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ADAPTATION, AFTER-EFFECT AND CONTRAST IN THE PERCEPTION OF CURVED LINES

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INTRODUCTION

The phenomenon with which this paper is chiefly concerned was first observed, quite incidentally, in March, 1929 at the end of an experiment which, in the tradition of Stratton's famous research,[1] was concerned with the formation of new space habits during a period of wearing glasses which distorted the visual field. Instead of a lens with curved surfaces, however, simple prisms were used, one in front of each eye, so that the visual field was shifted bodily to the right (approximately 15°) instead of being inverted. In addition to this shift of the field another, and for the purposes of this discussion more important, distortion was produced by the prisms—the bending of vertical straight lines into curves convex to the left. Horizontal lines were not affected. The vertical edges of doors and windows, for example, all appeared definitely curved in the same direction.

This curvature optically imposed by the prisms is constant in amount in the sense that the curvature of one line is visually congruent with the curvature of any other line in the field. Accordingly, the radius of the curvature varies with the distance of the line from the eye; it is about 9 meters at 3 meters distant, and 3 meters at one meter distant. A

[1] G. M. Stratton, Vision without inversion of the retinal image. *Psych. Rev.*, 1897, 4, 341–360 and 463–481.

somewhat simplified optical explanation of the bending effect is as follows. In the accompanying schematic diagram the ray of light entering the eye from point B the center of a vertical straight line, passes through the prism perpendicularly to its axis and is bent as shown. But the rays of light from *A* and *C*, the ends of the line, pass through the prism diagonally to its axis so that, in effect, they are transmitted through a prism of wider angle and are therefore bent more. Points *A* and *C* will therefore be displaced farther to the right than *B*. In other words, those rays of light from *A*, *B*, and *C*

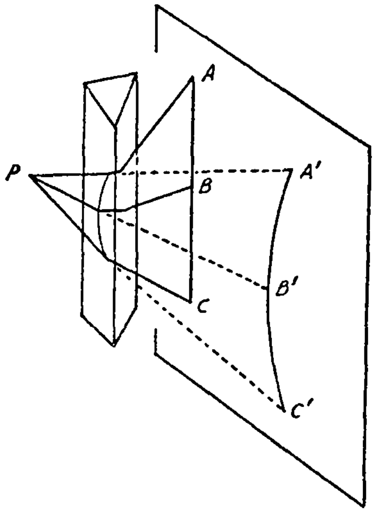

FIG. 1

which are destined to enter the eye at *P*, enter from directions such that when projected on the plane of fixation the points take the position *A'*, *B'*, *C'*. It should be noted that the sheaf of rays which enters the eye takes the form of a curved plane. The rule for the bending effect is therefore that any vertical line will appear convex on the side towards the base, or opposite the apex, of the prism. In the experiment now being described, lines were convex on the left.

The subject of the experiment, *G*,[2] wore the prism glasses continually, except when asleep, for a waking period running

[2] The writer wishes to express his admiration to his former student, Miss Janet Goldschmidt, for her fortitude and careful observation in this original experiment.

through four days and totalling 45 hours. The curvature of the visual world, which at first had been very striking and somewhat disconcerting, was reported on the third and fourth days to be less marked than at the beginning. When the glasses were taken off, and after the series of tests for various spatial reactions had been completed,[3] the subject reported that her visual world was now curved in the opposite direction. All vertical lines and edges now seemed definitely and unmistakeably to be curved with convexity to the *right*. This opposite curvature was more vivid and greater in amount than the prism curvature had been during the last day. The effect persisted strongly the rest of that day and was noticeable during the greater part of the next day.[4]

Here was a phenomenon which clearly demanded further investigation. In the effort to verify the observations of the first subject it was discovered that the curvature after-effect could be obtained with subjects who had worn the glasses for periods as short as an hour. Several experienced observers now served in the experiment, wearing the prisms for periods of an hour and upwards. Without exception all declared that when the glasses were removed vertical lines and edges looked unmistakably curved in a direction opposite to that existing while the prisms were worn. During the training periods these subjects simply walked about or sat, looking at and

[3] The primary purpose of the experiment was to investigate the modifications in auditory and kinæsthetic space habits resulting from a 15° displacement of the visual field. The results, together with those of subsequent experiments on the same problem, are significant but will not be reported in this paper. Prism glasses similar to ours have been used to investigate space perception by Margaret Wooster (Certain factors in the development of a new spatial coördination, *Psychol. Monog.*, 1923, 32, no. 4) and by David Camp Rogers in an unpublished research. In these investigations however the glasses were worn intermittently rather than continuously as in the present experiment.

[4] Another and no less striking after-effect of the prisms was reported but has not yet been confirmed. While wearing the prisms, as might be expected, dark lines on a brighter ground were bounded vertically by narrow bands of color, *i.e.* half-spectra, red on the right and blue on the left. This phenomenon was reported to be less marked at the end of the three-day period. When the glasses were removed, G stated that the colored bands were now seen with renewed vividness but that the effect was reversed, red now being on the left and blue on the right. The phenomenon persisted for several hours. For obvious reasons, explanation cannot be made in terms of ordinary negative after-images.

feeling objects, and in general becoming acquainted with the curved prism world.

The Experiments. Series I

The phenomenon having been verified to this extent, an experiment was planned with two ends in view, first, to measure the after-curvature, and, second, to test for and measure anything in the nature of adaptation during the period of wearing the prisms. It seemed very probable that if a straight line looked slightly curved to the right when the prisms were removed, this was due to the fact that a line curved to the left at the beginning of the period looked slightly less curved to the left at the end of the period. Or, in terms of an analogy with color vision, if there were a "negative after-image" of curvature there must also be a fading or desaturating of curvature during the period.

The Prism Glasses.—The glasses used in these experiments consisted of a pair of ordinary optometrist's trial prisms, mounted in trial frames, with the apex of both prisms towards the right. The angle of the prisms being close to 26°, the amount of deflection of a ray of light in the center of the visual field (angle of minimum deviation) was approximately 14°.[5] The glasses were set in a mask, at first of cardboard and cloth, later of leather, which fitted closely around the forehead and below the eyes, fastening behind the head. This device effectively excluded all light except that passing through the prisms.

Procedure During the Period.—Each of the subjects in Series I wore the prisms for a period of one hour. During the hour each subject underwent a fairly uniform program of training, which consisted chiefly in looking at and running the fingers along vertical lines and edges such as that of a meter stick. It was anticipated at the time of these experiments that a possible explanation for the 'after-curvature' might be found in terms of conflict between vision and kinæsthesis. Crudely, the hypothesis was that if a meter stick for example were seen as curved but felt as straight, adjustment would occur in the direction of less visual curvature. To facilitate such adjustment, should there be any, the training described was made to occupy intervals totalling about half of the hour period.

It was discovered, however, that in actual fact the kinæsthetic perception, in so

[5] The formula used for the calculation is $\delta = (\mu - 1)\alpha$, δ being the angle of deviation, μ being 1.53, and α being the angle of the prism.

far as it was consciously represented, did *not* conflict with the visual perception. When a visually curved edge such as a meter stick was felt, it was felt as *curved*. This was true as long as the hand was watched while running up and down the edge. If the eyes were closed or turned away, the edge of course felt straight, as it in reality was. This dominance of the visual over the kinæsthetic perception was so complete that when subjects were instructed to make a strong effort to dissociate the two, *i.e.* to 'feel it straight and see it curved,' it was reported either difficult or impossible to do so.[6]

The intervals of the test period not taken up by the activities just described were occupied with simple exercises designed to give practice in coördinating movement with the new visual space, which it will be remembered was shifted some 15° to the right. Objects, that is to say, were seen 15° to the right or where they really were. At first, therefore, errors to the right were made in reaching for or pointing to objects, the subject walked to the right of where he wished to go, bumping into objects and door frames on the right, etc. By the end of the hour, however, these errors had either decreased greatly in extent or completely disappeared.[7]

In order to measure the anticipated after-effect of curvature and also the possible adaptation to curvature, a 30 cm vertical straight line was drawn on a large sheet of white cardboard, which was then mounted on a screen and set up on a table with a head-rest clamped to its edge. The distance from the cardboard screen to the observer's eyes was 40 cm, so that the line extended over a visual angle of approximately 42°. To the right and left of the mid-point of this line there was a scale, in 4 mm units. With the aid of this scale, it was anticipated that, after the removal of the glasses, any apparent curvature of the line could be estimated with reasonable accuracy to the quarter of a unit (1 mm). This expectation seemed reasonable, since the subjects had heretofore reported that the 'after-curvature' was sufficiently stable to allow of a fairly careful estimate of its extent in terms of the apparent displacement to right or left of the center of a straight line.

For the measurement of the curvature adaptation during the period a somewhat more precise method proved to be possible. Immediately after putting on the prism glasses the subject sat at the table and, adjusting his head in the head-rest, faced the screen. The line appeared definitely convex to the left,[8] the center of the line being displaced about 10 mm. The amount of this displacement of the center of the line could be estimated on the scale without difficulty, but could be even more precisely determined in the following manner. S was given a slender flexible black fibre rod, 2 feet long. This rod, of course, likewise appeared convex to the left in prism vision, but it could be held against the screen touching the right edge of the line, with one hand at either end, and then could be bent convexly to the right until it looked perfectly straight. Bent in this way, the rod served as a straight-edge in an otherwise curved world and could be used to measure the apparent displacement of the center of the line with some accuracy. The top and bottom of the 'curved' line being in juxtaposition with the left hand edge of the 'straight' rod, the displacement at the center

[6] The fact of visual dominance under these conditions was noticed and reported by G, the original observer, during the 4 day experiment. She has since carried out a detailed investigation of this phenomenon.

[7] For a quantitative study of the improvement in localizing movements of the hand while wearing prism glasses, see Wooster, *op. cit.*, 13–47 and 63–67.

[8] During all the experiments of Group I, the prisms were worn with apex to right.

could be read off on the scale by the experimenter. The apparent curvature of the line was measured by this method in millimeters at the beginning of the period (Test I) and at the end of the period (Test II). Any adaptation which had occurred would show up as a decrease from Test I to Test II.

Results.—Ten subjects were used in this series of experiments. Only two of these had ever had any previous experience in psychological observation, but nevertheless no one had any difficulty in observing the phenomenon, and all without exception reported a marked negative after-curvature. Five of the subjects had heard of the effect and expected something similar to what they saw; the remaining five were completely in ignorance of the purpose of the experiment and the after-curvature was unexpected and was usually reported as surprising. As regards adaptation, three subjects reported spontaneously at some time during the hour that the curvature seemed somewhat less than at the beginning.

The results are given in Table I. Column 4 shows the estimates on the scale, of the negative after-curvature, and column 3 the decrease in perceived curvature from beginning until end of the hour (Test I minus Test II). Both after-

TABLE I

Adaptation and Negative After-Effect as Measured in Millimeters of Displacement at the Center of a 30 Centimeter Line. Curvature Produced by Prisms. Training Period of One Hour

Subject	Test I	Test II	Decrease from I to II (Adapt.)	Test III (Neg. Aft.-Effect)
A	10 left	7 left	3 right	2 right
B	7	6	1	1
C	9	8	1	1.3
D	9	8	1	1
E	10	9	1	0.5
F	9	8	1	1
G	9	7	2	2
H	10	8	2	2
I	9.4	9.2	0.2	2
J	9	7.7	1.3	2
Avg's.	9.14 left	7.79 left	1.35 right	1.48 right

Entries in fractional parts of a millimeter are averages of two or three measurements in cases where the subject was not satisfied with the first measurement and repeated it. The individual differences in perceived curvature shown under 'Test I' are due to slight variations in the fixation distance from subject to subject.

effect and adaptation occurred consistently and in the expected direction for all subjects. The averages of the two are respectively 1.48 mm and 1.35 mm. Allowing for the rather crude technique employed in this first series of experiments, the agreement is striking. It seems to indicate, as was expected, that the after-effect is of the same magnitude as the adaptation, and that therefore the two phenomena are essentially the same. In other words the curved line of Test I was decreased in curvature to the left at the end of the hour by as much as the straight line was then curved to the right.

A diagram may be of use here in visualizing the situation. Figure 2 shows schematically the relations between the

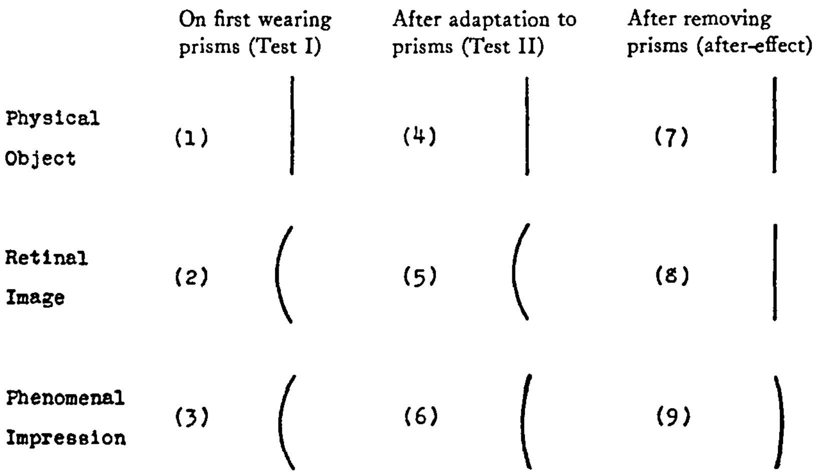

FIG. 2

physical object, the retinal image, and the phenomenal impression. The inversion of the retinal image is left out of account but its inclusion would not essentially alter matters. It is clear that if the phenomenal impression (6) is the correllate of the retinal image (5), then (9) should be the correllate of (8). In a sense, decrease in curvature to the left is the same thing as increase in curvature to the right. In this sense, the difference between (5) and (6) is the same as that between (8) and (9). Everything is clear in the diagram, then, except the question how (6) comes to be the correllate of (5). In other words, whatever it is in the organism which underlies what we have called the 'phenomenal impression,' be it cortical excitations or implicit responses, it changes in the course of an hour in such a way as to make (3) change to (6). Our next problem was to explain how this change came about.

Theoretical.—At this stage of the investigation, two very different types of explanation for the decrease in perceived curvature could be formulated.

1. It was possible that the explanation lay mainly in conflict between one type of experience and another. The subject could run his fingers along the edge of a meter stick and thus bring kinæsthetic cues into conflict with visual. Presumably, the visual impression would be modified as a result. Such a discrepancy between data from different sense departments has been considered the sufficient condition for changes of the type observed by Stratton, Wooster, Young, and Ewert.[9] It could be objected, of course, that these and other researches have never proved any significant tendency for visual perceptions to swing into line with conflicting perceptions from other senses. Indeed it could be shown that the opposite has always been indicated. And likewise it could be pointed out that the kinæsthetic and visual perceptions actually did not conflict in the prism situation, the visual perception dominating unmistakably. Despite these objections, however, it was considered that the explanation was a plausible one under the circumstances.[10]

A less specific hypothesis presented itself as a variant of the above. Since the subject knew that the lines which he

[9] G. M. Stratton, *op. cit.;* M. Wooster, *op. cit.;* P. T. Young, Auditory localization with acoustical transposition of the ears, *J. Exper. Psychol.*, 1928, 11, 399–429; P. H. Ewert, A study of the effect of inverted retinal stimulation upon spatially coördinated behavior, *Gen. Psychol. Monog.*, 1930, 7, 177–363.

[10] On first thought it might also appear that eye movement kinæsthesis would conflict with the visual perception. But it must be remembered that when the eyes behind the prisms follow a line up and down, they travel a curved path, since the curvature is imposed upon the sheaf of light rays before they enter the eye. Hence there is no discrepancy between eye movement and visual impression, and conflict between them is impossible.

saw as curved were 'really' straight, this knowledge itself might in some fashion modify the perception; that is, it might cause the subject to see a curved line as less curved. Precisely how this could occur was not clear.

2. The explanation for the decrease in curvature could be sought within the perceptual process itself, or in other words, the phenomenon might be akin to sensory adaptation. It is known that color perceptions in the course of adaptation approach gray, and it is at least conceivable that there is a general tendency for curved lines to undergo an adaptation in which they approach rectilinearity. The straight line is in a sense the average or mean of all lines, the neutral type from which the positive types deviate, in somewhat the same way as the achromatic series is in an average or neutral position in relation to the other colors. Accordingly the possibility had to be considered that curvature perceptions as well as color perceptions, when long continued, tend to approach their neutral type or norm.

The next step was to seek evidence as to which of the two explanations could best be applied. The first of the two could easily be subjected to an experimental test. If conflict between the visual impression and the kinæsthetic feel were the sole cause of the reduction in apparent visual curvature, then we should need only to eliminate all movements of the hands during the test period, and the after-curvature should fail to appear. This experiment was tried with instructions simply to sit motionless with the head in the head-rest and look at the vertical line on the cardboard screen. The line appeared curved to the left. Although under these conditions, the prisms were worn for only 10 minutes, S reported a definite after-curvature convex to the right, which was comparable in amount to the effects previously obtained. This result was immediately verified with two other experienced subjects.

The conclusion was inescapable therefore that conflict between vision and kinæsthesis could not explain the curvature adaptation. Adaptation occurred in the absence of any possibility of such conflict. Furthermore, as will be seen from Table II later, it occurred in slightly larger amount when such conflict was ruled out than when conditions favorable to conflict were maintained during the adaptation period. The main body of the first hypothesis had therefore to be rejected. Even the possibility next mentioned could now be tested experimentally. If knowledge that the curved line was 'really' straight had anything to do with the phenomenon, then there should be no after-effect from looking at an actually curved line which not only appeared curved but was thought of as curved. For the only essential difference between the perception of a directly seen curved line, and the perception of a straight line visually curved by prisms in front of the eyes, is that in the later situation, the line is known to be 'really' straight. A 30 cm curved line similar in other respects to the straight line heretofore used was drawn on a sheet of cardboard and this was placed in front of the old screen. The extent of curvature was the same as that induced by the prisms—approximately 10 mm, convex to the left. As before, the subject was instructed simply to look at the line, this time of course with undistorted vision, for 10 minutes. At the end of this time, the curved line was removed and the subject was told to report the appearance of the straight line on the screen underneath. Again the subject reported a definite after-curvature convex to the right, slight but unmistakable. The experiment was repeated with a second and a third subject. The reports were just as definite as before. The straight line looked curved to the right, the edge of the door looked curved, a meter stick held vertically looked curved. Evidently, the first hypothesis had to be rejected in its entirety. Only the second hypothesis remained.

This discovery showed the adaptation phenomenon in an entirely new light. Evidently the fact of optical distortion had essentially nothing to do with it. Subject to verification by future experiments, the principle could be formulated that *a curved line, when perceived for any considerable period of time, becomes phenomenally less curved than it was at the beginning of the period, and at the end of the period an objectively straight* *line will seem curved in the opposite direction. This fact holds whether the curvature is actually in the object, or is induced by the distorting effect of prisms.* The immediate inference was that we were dealing with a phenomenon strikingly similar to simple, sensory adaptation of the type exhibited by color and perhaps temperature. We apparently have to look within the perceptual process itself for the explanation of the adaptation.

A number of aspects of this newly discovered adaptation to 'real' curvature demanded immediate investigation. It was first demonstrated that whether the curved line were convex to right or left made no difference; the after-effect was always negative, *i.e.* convex on the opposite side. Next it was proved from the reports of several subjects that the after-effect could be observed just as well if the curved line and the subsequently seen straight line were horizontal or diagonal instead of vertical. Next an informal search was made for the degree of curvature which would give the strongest after-effect. A strongly curved line did not seem at this time to give a significantly better effect than the rather weak curvature induced by the prism glasses. Nevertheless, 25 mm of displacement at the center of a 30 cm line (instead of 10) was most frequently used in subsequent experiments.

It was also important to discover whether movement of the eyes during the adaptation period had anything to do with the occurrence of the after-effect. Heretofore the subjects had been instructed merely to 'look at' the curved line during the 10 minute period. This usually meant what we shall call 'inspection' of the line, namely, that the eyes moved freely up and down it and conditions were thus similar to those existing when the prisms were worn for an hour period. The effect of fixating the center of the line as steadily as possible for 10 minutes was now tested. Perfect fixation could not always be maintained, but was usually approximated. The after-curvature appeared as definitely as it had under past conditions. This after-effect was compared with that resulting from a 10 minute period in which the eyes were moved up and down the line regularly. The latter procedure seemed to give a slightly stronger effect, but the difference was not marked. Evidently neither the presence nor the absence of eye movements is a necessary condition for the occurrence of after-curvature.

It was also roughly determined that the use of a number of parallel curved lines side by side gave no stronger after-effect than one line alone, and that conditions were essentially the same when one used a line composed of dots, as when one used a continuous line. It was established that the phenomenon was unchanged whether one used a white line on black or a black line on white. If the former were used for fixation the after-effect would show up on the latter and *vice versa*. Likewise a thin line could be substituted for a thick line without destroying the effect.

The optimal length of time for fixating or inspecting the line was not determined, but it was found that any period about one or two minutes gave an unmistakable effect. As for the length of time during which the negative after-effect persisted, it was found to be somewhat difficult to determine and the reports were rather variable. After 10 minutes of fixation or inspection the effect usually persisted for at least a minute, and in some cases it was reported as noticeable after 5 minutes or more.

In the effort to obtain quantitative data, two new series of experiments were next undertaken, Series II and III.

Series II. Adaptation to Prism Curvature with 10 Minute Inspection Period

Method.—The experiments of Series II were performed in order to verify and measure the adaptation and after-effect of prism curvature using the brief inspection period. The apparatus was the same as that used in Series I, except that the 30 cm line had no scale to right and left of its mid-point. S wore the prisms for only 10 minutes and sat motionless with his head in the head-rest. The apparent curvature at the beginning and at the end of the period was measured as before by having S use a flexible rod as a 'straight-edge.' The amount of displacement at the center of the line, *i.e.* the distance between line and rod, was now measured by E with a small millimeter rule, instead of allowing the subject to read off the displacement on the scale. This procedure kept S in ignorance of any measurements and eliminated a great source of distraction. For greater reliability, 5 measurements of the curvature were taken at the beginning, and 5 more at the end of the 10 minute period. On removing the prisms, the after-curvature was measured by having S mark with a pencil the extent of displacement at the mid-point of a 30 cm straight line similar to the inspection line. Ten subjects were used, 8 of them being new to the experiment, and 5 being completely ignorant of the phenomenon in question.

Results.—The data are given in Table II. It may be noted that the curvature induced by the prisms, as measured before adaptation had set in (Test I), varies from 10 to 12.6 mm. These measures are somewhat larger than those recorded in Series I, where less care was taken to keep the 40 cm fixation distance constant. The average decrease in curvature during the period is 1.65 mm, and the average negative after-curvature is 1.67 mm. The agreement, as in Series I, is very close and serves only to strengthen the conclusion that adaptation and negative after-effect are aspects of the same phenomenon. It should also be noted that the amount of effect is, if anything, slightly greater than that occurring in Series I, where visual-kinæsthetic conflict could have entered into the situation. This fact lends weight to the conclusion that such conflict has no essential part to play in explaining the effect.

TABLE II

Adaptation and Negative After-Effect as Measured in Millimeters of Displacement at the Center of a 30 Centimeter Line

Subject	Test I	Test II	Decrease from I to II (Adapt.)	Test III (Neg. Aft.-Effect)
A	10.5 left	9.5 left	1.0 right	1.5 right
B	11.3	10.5	.8	1.0
C	10.7	8.8	1.9	2.0
D	11.7	10.4	1.3	1.0
E	12.6	10.2	2.4	2.0
F	11.9	9.3	2.6	1.7
G	11.9	9.7	2.2	1.5
H	10.0	8.8	1.2	1.5
I	11.4	9.5	1.9	3.0
J	11.6	10.4	1.2	1.5
Avg's	11.36 left	9.71 left	1.65 right	1.67 right

Mean variations for the averages given under Test I and Test II are all below 0.9 mm.

In order to furnish a control for the results of this experiment, two subjects went through the following procedure. Instead of inspecting for 10 minutes a straight line optically curved by the prisms, they looked at a curved line which was optically made to appear straight by the prisms. The result of inspecting this phenomenally straight line was, as might have been expected, that no after-effect whatever appeared. Evidently, then, it may be concluded that it is the fact of a visual curvature, not the prism situation itself, which is essential to the effects being investigated.

Series III. Adaptation to Real Curvature with 10 Minute Inspection Period

Method.—The next step was to verify and measure the curvature adaptation and after-effect resulting from a 10 minute inspection of a line which was actually curved. No prism glasses were worn. In other respects the procedure was the same as in earlier series. The 30 cm curved line was convex to the right, with 27 mm of displacement at the center.[11] The perceived curvature at the beginning of the period (Test I) was measured by holding the flexible rod already mentioned in what seemed a perfectly rectilinear position, just touching the two ends of the curved line on its concave side. E then measured the displacement at the center with a millimeter rule. This procedure was similar to that used in Series II, except that here of course the rod did not have to be strongly bent in order to appear straight. Measurements were repeated 5 times. The perceived curvature at the end of the period (Test II) was measured in the same way. By this time, however, the subject's perception of 'straightness' had changed, owing to the adaptation, and hence the flexible rod had to be bent slightly in the same direction as the inspection line in order for it to appear straight. The measured displacements of Test II were accordingly less than those of Test I. The after-curvature (Test III) was measured by marking with a pencil the apparent displacement at the center of a 30 cm straight line. During the inspection period, S was instructed simply to look at the curved line, moving the eyes up and down the central portion only. He was not to look away to right or left.

Results.—Note first that in Table III under 'Test I,' the measurements of the displacement of the center of the curved line are all (with one exception) under 27 mm. The fact was that the flexible rod, even before adaptation could occur, had to be very slightly bent in the same direction as the line in order to appear straight. Or in other words, an objectively straight line set alongside of a curved line will appear curved in the opposite direction. The fact is pointed out here as foreshadowing the results of the next series of experiments on simultaneous curvature contrast.

[11] Since the radius of such a curved line is large the most satisfactory method of drawing it on a sheet of cardboard is the following. Three points are marked out, the middle point being displaced to the desired extent. A flexible straightedge such as an architect's adjustable curve rule is bent into line with the three points and the ink line is ruled with a wide pen. The resulting curve is not usually perfectly circular but its departure from circularity is so slight as to be insignificant. In any case, the form of the curved line has no influence on the results.

TABLE III

ADAPTATION AND NEGATIVE AFTER-EFFECT AS MEASURED IN MILLIMETERS OF DISPLACEMENT AT THE CENTER OF A 30 CENTIMETER CURVED LINE WITH AN OBJECTIVE DISPLACEMENT OF 27 MILLIMETERS

Subject	Test I	Test II	Decrease from I to II (Adapt.)	Test III (Neg. Aft.-Effect)
A	26.1	24.6	1.5	1.5
B	26.6	23.7	2.9	2.5
C	26.5	24.7	1.8	1.5
D	27.9	26.7	1.3	1.0
E	26.2	23.9	2.3	2.5
F	26.8	25.4	1.4	2.0
G	26.5	25.1	1.4	1.5
H	25.4	24.8	.6	.7
I	25.4	24.5	.9	1.0
J	26.6	24.7	1.9	2.5
Avg's	26.4	24.8	1.60	1.67

Table III shows the same type of results as did Tables I and II. Adaptation and after-effect are again approximately equal (1.60 and 1.67 mm), as indeed they must be. The only new fact to be noted is that the adaptation and after-effect shown here are almost exactly the same as the adaptation and after-effect obtained in the corresponding prism situation (1.65 and 1.67 mm). The conclusion can no longer be in any doubt that a curved line, when inspected for 10 minutes, becomes apparently less curved by the same amount as a straight line thereafter appears curved in the opposite direction.

SERIES IV. THE CONTRAST PHENOMENON

Since curvature perception showed such a striking similarity to color perception with respect to adaptation and after-effect, it seemed possible that there might be a further similarity with respect to simultaneous contrast.[12] In color perception, a stimulus area of one quality surrounding a small stimulus area of neutral quality induces in the latter the opposite quality. Blue surrounding gray induces yellow. To test for contrast in curvature perception, therefore, we

[12] For this suggestion and for many others of great value during the course of the research, the writer is indebted to Dr. Alexander Mintz, formerly of the Smith College Research Laboratory.

have only to surround a straight line with curved lines. This was tried and as may be seen in Fig. 3, an opposite curvature is induced in the straight line. The effect, as in the case of adaptation, is slight but nevertheless definite. It is

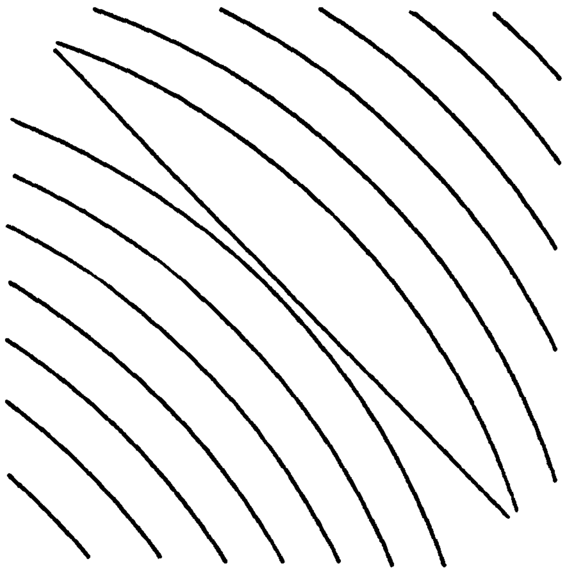

FIG. 3

somewhat greater in extent when the straight line is drawn so as to cut across the curved lines as in Fig. 4.

In an attempt to measure roughly the extent of the induced curvature, the lines shown in Fig. 3 were drawn on a square

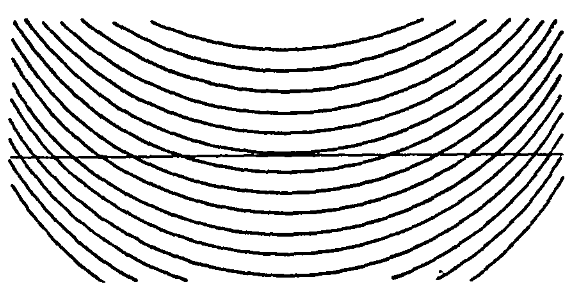

FIG. 4

of cardboard, the length of the lines being 25 cm and the curvature displacement 10 mm. Under these conditions there was an induced curvature on the straight line between 1 and 2 mm in extent, for every one of 20 subjects. This result was arrived at by (1) having S compare the contrast line with lines of zero, 1 mm and 2 mm curvature on a separate piece of cardboard—either the 1 or the 2 mm curve was always picked as the best match; (2) having S compare the contrast chart with a second chart, identical except that the contrast line was curved 2 mm in the same direction as the inducing lines. This curved line for most subjects appeared straight, and for all subjects appeared much nearer to straight than the actually straight line.[13]

Series V. Adaptation to Curvature in Kinæsthetic Perception

During the experiments of Series I it was noted that subjects, while wearing the prisms, reported that a straight vertical edge not only looked but felt curved when the fingers were run along it. If the eyes were closed, however, the edge felt straight. It could be concluded from these facts not only that the visual impression dominated the kinæsthetic, but also that kinæsthetic perceptions of rectilinearity and curvature are clear and discriminable experiences. In view of this apparently high degree of acuity, and to see whether or not an analogy held between visual and kinæsthetic perception, it was desired to find out whether adaptation and after-effect took place in kinæsthetic curvature perception unaccompanied by vision.

A large piece of heavy cardboard was prepared with the right hand edge curved convexly. The edge was 30 cm long and the curvature displacement was 2 cm. The cardboard was presented to a blindfolded subject and he was told to spread slightly the fingers of the right hand and run them from top to bottom of the edge, continuing for a period of 3 minutes. At the end of this time, the subject was given a straight card-

[13] Geometrical illusions closely related to what is here called curvature contrast may be found in the literature. See *e.g.* K. Bühler, *Die Gestaltwahrnemungen*, 1913, 39–40, and H. Werner, Studien über Strukturgesetze, I Über Strukturgesetze und deren Auswirkung in den sogenannten geometrisch-optischen Täuschungen, *Zschr. f. Psychol.*, 1924, 94, 257–262. Figure 4 of the present study is somewhat similar to the Hering illusion.

board edge to feel in the same way. Of 15 subjects who were given this test all stated voluntarily during the 3 minute period that the convex curvature seemed to decrease, and all reported subsequently that the straight edge felt definitely concave.

As a further check on this new phenomenon, another convexly curved cardboard edge was made with only 6 mm of displacement. This slightly curved edge and the straight edge were presented to subjects as paired comparisons, order being haphazard. Under these conditions all subjects (10) could distinguish with 100 percent accuracy which edge was straight and which was curved. If now the subject were instructed to feel the strongly curved convex edge for 3 minutes and then to feel the two edges described, the straight edge was always reported concave (*i.e.* curved inwards) and the slightly convex edge was usually reported straight or occasionally even slightly concave. Without exception the convex line was declared more nearly straight than the straight line.

Curvature adaptation and curvature after-effect, therefore, may be demonstrated in kinæsthetic [14] as well as in visual perception.

Series VI. Negative After-Effect with a Bent Line Instead of a Curved Line

It is clear that a straight line may become non-rectilinear in one of two regular ways, by being curved, or by being bent into an angle. In the former case the departure from rectilinearity is distributed over the entire length of the line; in the latter it is concentrated in one point. Of the two types of non-rectilinearity, then, does the angle, as well as the curve, manifest the phenomenon of adaptation and negative after-effect? This was the problem set for the present series of experiments.

A vertical line bent at the middle into an obtuse angle was used for fixation. As in previous experiments, it was 30 cm long and was exposed at a distance of 40 cm from the eyes.

[14] It is true that a component of touch experience enters into the feeling of an edge. But it is doubtful if this touch component has anything to do with the curvature perception as such.

The displacement in mm of the center or apex, rather than the number of degrees in the angle, will be stated hereafter in order to maintain the convention adopted for curved lines.

Preliminary experiments with a bent line of 23 mm displacement demonstrated that the negative after-effect showed itself clearly and unmistakably. After 10 minutes of fixation on the apex of the obtuse angle, a straight line seemed definitely bent the opposite way, the bend appearing to move up and down the line as the fixation point shifted.

When, however, the bent line was *inspected* during the ten minute period, *i.e.* if the eyes were moved up and down, the situation was somewhat more complicated. If the eye movements were limited to the middle part of the line close to the bend the after-effect showed itself with fair strength, but if the eyes were allowed to roam over the entire line little or no after-effect could be seen. These facts are intelligible on the supposition that adaptation occurs only in a region of actual non-rectilinearity, *i.e.* only in the neighborhood of the apex and not on the straight sides of the angle.

In an attempt to measure the amount of after-effect more accurately than had hitherto been possible, an apparatus was constructed. It consisted essentially of an adjustable line pivoted in the middle by a pin which was fixed to a sliding strip. (See Fig. 5.) By moving the latter, the line could be bent either to the right or left or made straight. A millimeter scale on the sliding strip made it possible to read the displacement of the center of the line to a fraction of a millimeter. The line itself consisted of two narrow strips of dark gray cardboard, 5 mm wide; the pivot in the middle was an ordinary nickel-plated pin, the head of which served as fixation point. The rest of the apparatus was made of heavy white cardboard.

The procedure adopted for measuring the after-effect was as follows. The center of the line was set at 15 mm from the rectilinear position, either to right or left, and S fixated the pinhead for 5 minutes.[15] At the end of the period S closed his

[15] Adequate fixation for longer than 5 minutes is very difficult and fatiguing. With the repeated trials necessary in this series of experiments, longer fixations than this could not be demanded of subjects.

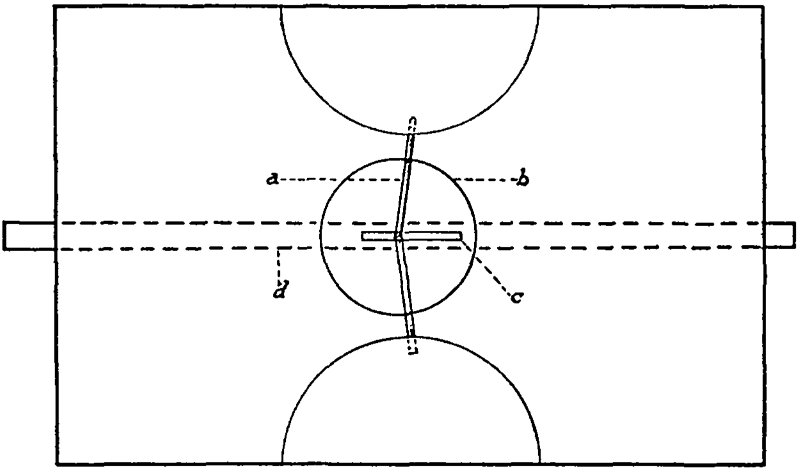

Fig. 5. Apparatus for measuring the after-effect of a bent line.

a—gray cardboard strips constituting the adjustable line; *b*—white circular screen, moving with the line, which covers slot *c*; *c*—slot in cardboard screen, along which pivot can move; *d*—sliding strip of cardboard running in grooves behind the screen.

eyes for 2 seconds while E set the line back to straight. S then opened his eyes and again fixated the pinhead.[16] If the line looked straight S was to so report; if it appeared bent he was to adjust it until it did appear straight. Ten seconds were allowed for this adjustment. No reports of 'straight' occurred; the S always set the line at a slight bend in the same direction as the fixation line. This displacement was of course the amount just necessary to counteract the negative after-effect. It was read from the scale in millimeters, fractions being estimated in tenths.

By this method and under these conditions, the negative after-effect was measured over a series of trials. The averages for 6 subjects are as follows: subj. F, 3.75 mm; subj. G, 2.2 mm; subj. J, 3.0 mm; subj. M, 4.3 mm; subj. S, 2.5 mm; subj. V, 3.2 mm.[17] These figures are averages of from 4 to 8 single

[16] It was discovered that, when S simply adjusted the line to 'straight,' starting from its bent position during fixation, a large constant error confused the results. That is, control experiments showed that when without previous fixation one merely attempts to straighten the bent line, one never moves it far enough.

[17] These averages, that of subj. F excepted, are given again in Table IV a few pages later on.

trials. The mean variation for any subject did not exceed 0.9 mm. The average for all subjects was 3.17 mm.

It is evident that there are individual differences in the amount of after-effect obtained under these conditions, one subject obtaining an effect of 4.3 mm, while another has only 2.2 mm. It is the impression of the experimenter from observations on many subjects that the differences between individuals show up quite consistently. It can also be noted from the above results that the amount of after-effect is greater than that found by using the earlier and cruder methods of measurement employed with the curved lines. This is probably to be ascribed to the fact that the measurement was here taken within 12 seconds after the end of the fixation period. Although the effect does not wholly die away for some time, it seems to be strongest in the first moments after fixation has ceased. It is similar in this respect to after-images of color. It is possible, of course, that this is not the whole explanation. Adaptation and after-effect may be stronger with a bent line than with a curved line. But the question can be decided only when a curved line apparatus, similar in principle to the one described for bent lines, is used. Technical difficulties have delayed the construction of such a device until the present.

Series VII. The Limitation of the After-Effect to the Stimulated Area of the Visual Field

The analogy between color adaptation and curvature [18] adaptation, so far as it has been developed, might lead to the expectation that the curvature after-effect should be limited to the specific area of the visual field which has undergone adaptation. It is well known that negative after-images of color appear with considerable precision, only in the area previously occupied by the stimulus object. The question is then whether or not the negative after-curvature will appear on an objectively straight line only when that line occupies

[18] Hereafter, for lack of a better word, 'curvature' will be used to include both the curve and the angle type of deviation from rectilinearity. 'Non-rectilinearity' is too ponderous a word, and such terms as 'flexion' or 'aberrance' are too vague.

approximately the same visual area as did the curved stimulus line.

Several experiments were performed which indicated that the curvature after-effect is so limited. The first of these was an experiment which demonstrated that two curved lines at right angles to each other induced their own after-effects independently on two straight lines at right angles to each other. The results were the same if the two curved lines, and the straight lines subsequently seen, intersected at their mid-points. If a pattern or grouping of curved lines were fixated, and subsequently a similar pattern of straight lines were substituted for it, each straight line showed the particular after-effect appropriate to its corresponding curved line.[19] In this procedure, of course, the fixation points were so placed as to bring the straight lines into the approximate visual positions previously occupied by the curved lines. These results seemed to indicate at least that the process of curvature adaptation could go on in several parts of the visual field independently. A more direct attack on the question of the limitation of the adaptation to the stimulus area was made in the following experiments.

1. After inspecting or fixating a curved line for 10 minutes, the subject was presented with a set of parallel straight lines drawn side by side filling most of the field of vision. In this situation, S usually reported that the line he was looking at showed the after-curvature, but that the lines right and left of the fixated line seemed straight. The apparent curvature shifted from one line to the other as fixation changed. The results were essentially similar when a bent line was used instead of a curved line.

2. In another procedure, S fixated a short curved line (15 cm) and then looked at a long straight line (100 cm). The report was that on the fixated portion of the straight line a 'bulge' appeared, opposite in curvature to the adaptation line, and that this bulge moved up and down the line as fixation

[19] Experiments with curved lines grouped together into geometrical forms are now being carried out. There is some evidence, as yet unverified, that the amount of after-effect in such arrangements varies with the nature of the form, particularly with its symmetry or asymmetry.

changed. A variation of this experiment was performed using fine lines drawn with a ruling pen instead of heavy lines. For fixation S was given a short fine curved line (5 cm), and for observing the after-effect he was shown a grill of lines set close together (2 mm), covering a relatively large area. The 'bulge' appeared as before, the significant fact being that this distortion seemed to spread very little to right or left, limiting itself to the two or three lines falling within the approximate area of fixation.

3. In still a third experiment S, instead of fixating the center of a curved line, fixated a point 2 cm to the left of it. If now he looked directly at a straight line it appeared straight, but with fixation on a point 2 cm to its left, it appeared definitely curved.

All of these experiments pointed to the conclusion that the negative after-curvature is fairly closely limited to the specific area in which adaptation has occurred. But in order to investigate further this rather important point, and in order to subject it to formal, quantitative test, the apparatus and procedure described in the last section were employed. Even very slight after-effects could be detected and measured when using the adjustable bent line, by requiring S to make the line appear straight and then reading its deviation on the scale.

Two fixation points were used. One was the pinhead at the mid-point of the adjustable line—the 'foveal' fixation point; the other was a small cross on the circular screen, which moved with the adjustments of the line, placed at a fixed distance of 4 cm from the mid-point of the line—the 'peripheral' fixation point. The 4 cm distance represented a visual angle of 5.7°. With this arrangement the line could be fixated either by holding the eyes on the pinhead for 5 minutes (foveal fixation), or by holding them on the cross (peripheral fixation). In turn, the test for after-effect could be made with eyes on the pinhead (foveal test) or on the cross (peripheral test). Both foveal fixation with foveal test and peripheral fixation with peripheral test gave a large after-effect, since the area tested was that in which adaptation had occurred.

Averages for 5 subjects are given in Table IV under the heading 'Same Area Tested.' For all subjects the adaptation and after-effect were somewhat greater when the bent line was exposed peripherally than when it was exposed with its mid-point on the fovea. A similar fact has been reported of the

TABLE IV

NEGATIVE AFTER-EFFECT IN MILLIMETERS OF DISPLACEMENT AT THE CENTER OF A 30 CENTIMETER LINE WHEN A DIFFERENT AREA FROM THAT OCCUPIED BY THE STIMULUS LINE IS TESTED AND WHEN THE SAME AREA IS TESTED

	Different Area Tested		Same Area Tested	
Subject	Foveal Fix. Periph. Test	Periph. Fix. Foveal Test	Foveal Fix. Foveal Test	Periph. Fix. Periph. Test
G	0.93 mm	0.25 mm	2.2 mm	2.8 mm
J	0.65	0.07	3.0	3.7
M	1.60	0.25	4.3	5.1
S	0.87	0.02	2.5	2.6
V	0.65	0.33	3.2	3.7

negative after-effect of movement, in that it is also relatively stronger (*i.e.* more rapid) in the periphery of the field of vision.[20]

The results with which we are primarily concerned, however, are those with foveal fixation and peripheral test and those with peripheral fixation and foveal test. Of these two methods for measuring a possible after-effect when fixation and test area are different, the second is probably the more accurate and reliable since the test is here made with foveal vision and the task of the subject is much easier. The results are given in Table IV under the heading 'Different Area Tested.' If the curvature after-effect were limited strictly to the area occupied by the stimulus line, we should expect to find zero or negligible values. The averages obtained with the second and more reliable method are so low as to be almost negligible. The averages obtained with the first method are higher, especially in the case of subj. M, and it may be that these figures constitute evidence for a very slight 'spread' of the after-effect to the surrounding non-

[20] A. Wohlgemuth, On the after-effect of seen movement, *Brit. J. Psychol. Monog. Suppl.*, 1911, No. 1, p. 70.

stimulated area of the visual field. It is, however, also possible that the figures are higher than they should be because of faulty technique in experimenting. At any rate it is safe to conclude at least that the negative after-effect of curvature in its full strength is limited fairly closely to the specific stimulated area of the visual field.

Series VIII. The Transfer of the After-Effect to the Corresponding Area of the Other Eye

It is an interesting fact that after one has fixated a patch of color with one eye, the negative after-image may be seen with that eye only and does not appear in the corresponding area of the unstimulated eye.[21] It is also interesting to note that, on the other hand, if one looks at a water-fall using only one eye the negative movement after-image does appear vividly in the corresponding area of the other eye.[22] In view of these two facts, it was thought worth while to find out how the curvature after-effect behaves in this respect. Preliminary experiments first demonstrated that curvature is here similar to movement rather than to color—the negative after-effect does transfer in part to the unstimulated eye. S fixated (or inspected) a curved line with one eye, the other eye being either covered with a closely fitting shield or held closed. At the end of the period S shifted to the other eye, and fixated (or inspected) a straight line. Some after-curvature was always reported.

In order to verify and measure this phenomenon of binocular transfer, the apparatus used in two previous experiments was again employed. In one procedure the same eye and the same area that were used for fixation were tested

[21] Under special conditions favorable for binocular rivalry, it may of course seem to appear there. There is, however, some evidence that fatiguing an area of one dark-adapted eye to achromatic light actually lowers the sensitivity of the corresponding area of the other eye. See M. N. Crook, A test of the central factor in visual adaptation, *J. Gen. Psychol.*, 1930, 3, 313–318, and references given therein; also E. Gellhorn, Die Erregungsvorgänge in der Sehrinde des Menschen auf Grund sinnesphysiologischer Experimente, *Zschr. f. d. ges. Neurol. u. Psychiat.*, 1927, 108, 481–490.

[22] This binocular transfer of the movement after-effect has been noted by several investigators. See for example A. Wohlgemuth, On the after-effect of seen movement, *Brit. J. Psychol. Monog. Suppl.*, 1911, No. 1, p. 28.

for after-effect; in a second the corresponding area of the other eye was tested. In the latter case S fixated the bent line at its mid-point with one eye for 5 minutes. He then closed his eyes while E set the line straight, opened the other eye and, while fixating, reported the appearance of the line. If it seemed bent, he was to adjust it until it was straight. The displacement of the center was then read off by E. The former procedure was identical except that the same eye was used for test. The averages for 3 subjects are given in Table V. Apparently 52 to 82 percent of the negative after-effect transfers to the corresponding area of the other eye.

TABLE V

NEGATIVE AFTER-EFFECT IN MILLIMETERS OF DISPLACEMENT AT THE CENTER OF A 30 CENTIMETER LINE WHEN ONE EYE IS TESTED AND WHEN THE CORRESPONDING AREA OF THE OTHER EYE IS TESTED

Subject	Same Area of One Eye Tested	Corresponding Area of Other Eye Tested	Percent of Transfer
V	3.5	2.1	60%
M	3.2	1.7	56%
J	2.5	1.3	52%
J *	2.7	2.2	82%

* These figures for Subject J apply to transfer from a *peripheral* area of one eye to the corresponding area of the other.

These results with regard to binocular transfer afford an opportunity for some interesting, although perhaps hazardous, deductions as to the locus of the physiological process or processes underlying curvature adaptation. In the first place it is clear that the process cannot very well be exclusively retinal, since in that case adaptation in one eye should have no effect on the vision of the other eye. We must assume that the independent excitations set up by each eye are combined at some point in the chain of visual processes, being thereafter no longer independent. Color adaptation must obviously in large part depend on processes occurring before this point, since the occurrence of this type of adaptation in one eye has no effect on the vision of the other eye. Most of the process involved in curvature adaptation, on the other hand, must take place at or subsequent to this point.

The location of this point of combination is, pending further knowledge of the anatomy and physiology of the visual nervous system, somewhat uncertain. If one could suppose that it is at the visual projection centers in the calcarine region of the occipital cortex, in other words if the right halves of both retinæ are projected in superposition on this region of the right hemisphere, and the left halves in the same region of the left hemisphere, then at least it could be said that curvature adaptation, as a physiological process, occurs wholly or in large part at, or subsequent to, these projection centers, whereas color adaptation occurs before them.

Summary and Tentative Conclusions

It has been shown that when a curved line has been perceived for any considerable length of time, it becomes phenomenally less curved than it was at first, and also that after such a period of fixation or inspection, a straight line appears distorted with an opposite curvature. The adaptation and the negative after-effect are of the same magnitude, the inference being that for the perception process a decrease in curvature to the left is equivalent to an increase in curvature to the right.

In addition to successive contrast in curvature perception, simultaneous contrast also may be demonstrated. The phenomenon is similar to a type of the geometrical optical illusions.

Curvature adaptation and after-effect occur for kinæsthetic as well as for visual perception.

The essential condition for adaptation and after-effect appears not to be merely curvature of a line, but rather departure from rectilinearity. The phenomena appear upon fixating an obtuse angle as well as upon fixating a curved line.

On the whole, the evidence seems to indicate that the negative after-effect of curvature is fairly closely limited to the specific area of the visual field previously occupied by the stimulus line. If a number of curved lines in a group are fixated, adaptation and after-effect can be correspondingly induced in a number of directions simultaneously in different parts of the visual field. The negative after-effect of curvature shows itself in the corresponding area of the other eye when only one eye has undergone adaptation, the effect, however, being less in the unstimulated than in the stimulated eye.

The adaptation and negative after-effect induced by curvature are similar to those induced by color and brightness in that both are limited to the visual area of the primary stimulus. These effects are dissimilar to those of color and brightness, and similar to those of perceived movement in that they are induced in both eyes by a primary stimulus which is presented to one eye alone. The conclusion may be drawn that the process involved in curvature adaptation, whatever its nature may be, takes place not in the sense organ but at or subsequent to an early stage of the central process.

The above set of facts suggests many lines of speculation and a variety of possible conclusions. But in any investigation of a new phenomenon such as this one, speculations and conclusions are not entirely safe until the phenomenon itself has been verified by other experimenters, and until the details and conditions of its occurrence have been more fully worked out. The present report is by no means complete, and further experimental tests suggest themselves on nearly every page. Those implications of the results, which are here suggested, therefore, are provisional to a more than ordinary degree.

We may first consider the analogy so frequently pointed out between perception of a line on the one hand, and of color (including brightness) on the other. For both types of perception, experiences may be classified into a continuous series with two opposed kinds at the ends and a definite and unique neutral experience in the middle, into which they both merge. The neutral experience may be considered the type or mean of the series. That is to say, for color there is the series blue-gray-yellow or black-gray-white, while for line there is the series convex to right-straight-convex to left. Now in the case of both line and color, the continuous maintenance in perception of one of the 'end experiences' results in the shift of this experience towards the neutral (adaptation). If now a 'neutral' stimulus is presented, it appears in perception as shifted somewhat towards the opposite 'end experience' (negative after-effect). Furthermore, for both line and color the adaptation and negative after-effect seem to take place only in the area of the visual field correllated with the stimulus object which produced the adaptation. And as a final parallel between line and color, in both cases an area of the neutral experience which is surrounded by an area of one of the end experiences appears slightly shifted towards the other end experience (simultaneous contrast).

On the basis of this set of analogies between line and color perception [23] some rather general inferences are possible. To the extent to which color and line perceptions behave in a similar way, to that extent at least are the perceptual mechanisms similar. And any similarity in the mechanisms underlying two such different kinds of perception is provocative of thought. Color has usually been regarded as 'sensory' while line has frequently been considered 'perceptual.' Color is a 'subjective' experience while line is 'objective.' The former is a 'secondary quality,' the latter is a 'primary quality.' Any interpretation of the facts presented would at least tend to break down rather than to more firmly establish the above distinctions.[24]

The fact of curvature adaptation and after-effect has some bearing on the question of whether or not it is possible to derive an explanation for form perception from the concept of the local sign. Could one start from the hypothesis that every retinal point has a specific spatial value (explaining the origin of the latter in any way one wishes) which differentiates

[23] The writer hopes in a later article, on the grounds of evidence now being collected, to show that the same analogies hold also for perception of visual movement, of direction (vertical and horizontal), and perhaps for certain non-visual perceptions including temperature.

[24] That perception of *line* is a very basic and fundamental kind of experience is convincingly pointed out by James (*Principles of Psychology*, 2, 148–152). Any experience of a brightness or color difference usually carries with it the perception of a line. It may be considered the simplest type, or the elementary unit, of all form perception.

it from all other points, and then ascribe the experience of form, for example a line, to the building up of a unique pattern of local signs, in the course of experience, which in the end comes to mean a line? On this hypothesis, a change in the particular pattern of local signs corresponding to a particular line could be effected only by experience—since experience is the only agent by which the pattern has been made to cohere. The situation to be examined in the light of the foregoing theory is this: a line which at one time appears straight may 10 minutes later appear definitely curved. If the perception of rectilinearity were supposed to be dependent on the arousal of a unique pattern of retinal local signs, which by experience has come to mean 'straight,' then such a phenomenon could not occur unless the local signs constituting the 'straight' pattern had been changed during the 10 minute period. But, from the standpoint of the theory expounded, nothing, under the conditions of the experiment, could have happened during the period which could reasonably be expected to shift the local signs. No conflicting experience from another sense department, for example, has occurred. It is only logical to conclude, therefore, either that some *non-experiential* agent has warped the pattern of local signs, or that the perception of a line cannot possibly be simply and wholly the result of a particular pattern of local signs bound together by experience. In either case, the suggested explanation of form perception fails. The facts seem to point in another direction—towards the hypothesis that perception of a line involves a much more unitary process which has at least some characteristics in common with the process underlying color.

On the other hand, even though the local sign hypothesis is not in itself adequate to explain the facts presented, there is no justification for postulating that perception of line depends upon a configuration in a single homogeneous field of stresses in the cerebral cortex, the configuration being wholly determined by the tendency of the forces within the conducting system to reach an equilibrium, and therefore in part *unpredictable from the stimulus conditions which aroused it.* The situation now to be faced is this: after 10 minutes of fixating a curved line, not only is the line seen as less curved by a certain amount, but also in this same visual area a straight line appears curved by the same amount in an opposite sense. If the cortical system of stresses is not closely related to the retinal conditions, why, in that case, should the straight line not appear straight?

The fact is that the results of this experiment, at least to the mind of the writer, imply both the lack of an exact point-to-point correspondence between the retinal field and the phenomenal field, and the existence of such a correspondence, each being true for a particular set of perceptual conditions. They imply, in other words, both that the peripheral (retinal) processes do not determine the central (phenomenal) processes, and at the same time that they do closely determine them; that the structural connections between the two are not precise and that they are precise. The fact of curvature adaptation means that a retinal curved line may come to be represented in consciousness as a phenomenal less-curved line. The inference, surely, is that a specific point-to-point correlation does not hold in these circumstances. On the other hand the phenomenon of negative after-effect means that when a retinal curved line is correllated with a phenomenal less-curved line, then for the area in question a retinal straight line is correllated with a phenomenal oppositely-curved line. The inference is that a point-to-point correspondence between the retinal and the phenomenal field does at this time exist—a correspondence which has been shifted from the normal one but which is nevertheless specific. The conclusion from these two propositions taken together would seem to be that there is a system of point-to-point correllations between retinal field and phenomenal field but that it is not a rigid system. So far from being rigid, the relations of correspondence are subordinate to the process of curvature adaptation, and, by the activity of this process, whole sets of point-to-point correlations are changed together. It may be inferred that the perception of a line as such cannot depend upon, or arise from, the fact of a point-to-point correspondence, since the point-to-point relations are under some circumstances modified by the perception of a line.

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