ADAPTATION, AFTER-EFFECT AND CONTRAST IN THE PERCEPTION OF TILTED LINES. I. QUANTITATIVE STUDIES

BY JAMES J. GIBSON AND MINNIE RADNER
Smith College

THE PROBLEM

An essential element in visual perception is one indicated by the terms edge, boundary, contour or line. Things are seen because they are delimited from the rest of the visual field and this delimitation depends on, or consists of, the formation of a visual *line*. A line has the function of enclosing, in addition to its function of simply delimiting, but we are here concerned with it in the latter function only. Conceived in this way a visual line, or any designated portion of a line, may be said to have two characteristics: its *shape*, straight, curved, or 'bent,' and its *direction*, vertical, horizontal, or oblique. It has already been demonstrated that the shape of a line is subject to what has been termed adaptation and negative after-effect with respect to rectilinearity. That is, a curved or bent line-segment changes during continuous perception in the direction of becoming straight, and thereafter an objectively straight line appears curved the opposite way.[1] By analogy, the direction of a line might be expected to behave in the same manner with respect to the vertical and the horizontal axes. Experimental test of this possibility bears out the expectation; that is, a line seen as tilted somewhat from the vertical or the horizontal axis appears progressively less tilted during the course of perception, and a line objectively vertical or horizontal appears thereafter as tilted in the opposite direction.[2] In short,

[1] J. J. Gibson, Adaptation, after-effect and contrast in the perception of curved lines, J. EXPER. PSYCHOL., 1933, 16, 1–31. Also J. F. Bales and G. L. Follansbee, The after-effect of the perception of curved lines, J. EXPER. PSYCHOL., 1935, 18, 499–503.

[2] J. J. Gibson, *op. cit.*, 29, footnote 23, and Vertical and horizontal orientation in visual perception (Abstract), *Psychol. Bull.*, 1934, 31, 739. Also M. D. Vernon, The perception of inclined lines, *Brit. J. Psychol.*, 1934, 25, 186–196.

deviation of a line from the vertical or horizontal does produce an effect analogous to deviation of a line from the rectilinear.

If a subject seated squarely at a table is required to look for several minutes at a 20 cm line-segment drawn on a large square of cardboard, the line being tilted let us say 10° from the vertical, he will frequently but not always report spontaneously that the line seems slightly less tipped at the end of the period than it did at the beginning. If now a vertical line is substituted for the tilted one, he invariably reports that the line looks tipped the other way. The effect is slight but definite and may persist for several minutes. It occurs indifferently whether the subject fixates the mid-point of the line or simply inspects, *i.e.* looks at, the line during the period. Whether the line is tilted in a clockwise or a counter-clockwise direction makes no difference; the after-effect is always negative, *i.e.* in the opposite direction. If the inspected line deviates from the horizontal then an after-effect appears on a horizontal line; if from the vertical then on a vertical line.

Preliminary Experiments

In order to investigate this phenomenon, a series of experiments was undertaken. As a preliminary method of measuring the effect, a 20 cm line was drawn in india-ink on a large cardboard disk pivoted at its center to a rectangular upright screen. By rotating the disk the line could be set in any desired position. A scale, reading in degrees and visible from the rear through a slot in the screen, made it possible for E to record the position of the line. The amount of the negative after-effect could then be measured in the following manner. The line was set at the inclination desired for the inspection of the subject; at the end of the inspection-period E returned the line to the zero position, whereupon S corrected the apparent negative tilt by adjusting the line to that position at which it appeared to him vertical (or horizontal), that is at a degree of actual tilt just sufficient to counteract the negative after-effect. Hence the measured deviation from the objective vertical (or horizontal) was always in the same direction as had been the inspected tilt. A number of such measurements were taken with each subject, using in alternate periods lines tilted to the right and to the left in order to eliminate in the final average the influence of slight constant errors in the perceptual axis. The average of the measured deviations from zero obtained in such a series was taken as the amount of negative after-effect. Under these conditions variable errors were slight, and after-effects varying from 0.5 degrees to 3 degrees were found, depending on the subject and the amount by which the inspected line was tilted.

In our procedure the line was returned to the zero position before S made his adjustment. This was done in preference to having him adjust the line to vertical from the starting-point of the inspected tilt because of the tendency to stop short of the correct position when moving in toward it. This tendency, easily demonstrated by control tests, holds apparently in any experiment involving the reproduction of norms.

Several problems of an exploratory nature were investigated with the simple apparatus described. The fact was verified that, like the after-effect of curvature, the after-effect of tilt occurred following either *fixation* or *inspection* of the line. When the eyes were allowed to move freely along the line the effect was somewhat greater than when fixation was maintained at the mid-point[8] but such eye-movements were not necessary for the appearance of the effect. In the experiments which follow, inspection rather than fixation of the line was required of the subjects, chiefly for the reason that a confusing brightness-after-image was thereby avoided.

A preliminary search for the optimal degree of tilt showed that, although the negative after-effect appeared in measurable amount even when the inspected line was tipped only a few degrees from the reference-axis, it was more pronounced at greater inclinations. At deviations nearing 45°, however, little or no after-effect could be obtained on either a horizontal or a vertical line. On the basis of these observations the optimal degree of tilt for a maximum after-effect was estimated to be about 10° of inclination.

A number of tests were made with inspection-periods of varying duration which indicated that an appreciable after-effect could be obtained after a period as short as a minute. The occurrence of the phenomenon did not seem to depend on the distance between the eyes and the line, nor on the length of the line itself. If, on the other hand, a short tilted line were used for inspection and a long vertical line for the test, or *vice versa*, the after-effect was much reduced or even non-existent; the subjects' reports were variable rather than consistent.

It was found that a margin or edge, such as that between a black and a white area, would serve as well to show the phenomenon as would a black line on a white ground. Finally, if a tilted rectangular cross made of two lines intersecting at their mid-points were substituted for a single line, then the negative tilt would appear on *both lines* of a similar but normally oriented cross. In other words, the after-effect could be made to appear on a horizontal and a vertical line at the same time—a fact which raised the problem of whether the horizontal and vertical axis are mutually dependent or are to some extent independent.

Most of the phenomena which have been described may be verified without difficulty with no more elaborate materials than a pencil, ruler and some sheets of heavy paper or cardboard. The tilted line or lines and the subsequently inspected upright counterpart may be drawn in the central areas of two separate rectangles. The former should be inspected for two minutes or more and then the latter quickly substituted. The after-effect on a straight line of curvature or 'bending' may also be observed with this simple procedure.

In the experiments so far described, the tilted adaptation-line was always seen against a rectangular background. The negative after-effect likewise appeared on a line seen within this rectangle and framed by it but the effect did not, so far as could be noted, appear on the horizontal and vertical edges of the ground itself. So long, at least, as the objectively vertical line was looked at, it appeared tilted and the background upright; if an edge were looked at directly there might appear a slight effect but the subjects' reports were hesitant and doubtful. As compared with the after-effect of curvature, the tilt phenomenon could not so readily and certainly be observed

[8] This fact was also noted with the curvature-phenomenon (Gibson, *op. cit.*, 11f.). Bales and Follansbee found, in addition, that the curvature after-effect *persisted more strongly* if S read print for 60 sec. at the end of the inspection than if he merely fixated a point (*op. cit.*, 502).

on lines of a different length formed by the edges of doors and windows or by the corners of the room. In other words the phenomenon had so far been observed only in a visual field the periphery of which included objectively vertical and horizontal lines which remained relatively stable.

The experiment was now varied by requiring the subject to look through a tube during the period of adaptation and test—a procedure which eliminated these peripheral visual cues for vertical-horizontal orientation. The occurrence of the after-effect was not affected by this change. An objectively vertical line looked as definitely tilted as it had before, and it could be adjusted to a phenomenally vertical position with as much certainty as before. Neither the phenomenon of tilt-adaptation nor the more basic fact of vertical-horizontal orientation of a line in the frontal plane would seem to be necessarily conditioned by the presence of visible reference-lines in the field. Evidently we carry around with us our own visual reference-axes with respect to which a line may be seen as upright or tilted; in short we possess a 'sense' of visual direction.[4] Judgment of visual uprightness or tilt under certain circumstances is absolute; a line perceived in an otherwise homogeneous field has *intrinsic* direction.

In subsequent experiments the restricted circular field demanding absolute judgment of direction was used, rather than the unrestricted field which included upright lines making relative judgment possible.

The preliminary tests described had served to verify the general phenomenon and indicate a few of its main features. But chiefly they posed questions which required formal and quantitative investigation. Of these questions we undertook to answer the following, devoting an experiment to each.

First, what is the average acuity in detecting deviations of a line from the vertical or horizontal; with what accuracy can these fundamental directions be produced in a homogeneous circular field of view? Furthermore what is the difference, introspectively and quantitatively, between the production of horizontal or vertical lines, and lines at specified degrees of inclination—more especially the 45° position?

Second, what is the course of the adaptation-process in time? Does the degree of adaptation toward the vertical or horizontal increase with longer and longer periods of inspection and does complete adaptation ever occur, or not? So far, no subject had reported that a tilted line appeared completely vertical even after looking at it for a considerable period. In order to answer these questions, the amount of after-effect had to be measured after varying durations of inspection.

Third, does a line tipped from the vertical produce a negative after-effect on the horizontal in addition to the known effect on the vertical itself? If so, will the effect be in the same direction as on the vertical? Are the two axes, in short, modified as a unit; are horizontal and vertical mutually determined within a single system of spatial orientation or are they relatively independent?

Fourth, what is the relationship between the amount of negative after-effect and the degree of tilt, starting with 0° and increasing the inclination up to 90°? Where is the optimum, and why does 45° yield no after-effect?

These four problems will be dealt with in the present report. Two additional problems are postponed for subsequent treatment. The first is the question of whether

[4] Helmholtz for example reports an experiment in which a line, seen with one eye through a tube, could be set to the vertical position with some accuracy. This accomplishment was independent of the position of the eyes in the head; that is, it was undisturbed by a slight objective tilt of the retinal meridians (*Physiological optics* (Tr by J. P. C. Southall), Vol. 3, 256).

simultaneous contrast between neighboring regions of the visual field can be shown to operate in the perception of tilt. The second is the problem of whether the negative after-effect is akin to an after-image in being confined to the stimulated area of the visual field or is a generalized shift affecting the vertical and horizontal norms uniformly throughout the field. Observations already described pointed to the former alternative. If this were established, it would be difficult to maintain that the after-effect was an 'illusion of judgment' or a cognitive process of any sort.

The Major Experiments

Apparatus.—In order to measure the after-effect more accurately than had hitherto been possible, an apparatus was constructed similar in principle to the cardboard device already described. It consisted essentially of a large upright disk mounted at its center so that it could be rotated. The front bore a black line on a white ground; the rear a scale in degrees. The subject's vision was so restricted that he could see the black line bisecting a circular field (concentric with the disk) having a visual angle of 75°. He could grasp the edges of the disk with both hands, outside the field of view, and rotate the line about its mid-point to any required position, which it would maintain.

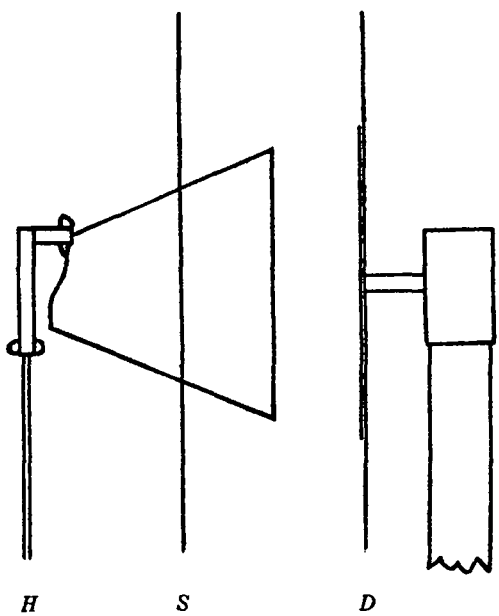

FIG. 1. The apparatus (*H*, headrest. *S*, screen with cone. *D*, adjustable disk).

The disk was made of reinforced beaverboard, 1 meter in diameter, and was mounted at its center to a heavy support. Attached to the front was a circle 56 cm in diameter of dull white drawing paper bisected by a line ½ cm wide. In front of the disk at a fixed distance the subject sat with his forehead and chin supported by a headrest, and the upper part of his face fitted into the small end of a cone of white cloth-paper permitting binocular vision. The axis of this cone would fall on a horizontal line drawn from the mid-point of the line to a point between the subject's eyes, a dis-

tance of 36 cm. The cone passed through a screen which served to cut off vision of the apparatus between trials and also to make rigid the cone itself. The subject's field, which was illuminated dimly and evenly by reflected light, included the circular rim of the cone and within it the circular disk of white paper bearing the line. The scale on the rear of the apparatus was of such size that readings could be taken to the nearest tenth of a degree. It was calibrated to the objective position of the line with a precision greater than this amount. A diagram of the apparatus is given in Fig. 1.

I. The Relative Accuracy with which Frontal Plane Directions may be Produced

Tests were made of the accuracy with which subjects could set the line at a horizontal and at a vertical position, and, for comparison, at 45°, 30° and 60° from the vertical. The adjustments were always made from a starting position 5° from the required position, alternately from the right and from the left. Five subjects who were to serve in subsequent experiments were given 8 tests at each position.

The results showed that in the visual field employed, the vertical and horizontal directions were produced with slight but consistent constant errors, varying from subject to subject. In other words the apparent vertical might deviate from the objective vertical either clockwise or counterclockwise, but this deviation tended to remain constant. The constant error for the horizontal and that for the vertical of any one subject tended to be in the same direction. Constant errors varied in amount from a few tenths of a degree up to 2°, depending on the subject.

The measure of acuity for the horizontal and the vertical axes was taken to be the average deviation from the constant error, which is an index to the consistency of the subjects' adjustments. Table I gives the results of all five subjects

TABLE I

Average Deviations in Degrees of Five Subjects in Producing Visual Direction

Subj.	Vert.	Horiz.	45°	30°	60°
B	.32	.46	.95	1.86	.29
L	.44	.64	1.18	1.65	2.98
H	.17	.54	1.84	2.14	3.07
M	.26	.56	2.43	2.64	1.05
R	.23	.40	.77	1.65	1.30
Avg.	.28	.52	1.45	1.99	1.74

for each of the five positions. It can be seen that acuity for the vertical and horizontal is greater than for the other directions, whose variability is from 3 to 6 times as great. These figures themselves are based on too few data to merit complete reliance. Other investigators, however, find the same thing. Jastrow [5] has reported findings obtained under comparable conditions which are similar in all respects. Neal [6] has found that even in complete darkness, a luminous line can be set to vertical with an average variable error of less than one degree. J. Volkmann has determined (investigation to be published) that under the same circumstances of complete darkness, the ability to discriminate directions of a line is very much higher in the immediate neighborhood of the horizontal and vertical than in other positions.

This fact of their greater perceptual accuracy would itself argue for the special character of horizontal and vertical lines, but the subject's introspective reports in our experiment are equally significant. They stated that the method by which a 30°, 45°, or 60° line was produced was to imagine a vertical and horizontal line in the field and then estimate in terms of one-third, one-half, or two-thirds of the imagined angular area. In short the vertical and horizontal directions *had to be present implicitly before other directions could be produced.* It may be concluded on both factual and *a priori* grounds that the up-down and right-left directions are fundamental, or better are *norms* for the perception of direction in the frontal plane.[7] Finally, it may be noted, these *normal directions* may be produced with a high degree of accuracy.

II. The Course of the Process of Tilt-Adaptation in Time

The amount of negative after-effect as a function of the time of inspection was next investigated. The five subjects

[5] J. Jastrow, On the judgment of angles and positions of lines, *Amer. J. Psychol.*, 1893, 5, 220ff. The present data also corroborate Jastrow's finding that the 45° position is produced with a large constant error toward the horizontal.

[6] E. Neal, Visual localization of the vertical, *Amer. J. Psychol.*, 1926, 37, 287–291.

[7] *Cf.* M. Radner and J. J. Gibson, Orientation in visual perception; the perception of tip-character in forms, *Psychol. Monog.*, 1935, 46, No. 210, 63.

of the previous experiment were each given six tests at every one of the following durations: 1, 5, 10, 20, 45, 90, and 120 sec. A line tilted 5° from the vertical was inspected in one series of tests and the experiment was then repeated with a line tilted 5° from the horizontal. Three of the five subjects were ignorant of the phenomenon being investigated; at all times the subjects were not permitted to know their results. In all, 420 tests were run off. A test consisted of (*a*) the inspection of the line, (*b*) a one second interval during which S closed his eyes and E set the line at approximately zero on the scale, and (*c*) the adjustment of the line by S within 8 sec. to his phenomenal vertical (or horizontal). The deviation of the scale-reading from zero, together with its direction, was recorded.

Rest-intervals were introduced between tests varying in length from 15 sec. after the shortest inspection-periods to 3 min. after the longest. In order to avoid any possibility of a cumulative negative after-effect, and also in order to enable the data to be treated without correcting for a constant error, tests were given with the inspection-line tilted alternately to the right and to the left of the reference-axis. Of the 6 tests at each time of inspection, 3 were inclinations in one direction and 3 in the other. These two sets of scale-readings were averaged separately and the negative after-effect was computed as half the angular distance in degrees between the two averages. Normally this meant merely averaging the two, since they were on opposite sides of the absolute vertical, but occasionally a subject's constant error in one direction would be greater than his average after-effect, in which case it meant averaging the difference between the two. It was discovered that a subject's constant error shifted somewhat from day to day. The procedure of alternating tests to the left and right of the vertical with only short rest intervals probably reduced the obtained amounts of negative after-effect, but this was safer than a procedure which might have enhanced them.

Results.—The data of the experiment, averaging all 5 subjects together are shown graphically in Fig. 2. The individual graphs differ from the average only in showing

less regularity. After one second of inspection of the tilted line there was no after-effect (.09° for the horizontal and — .008° for the vertical). After the 5 sec. period, however, an appreciable effect appears of .28° for the vertical and .38° for the horizontal. The curve of the effect rises rapidly with increasingly larger periods until 45 sec., beyond which it continues to rise but very slowly. It is notable that adaptation occurs fairly quickly; a 20 sec. inspection suffices to produce a shift of nearly 1° which is a quite noticeable tilt under normal circumstances. The process of color-adaptation which produces ordinary negative after-images is not much faster than this.

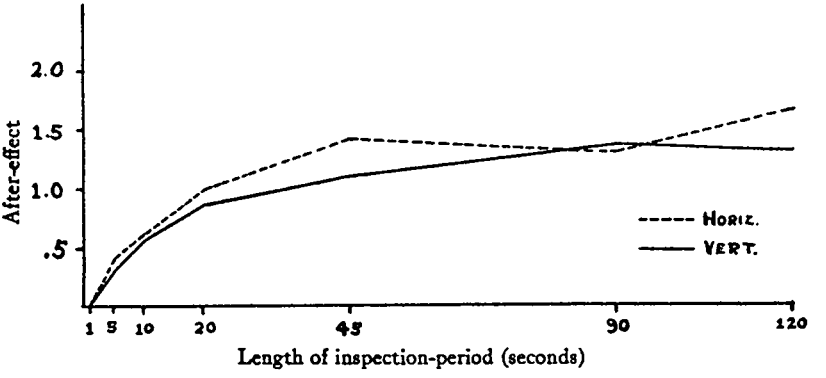

FIG. 2. Negative after-effect on a vertical and a horizontal line as a function of increasing times of adaptation.

A second notable feature of the curve is its asymptotic shape. The process of adaptation apparently tends to level off at an average of about 1.5° for the subjects tested. The individual curves, although less regular than the average curve, show this same characteristic. Several tests with 5 and 10 minute inspection-periods yielded after-effects not much higher than the average obtained at 120 sec. As a crucial test, one additional subject inspected a line tilted 5° to the right of the vertical for 30 minutes, repeating the experiment the next day with a line tilted to the left. The average of these two results was almost exactly the same as that obtained by this subject with a 90 second inspection

(approximately 1°). It may be concluded that under our conditions a perceived tilt does not reach complete adaptation, *i.e.* disappear entirely, but rather that after a few minutes of inspection a virtual equilibrium is attained in which either the perceived line has shifted toward the reference-axis or the reference-axis has shifted toward the perceived line. Curvature-adaptation also behaves in this way, and it is interesting to note that localized color-adaptation ordinarily does not reach zero saturation, although Hering believed that it should do so.[8]

The possibility advanced at the beginning that a cumulative effect might appear with a series of tests in the same direction is rendered unlikely in the light of the two 30 min. inspections. As a further check, however, one subject made 12 successive one minute inspections of a line tilted to the right, at half-minute intervals. At the end, his after-effects were averaging very nearly what they were at the beginning—in this case 1.7°.

A comparison of the horizontal and the vertical curves shows that the after-effect was on the whole greater for the horizontal axis, although the differences may not be reliable. The average deviations in this experiment for the 6 tests at each period for each subject are of the same order as were those of the previous experiment, which indicates comparable accuracy. At the 45 sec. period for example they averaged 0.45° and 0.29° for the vertical and horizontal respectively.

It would be interesting if the curve of the disappearance of the after-effect in time could be compared with the foregoing curves of its development. Unfortunately no systematic experiment has been done on the persistence of the effect. It may be said with certainty that the after-effect does not disappear immediately after inspection has ceased, and it is the impression of the writer that the longer the inspection-period has been, the more strongly does the after-effect persist. Vernon [9] found that after a 10 minute inspection, the effect on the vertical was still appreciable 5 minutes later.

[8] L. T. Troland, The colors produced by equilibrium photopic adaptation, J. Exper. Psychol., 1921, 4, 344–390.

[9] M. D. Vernon, The perception of inclined lines, *Brit. J. Psychol.*, 1934, 25, 189.

III. The Interdependence of the Horizontal and Vertical Directions

The third experiment was undertaken in order to determine whether a negative after-effect obtained on one reference-axis transferred to the other; whether horizontality and verticality function as norms relatively independent of one another, or whether they function together as merely two aspects of a single system for visual orientation. In the latter event a shift of one reference-axis, clockwise or counter-clockwise, should be accompanied by a similar shift of the other axis.

From the data of the previous experiment the average after-effect on the vertical axis of a line tilted 5° from the vertical was manifested and also the effect on the horizontal axis of a line tilted from the horizontal. We may call these *direct* after-effects. Using these results at the 45 sec. period of inspection we now had to obtain for comparison results with the same 5 subjects for the after-effect on the *horizontal* of a line tilted 5° from the *vertical* and the effect on the *vertical* of a line tilted from the *horizontal*. These are *indirect* after-effects. No change in the procedure of the experiment was made except to test the other axis of reference. Six tests were given each subject, as before, alternating the direction of tilt of the inspected line.

Results.—Averages of the 6 scale-readings were computed as before and are given for each subject individually in the second and fourth columns of Table II. The figures in the

TABLE II

A Comparison of Direct and Indirect After-Effects in Degrees Following a 45-Second Inspection of a 5° Tilt

Subj.	5° Tilt from vertical		5° Tilt from horizontal	
	Direct effect on vert.	Indirect effect on horiz.	Direct effect on horiz.	Indirect effect on vert.
S	1.47	.49	2.55	.62
L	.98	1.03	1.30	.85
H	.68	.03	.97	.74
M	1.12	.45	.70	.55
R	1.22	.70	1.60	.97
Averages	1.09	.54	1.42	.75

first and third columns are taken from the last experiment. The indirect after-effects are in every case deviations *in the same direction* as the direct after-effects. In other words the figures show that for all subjects when the phenomenal vertical had become tilted in a certain direction from the objective position, the phenomenal horizontal had also become tilted in the same direction and *vice versa*. These transferred after-effects are in general, however, smaller than the direct effects. In this respect the individual averages of the table show some regularity, with the exception of the results of subject L in the second column which indicates an indirect after-effect even larger than the direct effect. Subject H yielded almost no indirect effect whatever. But the remaining results are consistent with the group averages at the bottom of the table. They point to the conclusion that an after-effect on one axis is accompanied by a corresponding indirect after-effect on the other axes, and that the indirect after-effect is not as great as the direct after-effect.

The answer to the question put at the beginning of the experiment would seem to be that perceptually the horizontal and vertical directions do behave as if they were aspects of a single system for visual orientation, or a single *spatial framework* [10] but that on the other hand they are not rigidly linked together; there is, as it were, a certain amount of 'play' or 'lost motion' between them. Presumably therefore they may function as spatial standards with a certain limited degree of independence.

IV. The Negative After-Effect as a Function of the Degree of Tilt of the Inspected Line

A line tilted clockwise from the vertical produces an after-effect on both the vertical and horizontal axes such that they must be objectively tilted clockwise in order to appear normal. But if the line to be inspected is inclined still more in a clockwise direction it may reach a point at which it deviates perceptually not clockwise from the vertical but counterclockwise from the horizontal. In this case, as

[10] K. Koffka, *Principles of gestalt psychology*, Harcourt Brace, 1935, 211ff.

we have seen, the after-effect on the horizontal and vertical is in the opposite direction to what it has been before. In other words, a line may change from one kind of perceived tilt to another as it is rotated from 0° through 90° and there is a correlative change in the negative after-effect. This principle is, in fact, only to be expected if tilt is a deviation from normal orientation *in a certain direction*, and if a line may be normally oriented when either horizontal or vertical.[11] At 45°, half way between the two, the perceived tilt should be equivocal; at this point it is perceptually changing its reference from one norm to the other. In a psychological sense there is a limit to the amount of tilt which a line may bear.

In the following experiment the negative after-effect on the vertical axis was measured for inclinations up to 90°. Beyond 45° an indirect after-effect was to be expected in accordance with the outcome of the last experiment. The adaptation-line was inspected at the following inclinations: 2.5°, 5°, 10°, 20°, 30°, 45°, 60°, 70°, 80°, 85°, 87.5°. Six tests were made at each inclination, as before, alternately to the right and to the left of the vertical. The length of each period of inspection was 1½ min., with a rest interval of 2 min. Two subjects were employed in this experiment who had not taken part in the previous experiments. They were tested alternately one during the rest-period of the other. Subject J began with the 2.5° line and proceeded to greater degrees of tilt, while G was given the reverse procedure. This precaution against any progressive habituation proved to be unnecessary, however.

Results.—Computations of the after-effects were made in the same manner as before. The averages for both subjects separately were plotted and are shown in Fig. 3. At a tilt of only 2.5° from the vertical an appreciable after-effect appears. At 5° for subject G and at 10° and 20° for subject J, a maximum is reached, beyond which the after-effect declines

[11] Visual forms possessing a contour, and other visual patterns less elementary than simple lines, may pass from one normal orientation to another with a smaller rotation than one of 90°. A square, for example, becomes a normally oriented diamond at 45°. *Cf.* M. Radner and J. J. Gibson, Orientation in visual perception; the perception of tip-character in forms, *Psychol. Monog.*, 1935, **46**, No. 210, 49f.

with increasing degrees of tilt, until at 45° the effect has disappeared for one subject and is almost negligible for the other. Beyond 45°, an after-effect in the opposite direction begins to show itself, since the line now begins to be tilted not to the right (or left) of the vertical but to the left (or right) of the horizontal. The curve of this indirect after-effect is roughly symmetrical with the preceding curve of the direct effect; it has the same relationship to the horizontal axis that the direct curve has to the vertical axis. If the two axes are

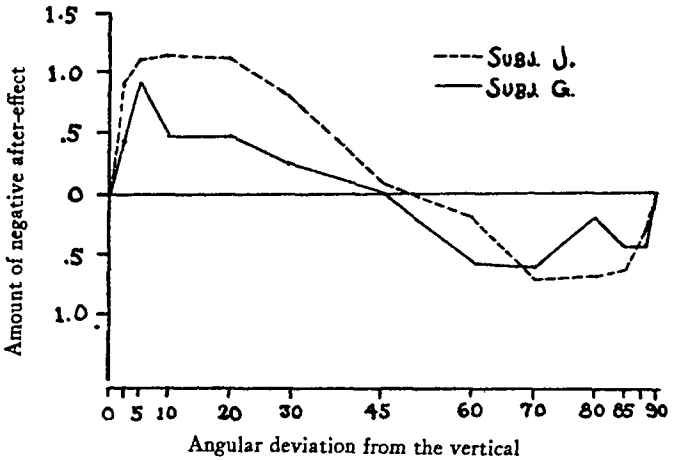

FIG. 3. Negative after-effect in degrees on the vertical axis as a function of the objective deviation from that axis of the inspected line (points above the abscissa indicate a shift of the subjective vertical toward the inspected line; points below indicate a shift in the opposite direction).

in part interdependent, this is only to be expected. The chief difference between the curves lies in the fact that the 45° to 90° effects are considerably smaller than the 0° to 45° effects. This fact also tends to corroborate the finding of the preceding experiment in which indirect effects were smaller than direct effects.

SUMMARY

It has been shown that not only the shape of a visual line but also its direction undergoes adaptation with negative after-effect. These qualities of curvature and of tilt may be

considered fundamental; they are the characteristics with respect to which a line may vary and by specifying these characteristics one defines the line either as a whole or in any given portion.

The norms of vertical and horizontal are discriminated and reproduced with considerable accuracy. Variable errors did not rise above .6 of a degree. A tilt of less than one degree, therefore, was perceptible to all subjects.

By measuring the amount of linear tilt-adaptation it was shown that it increases with continued inspection of the line in a time-curve similar to those of other processes of adaptation. Tilt-adaptation is not complete but instead levels off long before the quality of tilt is eliminated.

A negative after-effect on one reference-axis is accompanied by a corresponding indirect effect on the other axis, less in amount than the direct effect.

A line may be tilted up to 45° in either direction from the horizontal or vertical norm. The tilt may vary within fairly definite limits and it may be described in terms of two opposite qualities with a normal quality between them.

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