5°38′.8	2°49′.3	4°39′.9	4°22′.6
Middle line heavier	8°44′.3	9°38′.8	11°48′.7	10° 3′.9
Normal through pinhole	4°33′.8	9°40′.9	14° 3′.7	9°26′.1
Through colored media	[1]11°33′.7	13°24′	[2]15° 9′.5	
Electric spark	9°33′.4	7°11′.8	8°57′.3	8°34′.2
Fig. 14a		10°24′.7	11°31′	10°57′.8
Fig. 14b		11°41′.2	15°47′.5	13°44′.3
Fig. 14c		8°43′.5	13° 0′ 3	10°51′.9
Fig. 14d		4° 7′.7	3°57′.2	4° 2′.5

In Table XIX. are collected for convenient comparison the results of experiments of the 'normal' form, series 2, under the twelve conditions indicated at the left. The often striking deviations from the typical form require no special emphasis here.

TABLE XX.—GRAND AVERAGE OF 'NORMALS,' FORM OF TABLE III., SERIES 2.

Observer.	Normal.	N.
C.	11° 5′.2	25
E.	12°14′.6	26
P.	16° 8′.6	40
Av. and Tot.	13° 9′.5	91

Finally, Table XX. gives the grand average of results from the typical figure, gathered from the various control experiments of the different tables. The final average, 13° +, may be taken roughly as the probable measure of the illusion under most favorable conditions. But there is no wish here to insist upon absolute numbers, for that would involve both a consideration of our ability to establish parallelism between lines and a discussion of discriminative sensibility for angular magnitudes—matters which must remain unconsidered here.

[1] Red and yellow only.
[2] Smoked glass not included.

The illusion under discussion has now been subjected to both a qualitative and a quantitative examination. The former has shown us that whenever irradiation is excluded the illusion vanishes. The latter has shown that whatever alters the amount and character of irradiation produces an alteration in the amount of the illusion, as conveniently seen in Table XIX. If now we combine these two lines of evidence, the conclusion seems irresistibly forced upon us that irradiation, and that alone, is adequate to explain the phenomenon of the Münsterberg illusion.