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PHENOMENAL REGRESSION TO THE REAL OBJECT. I.

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I. THE APPARENT SHAPES OF FIGURES OBSERVED OBLIQUELY.

IT is commonly stated in textbooks of psychology that when we observe figures inclined to us, we see them not in the shapes indicated by the laws of perspective but in the shapes which these figures 'really' possess. Thus when we look obliquely at a circular object, we see it not as an ellipse but as a true circle[1]. While it is undoubtedly true that such an object seen in these conditions is judged to be of its true shape and also that we are prepared for motor reaction to a circular object, I do not find that experiment confirms this statement as to what shape is seen. If a subject is shown an inclined circle and is asked to select from a number of figures the one which represents the shape seen by him, he chooses without hesitation an ellipse. This ellipse, however, is widely different from the one which represents the shape of the inclined circle indicated by the laws of perspective, being much nearer to the circular form. The subject sees an inclined figure neither in its 'real' shape nor in the shape which is its perspective projection but as a compromise between these.

This result is equally at a variance with the view widely held by those who are not psychologists that the perceived characters of an object are those of its projection on the retina. This view is particularly to be found amongst writers on perspective. Thus the writer on perspective in the 14th edition of the *Encyclopaedia Britannica* (2) sums up the laws of perspective in a series of 'axioms' which are not given as axioms about the plane projection of solid figures but of how we perceive them. Thus: "Axiom 1. Parallel lines appear to approach one another as

[1] H. J. Watt, for example, says: "Generally a plate looks what it 'really' is, circular, not elliptical as the retinal image of it really is (1)."

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they vanish, and to meet at an infinite distance from the observer in an imaginary point called the vanishing point of the system. Axiom 2. Parallel planes appear to approach one another as they recede from the eye, ..."

What this writer regards as axiomatic is that the characters of perception are identical with those of peripheral stimulation. While receding parallel lines do appear to converge, the proposition that they converge in appearance in the same way as they do in the projection on the retina or in a photograph (*i.e.* to the perspective vanishing point) is not only not axiomatic but experiment shows that it is not true.

The first experiments on apparent shapes were done with a subject looking from a controlled height at a circular or square disc lying on a table at a measured distance from the vertical line through the subject's eyes (Fig. 1). The purpose was to discover the apparent shape of the

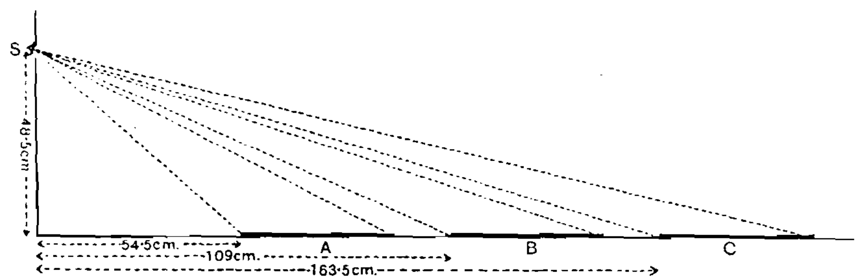

Fig. 1.

object from this point of view and to compare this with the shape of the perspective projection of the object on to a plane at right angles to the line of sight (*i.e.* with the shape which it would have in a photograph or in a drawing made in accordance with the laws of perspective). For the sake of brevity, I shall refer to this as the 'perspective shape' or 'stimulus shape.' The shape reported by the subject as seen by him may be called the 'apparent shape' or 'phenomenal shape.' This was at first measured by asking him to draw the disc as it appeared to him from that point of view. Later, it was found better to make the subject match the apparent shape of the circle with one of a series of ellipses cut out of cardboard with different ratios of short to long axis[1]. This ratio differed by 0·05 in successive ellipses. These ellipses were presented successively

[1] The perspective shape is not, of course, exactly an ellipse, but a figure resembling an ellipse with one of the short semi-axes longer than the other. The difference, however, is small and, since the judgments of the subject were only with respect to the relative lengths of the axes, it is of no importance for the purpose of the experiment.

to the subject (using the method of complete ascent and descent) and he was asked to judge whether the presented ellipse was 'fatter,' 'thinner' or 'the same as' the apparent shape of the circular disc. Preliminary practice was given, and the usual precautions of psychophysical experimentation were taken. These two methods I shall refer to as the 'drawing method' and the 'matching method,' respectively. Since it was no part of the aim of the drawing method to test the subject's drawing ability, he was allowed to alter his drawings as he pleased or to start them again until he had produced one which he was satisfied represented the shape as he saw it. In all experiments, except when otherwise stated, observation was with both eyes fully open and focussed on the object. The real shape of the disc used was therefore known by the subject.

The objects used were a white cardboard circle of 39·75 cm. diameter and a square of diagonal 38·0 cm. The object used lay on a dark table and was observed by the subject with his eyes 48·5 cm. above the end of the table (Fig. 1). The square was always placed with one of its diagonals in line with the subject. Three positions were experimented with: *A*, in which the nearest point of the object was 54·5 cm. from the point below the subject's eyes; *B*, in which it was 109 cm.; and *C*, in which it was 163·5 cm. from the same point.

Tables I and II show respectively the results for the subject S. drawing the circle and the square respectively. Table I shows all results (except of preliminary practice); Table II shows mean results of nine experiments at each position of the object. The figures given in the first and second columns are the ratios of short to long axis in the reproduced

Table I. *Drawings of circle by subject S.*

	Circle at *A*			Circle at *B*			Circle at *C*		
	Reproduced ratio	Perspective ratio	Index of phenomenal regression	Reproduced ratio	Perspective ratio	Index of phenomenal regression	Reproduced ratio	Perspective ratio	Index of phenomenal regression
(1)	·755	·56	·50	·575	·36	·46	·455	·255	·42
(2)	·76	·56	·53	·60	·36	·50	·445	·255	·41
(3)	·82	·56	·66	·56	·36	·43	·51	·255	·49
Mean	·78	·56	·57	·58	·36	·465	·47	·255	·445

Table II. *Mean of nine drawings of square by subject S.*

Square at *A*			Square at *B*			Square at *C*		
Reproduced ratio	Perspective ratio	Index of phenomenal regression	Reproduced ratio	Perspective ratio	Index of phenomenal regression	Reproduced ratio	Perspective ratio	Index of phenomenal regression
·86± ·03	·565	·74	·73± ·04	·36	·69	·58± ·035	·255	·60

figure and in the perspective shape respectively; those in the third columns are measures of the degree to which the 'real' determines the 'seen' shape, calculated by a formula explained below.

The same results are shown diagrammatically in Fig. 2. In each diagram the inner blackened figure shows the perspective shape of the object, the outer broken line marks its true physical shape, while the continuous line shows the mean reproduced figure (*i.e.* its phenomenal shape). In all cases it will be seen that the reproduced figure lies between

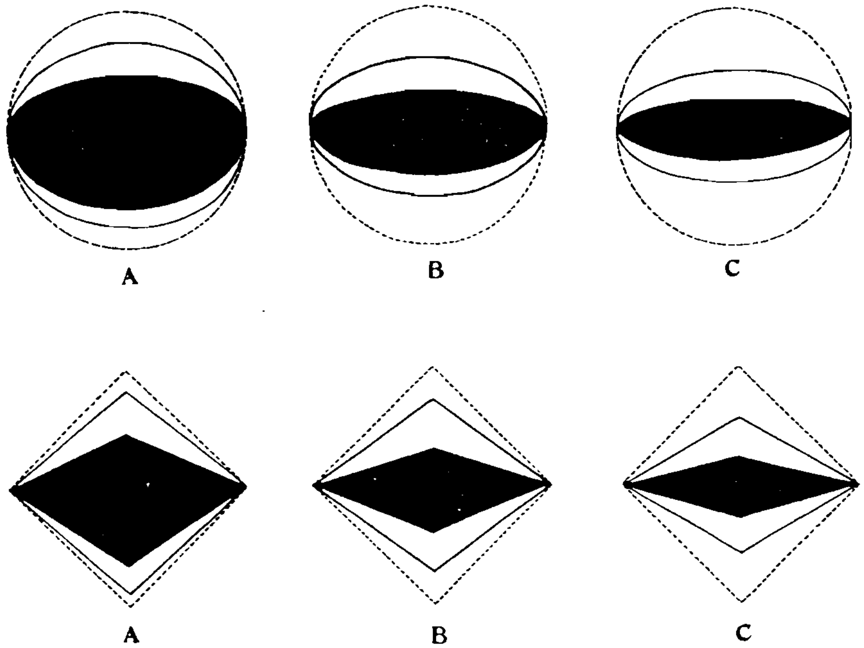

Fig. 2. S.'s mean reproductions of circle and square. Broken line shows physical shape of object. Black figure shows its perspective shape. Continuous line shows mean shape of reproduction.

these two extremes, and that it sometimes lies nearer to the physical shape than to the perspective shape. It is as if the known physical shape of the object distorted towards itself the seen shape from that which we should expect to result from the sensory cue of the image on the retina.

The first doubt that occurs to one's mind in attempting to explain these results is whether it is not possible that in all reproductions of ellipses or of trapezia there is a tendency to revert to the circular or square form. If this were the case, the assimilation to these shapes here found would not be the result of the stimulus being a projection of a physically circular or square object but would be characteristic of any reproduction of an ellipse or a trapezium. This, however, was proved not to be the case by a subsidiary experiment.

The subject was given actually elliptical discs to reproduce from normal (*i.e.* not inclined) observation. The three ellipses given to the subject to copy had ratios of short to long semi-axis of 0·7, 0·45, and 0·25. The means of three reproductions by drawing of these were respectively 0·69, 0·45, and 0·245. Thus there is no tendency to revert to the circle in copying an ellipse[1]. The tendency observed when drawing an inclined circle or square must, therefore, be due to the effect of the actual shape of the physical object.

This experiment also eliminates the possibility that any appreciable part of the observed effect is due to irradiation of the white surface over the darker background. Any such action would take place equally whether the stimulating object were an ellipse viewed normally or an inclined circle giving the same retinal image.

In this failure of seen shapes to obey the laws of perspective, we are reminded of analogous phenomena in perception. Hering (3) showed that a white disc in shadow may appear brighter than a strongly illuminated grey disc even though the degree of shadowing is so great that the white is actually reflecting less light to the eye than is the grey disc. Apparent brightness is thus determined partly by the 'real' brightness or reflectivity of the object seen and not solely by the intensity of the retinal image. Similarly, if two objects of the same shape but different size are placed at such distances from the eyes that their apparent sizes are equal, it is found that their relative distances are such that the retinal image of the 'really' larger object is considerably smaller than that of the other. Apparent size is a function of 'real' size as well as of size of retinal image. In later sections, it will be shown that in these two cases also the same law of compromise holds. Under ordinary conditions of binocular vision, the actually experienced character of the object (or the 'phenomenal character') is a compromise between the 'real' character of the object

[1] There is, however, distortion in copying ellipses with larger ratio of short to long semi-axis. An ellipse with short axis vertical and of ratio 0·95 was copied as an ellipse of ratio 0·93, while a true circle normally observed was copied as an ellipse of ratio 0·975 (short axis vertical). The distortion is small and in the opposite direction to that due to phenomenal regression. It is probably due to the 'horizontal-vertical illusion.' It was one reason for later abandoning the drawing method in these experiments. The other reason was the possibility that training in drawing may tend to condition the drawing response to the stimulus shape even though the subject's perception of the object would be intermediate between the stimulus shape and the 'real' shape if this perception were tested by some form of response in which the subject had received no previous training.

and the character given by peripheral stimulation, whether this character is shape, relative size, or relative brightness. In all of these cases, the phenomenal character shows a tendency away from the stimulus character towards the 'real' character of the object. As a general name for this tendency, in whatever kind of perceptual character it is found, we may use the term *phenomenal regression to the 'real' object* or, more shortly, *phenomenal regression.*

It is also convenient to have a numerical measure, applicable to any perceptual character, of the degree to which this regression takes place. Let us use the symbol S for a stimulus character (*e.g.* the ratio of short to long axis in the perspective shape of square or circle in the above experiments), the symbol P for the corresponding phenomenal character (the corresponding ratio in the figure matched or drawn by the subject), and R for the corresponding 'real' or physical character of the object (the ratio in the actual object—unity in the square or circle). An obvious measure of the degree of regression of the phenomenal character away from the stimulus character towards the 'real' character of the object is the fraction of the distance separating the real from the perspective character over which the phenomenal character has regressed: *i.e.* the fraction $(P - S)/(R - S)$. This proves, however, not to be a satisfactory measure, since it leads to certain anomalies (particularly when used for the brightness and size regressions). A formula, only a little more complicated, which is free from these difficulties is

$$(\log P - \log S)/(\log R - \log S).$$

This is the measure which I have used throughout these experiments and have called the *index of phenomenal regression.* Its value is zero if there is no phenomenal regression, that is, if the phenomenal character is identical with the stimulus character; while it is unity if regression is complete, that is, if the phenomenal character coincides with the 'real' character of the object.

Determinations of the phenomenal shape of the inclined circle were also made with other subjects by the matching method. Mean results by this method with S. and other subjects are shown in Table III. It will be noticed that there are considerable individual differences in the amount of phenomenal regression.

The results (Table III) show that the index of phenomenal regression varies for different inclinations of the object to the line of vision. It seems also to vary somewhat with the size of the object, its distance and its shape (whether square or circular). The three latter sources of variation were not investigated. An experiment was performed, however, to discover how the amount of phenomenal regression varied with different angles of inclination of the object. For this purpose, a white circular disc of 29·7 cm. diameter was mounted on a turntable with its axis of rotation horizontal and at right angles to the subject's line of vision. The disc was mounted with a diameter in line with the axis of rotation of the apparatus, so that turning the apparatus presented the disc to the subject at varying angles of inclination. The centre of the disc was 142·5 cm. from the subject's eyes. Eight observations in each position were made with the subject S. by the matching method at

Table III. *Mean matchings of phenomenal shape of inclined circle by four subjects.*

	Circle at *A*			Circle at *B*			Circle at *C*		
Subject	Matched ratio	Perspective ratio	Index of phenomenal regression	Matched ratio	Perspective ratio	Index of phenomenal regression	Matched ratio	Perspective ratio	Index of phenomenal regression
S.	> ·7*	·56	> ·39	·495	·36	·31	·46	·255	·43
X.	·74	·56	·48	·59	·36	·50	·43	·255	·38
B.	·785	·56	·58	·56	·36	·43	·435	·255	·39
D.	·84	·56	·70	·725	·36	·685	·645	·255	·68
M.	—	—	—	·575	·36	·46	—	—	—

* No standard ellipse of larger axis-ratio than this was available at the time of experimenting with S.

approximately the following angles of inclination: 7°, 10°, 20°, 30°, 45°, 65°, and 90°. The angles could not themselves be measured with sufficient accuracy for exact calculation of their perspective shape in each position, so this was done by placing a camera in the position of the eyes and measuring the ratios of the photographed ellipses with a travelling microscope. The results of this experiment are shown as a graph in Fig. 3.

In this figure, the broken line shows the variation of phenomenal shape with perspective shape. If the seen shape were identical with the perspective shape, all observed values would fall on a straight line passing through the origin and inclined at an angle of 45° to each axis. A continuous line has been drawn in this position. The amount of phenomenal regression is, therefore, shown by the height of the broken line above the continuous line. The diagram indicates that the amount of phenomenal regression diminishes to zero as the angle of inclination approaches 90° and (less certainly) as it approaches 0°. The indices of phenomenal regression are as follows: 7°, 0·28; 10°, 0·41; 20°, 0·33; 30°, 0·32; 45°, 0·16; and 65°, 0·1.

It has already been shown by the earlier experiment in reproduction of actually elliptical figures viewed normally that these results are not the consequence of a tendency to prefer the circular shape in perception and to assimilate other closed curves to the circular form in reproduction. This is shown more strikingly in the following experiment, in which the regression was from the circular shape and not towards it.

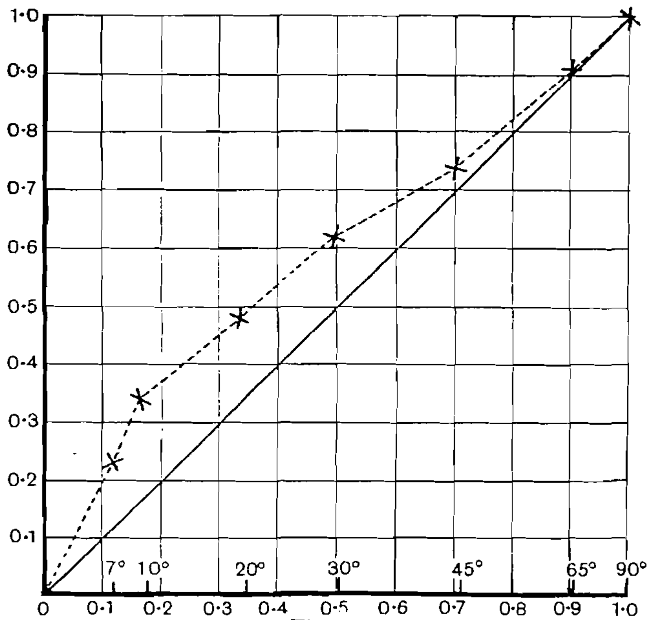

Fig. 3.

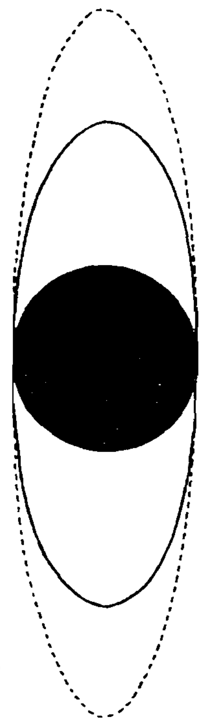

Fig. 4.

Fig. 3. Variation of phenomenal shape and of index of phenomenal regression for different inclinations of circular disc to line of vision. *Horizontal axis.* Ratio of axes in stimulus shape (corresponding angles of inclination shown above the axis). *Vertical axis.* Ratio of axes in phenomenal shape.

Fig. 4. S.'s mean matching of phenomenal shape of elongated ellipse so arranged that its perspective shape is approximately circular. Broken line shows physical shape of object. Black figure shows its perspective shape. Continuous line shows mean phenomenal shape.

Instead of using a circle as stimulus object an ellipse was used with long axis pointing away from the subject and the ratio of the axes was so chosen that the perspective figure would have equal axes (*i.e.* would be as nearly a circle as it is possible to get with a perspective projection of an ellipse). The actual shape of ellipse necessary in the position used was found to have a ratio of long to short axis of 3·95. The result of this experiment is shown in Fig. 4. If the tendency were simply to assimilate the phenomenal figure to a circle, then no distortion should take place. In fact, there is still distortion and its direction is away from the circle and towards the physical shape of the object perceived—the ratio of the phenomenal shape was 2·65. It is the physical shape of the object, therefore, and not a preference for the circular form that determines the change in the phenomenal shape.

It is also possible, of course, to arrange an elliptical object so that the phenomenal shape is itself circular. The condition for this is that a sufficiently elongated ellipse with its long axis pointing from the subject shall cast on the retina an image of an ellipse with long axis horizontal. This case is of no special theoretical interest[1].

The full series of experiments from which the example in Fig. 4 was drawn is shown in Table IV. The ratios in columns 2 and 3 are of vertical to horizontal axes, in column 1 of axis in line with subject to that at right angles to him. It will be seen that not only is there no tendency for phenomenal regression to diminish as the perspective shape approaches circularity, but even that under those conditions the index found was greater than with any other perspective shape.

Table IV. *Mean matchings of phenomenal shapes of various elliptical discs viewed obliquely.* (*Subject S.*)

Ratio in observed disc of axis in line with subject to that at right angles to him	Ratio of vertical to horizontal axis of perspective shape	Mean ratio of vertical to horizontal axis of phenomenal shape	Index of phenomenal regression
3·93	1·05	2·65	0·70
2·01	0·54	1·19	0·60
1·33	0·355	0·825	0·64
1	0·27	0·50	0·47
0·75	0·20	0·40	0·52

II. HERING'S OBSERVATIONS ON *Gedächtniss-farben*.

In his *Grundzüge der Lehre vom Lichtsinn* (3), Hering records a series of observations on the perception of relative brightnesses and colours, of which the following is typical. If a piece of grey paper is placed near a

[1] It is, however, one of the most convenient methods of demonstrating the effect. If we discover the ellipse which, with its long axis pointing from the subject, appears to him at a given inclination approximately circular (*i.e.* with equal horizontal and vertical axes), we can demonstrate to the subject the fact that the perspective figure is really a flattened ellipse by allowing him to look at the object through a circular aperture held at right angles to the line of vision at such a distance from the eyes that the longest axis of the perspective ellipse just fits inside the circle.

window and compared with a piece of white paper so much farther away from the window that its luminosity is less than that of the grey paper, the grey paper is, nevertheless, seen as grey and the white as white—*i.e.* the less luminous surface of the white paper is seen as the brighter. If the two pieces of paper are now simultaneously examined with one eye looking through a blackened tube, the apparent brightness relationship is reversed, the white paper appearing to be of a darker shade of grey than the other. If they are again examined as part of the full field of vision of both eyes, the brightness relationship is seen as at the beginning—the less luminous white paper is seen as the brighter.

Similar effects were observed with tinted objects whose apparent hues were found to tend to remain constant in spite of changes in colour of the illuminating light. These shades or hues, which persisted in spite of changes in illumination, Hering called *Gedächtniss-farben* (usually translated as *memory colours*), and he picturesquely describes us as seeing certain classes of objects "through the spectacles of memory colours."

A mere repetition of the experiment on brightness described above might lead us to a conclusion which a more careful study shows to be wrong. The white paper appears brighter than the grey, although so much less illuminated that its luminosity is actually less. We might be led to suppose, therefore, that there is a law of absolute 'constancy of brightness' by which the paper of greater reflectivity[1] appears the brighter under any illumination however much reduced.

Further experiment, however, shows that the matter is less simple. If the white paper is further shadowed, a point is reached at which it appears of the same brightness as the grey paper, and if the reduction of its illumination is carried beyond this point, the white paper appears the darker. We are again dealing with a compromise effect, the apparent brightness is neither determined solely by the 'real' character of the paper's reflectivity nor solely by the stimulus character of luminosity, but is a compromise between them.

The fact of this compromise may be made clearer by a quantitative example. I took two squares of paper (20 cm. × 20 cm.) vertically mounted on cardboard. One was white, *A* (slightly brighter than the no. 1 of Zimmermann's scale); the other was a light grey, *B* (between

[1] I am using this word 'reflectivity' for the position of the paper itself on the white-black scale in order to avoid the ambiguity attached to the term 'physical brightness.' Psychologists commonly refer to this quality as the 'brightness' of the paper. Physicists, however, generally use 'brightness' in the same sense as 'luminosity' for the intensity of reflected light under given conditions of illumination. For this I shall use the word 'luminosity,' reserving 'brightness' for the phenomenal character.

Zimmermann's 3 and 4). Their relative reflectivities were first determined by rotating a sector of the white before a blackened chamber and matching with the grey. The amount of the white required for a match was found to be 135·5°, so the reflectivity of *A* was 2·65 times that of *B*. The two papers were normally illuminated in a darkened room by a 4-volt (1·2 watt) electric bulb in a blackened case with a filament of size negligible compared with the distance of the papers. The intensity of illumination of the papers was, therefore, inversely proportional to the square of their distances from the lamp.

The subject S. looked at the two papers with both eyes open and his head in such a position that the papers were not immediately adjacent but separated by a short space of black background. *B* was 100 cm. from the lamp and the mean distance at which *A* was found to be of equal phenomenal brightness was 184 cm. At a greater distance, *A* appeared the darker. At this distance of 184 cm., the calculated luminosity of *A* was 0·785 that of *B*. In other words, a paper about 2½ times as reflective as another appeared equally bright to binocular observation when its actual luminosity was about three-quarters that of the other.

The white paper was next adjusted to phenomenal equality with *B*, but observed under different conditions. The subject looked with one eye through a blackened tube which cut out all surrounding objects, and with his head in such a position that he saw through the tube the surfaces of the two papers adjacent to one another. The mean distance of *A* at which the papers appeared equally bright was now 162·5 cm. Calculation shows that the ratio of the luminosity of *A* to *B* was now 1·0035 : 1; that is, the luminosity of the two papers was, as nearly as possible, equal.

A similar experiment was performed with the same subject on another day with a paper *C* of a much darker grey (no. 41 of Zimmermann's brightness scale of 50 shades). This was adjusted by the same light to phenomenal equality with each of the other two papers at 507·5 cm. from the same lamp as was used in the earlier experiment. In this case, the reflectivity of *C* was not determined independently but was assumed to be given by adjusting to apparently equal brightness with monocular observation through a blackened tube. In this experiment the effect of the inclination of *C* to the source of light was not negligible, so its luminosity was calculated from the formula:

$$\text{luminosity} \propto \text{reflectivity} \times \frac{\cos\theta}{d^2}.$$

The results of this experiment and of the earlier one are given in Table V.

Table V. *Phenomenal regression of papers of differing reflectivity so illuminated that they appear of equal brightness.*

Papers used	R_1/R_2	P_1/P_2	S_1/S_2	Index of regression
A and *B*	2·65	1	·785	·19
B and *C*	4·95	1	·298	·43
A and *C*	13·1	1	·175	·405

We are here dealing with an effect analogous to that of the phenomenal regression of perceived shapes. The relative reflectivity of the papers is the physical property of the papers themselves corresponding to the 'real' shapes of perceived figures. Their relative luminosity (which is equal to the relative luminosity of the retinal images) is the character of peripheral stimulation corresponding to the perspective shapes of the figures. Their relative phenomenal brightness (adjusted in this experiment to unity) corresponds to the phenomenal figure. The effect observed is that the relative phenomenal brightness is not determined solely by the relative stimulus brightness (*i.e.* relative luminosity) of the papers but also by their relative 'real' brightness (*i.e.* relative reflectivity). The relative phenomenal brightness is, in fact, a compromise between these two. As was observed with the perception of shapes, the greater the difference is between the reflectivities of the papers used, the greater must be the difference in their relative luminosities if they are to appear equally bright. If we indicate the relative reflectivities, luminosities, and phenomenal brightnesses by the symbols R, S and P respectively, the index of regression is given by the formula

$$(\log P - \log S)/(\log R - \log S),$$

or (since P is unity) by $(-\log S)/(\log R - \log S)$.

In a beautiful and ingenious series of experiments Köhler (4) has shown that both chimpanzees and hens show the tendency to constancy of brightness. He demonstrated that when these animals are trained to react to the brighter of two papers equally illuminated, they continue to react to the more reflective paper even when its illumination is so much reduced that it has a lower luminosity. He did not, unfortunately, investigate the further problem of the maximum degree of lowered luminosity of the whiter paper at which it still called out the same response and beyond which it was reacted to as the darker paper. It is not, therefore, possible from his results to calculate an exact value for the phenomenal regression but only a value which it must have exceeded.

With chimpanzees, the greatest disparity of illuminations was when the whiter paper (no. 3 of the Zimmermann scale) had a luminosity

0·0795 that of the darker (no. 41). If we take their relative reflectivities as about 5, this gives an index of regression greater than 0·61. There is some indication that the stimulus difference is here reaching the value at which reversal of the reaction would take place, since the ape makes two wrong reactions out of ten (although he makes none at all when the stimulus difference is less). It is, therefore, probable that the index of regression does not much exceed this value.

With hens there was no sign of an approach to the point of reversal when the relative stimulus values were 0·0807 : 1 with the papers 3 and 30 of Zimmermann's scale. I do not know the relative reflectivities of these papers, but since their difference is less than that between the papers used for the apes, the index of regression for the hens must be considerably greater than 0·61.

Katz (5) has used human subjects in an experiment in which rotating colour wheels with black and white sectors were adjusted to phenomenal equality when one was in shadow, and obtained results which give indices of phenomenal regression ranging in one experiment from 0·33 to 0·69.

Obviously, there are insufficient data for determining whether phenomenal regression is greater for chimpanzees and hens than for human beings, particularly since the experiments were not carried out under comparable conditions. The precise determination of the answer to this question would be an interesting problem for an animal psychologist.

III. Experiments on apparent sizes.

Another example of the same character of perception is to be found in the dependence of the apparent size of a seen object not only on the size of its retinal image but also on the physical size of the object, so that of two things producing equal retinal images the one that is more distant and actually larger also appears the larger. In order to measure this effect, two white circular discs of different sizes were fixed upright on movable stands, which were adjusted to different distances from the subject along two graduated lines on a table so diverging that there was no overlap of the retinal images of the two discs. The arrangements for viewing the discs were similar to those shown in Fig. 1. The larger disc remained fixed, while the distance of the smaller disc was varied until the subject reported that the apparent sizes of the two discs were equal. The 'limiting method' of experimenting was used. The perspective sizes of the two discs were then calculated from their diameters and their distances from the subject's eyes.

When the phenomenal sizes were thus adjusted to equality, in all cases the physically larger disc was at such a distance that its perspective or stimulus size (*i.e.* the size of the image actually cast on the retina) was considerably smaller than that of the other. In other words, phenomenal size also is a compromise between stimulus size and the physical size of the object.

Fig. 5 represents the mean of two sets of experiments with the subject S. The discs were 39·7 and 29·7 cm. in diameter, and appeared equal when they were at 240·5 and 117·5 cm. from the eyes respectively. Thus the larger disc, which was only about four-thirds the diameter of the other and a little less than twice its area, had to be slightly more than

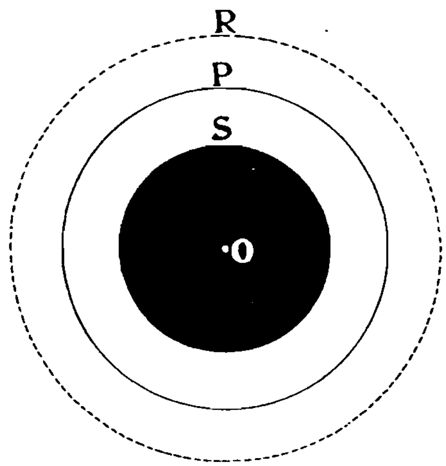

Fig. 5. Conditions for phenomenal equality of two circular discs of different physical size (Subject S.). Broken line shows relative physical size of larger disc. Black figure shows its relative stimulus size. Continuous line shows its relative phenomenal size.

twice its distance from the subject for the two discs to appear equal. At this distance the diameter of the retinal image of the larger disc would be about two-thirds and its area less than half that of the smaller. In the diagram, the dotted circle (R) has been made proportional to the ratio of the physical size of the large disc to that of the small one, the inner blackened circle (S) to the ratio of their stimulus sizes, and the continuous circle (P) is proportional to their relative phenomenal sizes (*i.e.* to unity). If there were no phenomenal regression, the circle P would coincide with S whatever might be the size of R.

The index of phenomenal regression is calculated exactly as for the experiments in phenomenal brightness. R is the relative size of the actual objects, S their relative stimulus size, and P their relative phenomenal size (unity in these experiments)[1].

Table VI shows mean results of this experiment for four subjects. The first two rows were made with the same subject on different days. The subject D. showed so large an amount of phenomenal regression that, when discs of diameters 39·7 and 29·7 cm. were used, the smaller disc was too near the subject for convenient measurement. Discs were therefore used with a smaller difference of size between them. If there were no phenomenal regression, row 8 would be, in all cases, unity. Phenomenal regression is shown by the tendency of the phenomenal diameter ratio (*i.e.* 1) not to coincide with the value in row 8 but to be intermediate between that and the value in row 5.

Table VI. *Mean results of experiments on phenomenal size.*

1 Subject	S.	S.	M.	D.	D.	C.	C.
2 No. of observations from which mean is calculated	12	8	6	—	8	4	8
3 Diameter in cm. of large disc (D_1)	39·7	39·7	39·6	39·7	29·7	39·7	29·7
4 Diameter in cm. of small disc (D_2)	29·7	29·7	29·7	29·7	26·5	29·7	26·5
5 Relative diameters (D_1/D_2)	1·335	1·335	1·333	1·335	1·12	1·335	1·12
6 Distance in cm. of large disc (L_1)	240·5	240·5	230	240	240	240	240
7 Mean distance in cm. of small disc for phenomenal equality (L_2)	120	114	114	$<$ 70	162	93	162
8 Relative perspective diameters (D_1L_2/D_2L_1)	·665	·635	·66	$<$ ·39	·755	·545	·755
9 Index of phenomenal regression $\frac{-\log(8)}{\log(5)-\log(8)}$	·585	·61	·59	$>$ ·76	·715	·68	·715

Here also, it is to be noted that we are dealing not with an absolute constancy of phenomenal size but with a tendency to constancy. At no distance from the observer is it true to say that changing distance of the object makes no difference to phenomenal size. As the distance of an object changes, its phenomenal size changes, whether the object be far or near. It changes, however, less rapidly than does the size of the retinal image. The tendency to constancy is shown by the amount of change being a compromise between the changing size of the peripheral stimulus and the unchanging 'real' size of the object.

In order to demonstrate this more fully an experiment was devised in

[1] It is an advantage of the formula $(\log P - \log S)/(\log R - \log S)$ over the simpler $(P - S)/(R - S)$, that the index has the same value whether the characters used in its calculation are the linear dimensions of the objects, their areas or their volumes. A more important advantage is the fact that it does not matter which of the objects compared provides the numerator and which the denominator for R, P and S. This is not true of the simpler formula. A further objection against the simpler formula is that it leads to absurdly small values of the index if the difference between the real sizes of the objects compared is great.

which a light circle was thrown on to a screen 5 m. from the subject, by means of a diaphragm of adjustable size in a projection lantern. A circular white disc supported vertically, of diameter 13·15 cm., was presented to the subject at distances of 1·33, 2, 3, 4, 5, and 6·5 metres. For each of these positions, the subject was required to adjust the circle cast by the lantern until it appeared equal to the disc. Fig. 6 shows the mean of ten observations in each position of the disc.

If the phenomenal size of the disc obeyed the laws of perspective, its changes would be proportional to the changes in stimulus size. The

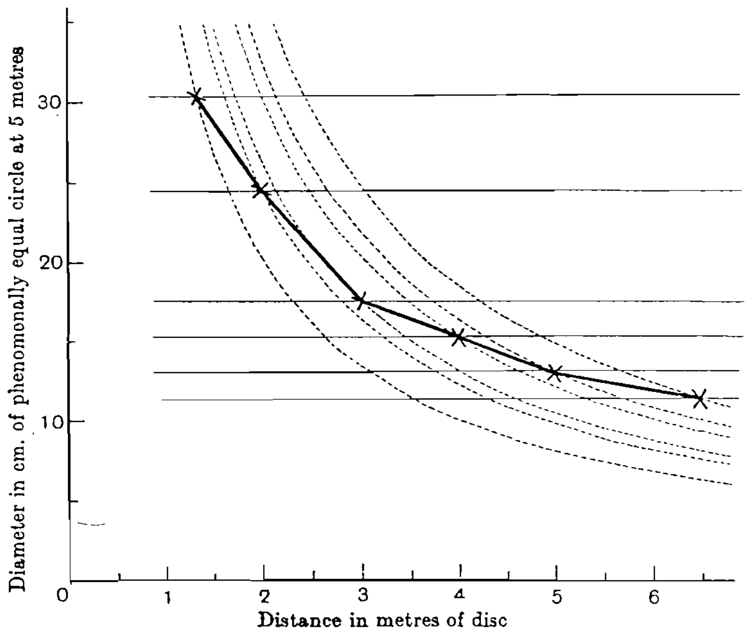

Fig. 6. Change of phenomenal size of circular disc with changing distance.

phenomenal length of diameter would, therefore, be proportional to the reciprocal of the distance of the disc from the eyes. All variations of apparent size with distance in Fig. 6 would lead to values lying on one of the series of curves $y = 1/x$, which is the curve of decrease of stimulus size with increasing distance. To show how far this is from being true of phenomenal size, I have drawn a curve $y = 1/x$ through each of the recorded values of the phenomenal size. The curve of change of phenomenal size cuts across these curves and follows a course intermediate between them and the curve of absolute constancy of shape (shown as a thin straight line parallel to the base through each recorded value). The curve of decrease in phenomenal size is seen to fall all the way between these limits. Nowhere does the apparent size of the disc remain constant in spite of changing distance; nowhere does it change as rapidly as does the retinal image. The apparent change in apparent size is always a compromise between the change in stimulus size and the constancy of the 'real' size.

Köhler (4) has demonstrated that apes trained to react to the larger of two similar boxes continue to do so when its distance is so great that its perspective size is less than that of the other. Again, since he did not determine the distance at which the reaction was reversed (as from analogy with the above experiments we should expect it to be), no exact index of phenomenal regression can be determined. In Köhler's experiments R_1/R_2 (linear) was 4/3, while the greatest difference of stimulus sizes was when S_1/S_2 (linear) was 0·61. This shows that the index of regression was greater than 0·63. Since in my experiments, using discs of the same relative linear dimensions, most human subjects gave indices of regression greater than this, we cannot conclude whether or not the index of regression for chimpanzees is greater than that for human beings. A comparison of the results indicates that, at any rate, it is not much less.

IV. THE TENDENCY TO EQUALIZE VERTICAL SEMI-AXES IN PERCEPTION OF THE INCLINED SQUARE AND THE PHENOMENAL REGRESSION OF PARALLEL LINES.

In Section II, we considered only one respect in which the perception of the circle or square showed regression from the perspective to the physical figure—the ratio of the vertical to the horizontal axis. There is another character of the shape of the perspective figure which might also show phenomenal regression—the ratio of the upper to the lower semi-axis. In the perspective shape of an inclined square (Fig. 7), the

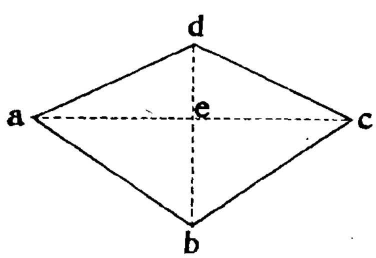

Fig. 7. Perspective shape of inclined square.

upper vertical semi-axis *de* is shorter than the lower one *eb*[1]; in the actual physical figure this ratio is unity. Phenomenal regression would, therefore, tend to make the ratio in the perceived or reproduced figure more close to unity than to its value in the perspective figure. Only a few observations were made on this matter. These indicated with certainty that this tendency to equalization of the vertical semi-axes is present in a large degree, although the number of observations was insufficient for exact measurement of its amount. Regression appeared to be more complete with respect to this character than in the character of equality of the ratios of the vertical and horizontal axes.

For this part of the investigation the square was necessarily used as object, since a reproduction of the circle gives no definite point from which the semi-axes can be measured. Also it was obviously more convenient to use the drawing rather than the matching method. The results of four experiments with the subject S. are shown in Table VII. It will be seen that for the nearest position of the object, this character showed the very large index of regression of 0·76, while for the other two positions it was not significantly different from unity, *i.e.* regression was apparently complete.

Table VII. *Tendency to equalize vertical semi-axes in drawing inclined square.*

Position of object	Ratio of semi-axes in perspective figure	Ratios of semi-axes in reproduced figure					Index of phenomenal regression
		1	2	3	4	Mean	
A	·69	0·96	0·95	0·88	0·875	0·915	0·76
B	·77	1·055	1·02	0·85	1·06	0·995	1·0
C	·82	0·97	1·02	1·115	0·92	1·005	1·0

It may be noted that this character is also an indication of the degree of convergence of opposite sides of the figure. The index of regression is a measure of the extent to which the converging lines of the perspective figure undergo regression in the phenomenal figure to the parallelism of the sides of the actual object.

There are other interesting consequences of this tendency of receding parallel lines to regress from the convergence of their stimulus character

[1] Their relationship is given exactly by the equation

$$de/eb = (D - R \cdot \cos\theta)/(D + R \cdot \cos\theta),$$

where *D* is the distance of the subject's eyes from the centre of the square, *R* is half the diagonal of the square, and θ is the angle between the plane of the square and the line of vision. Fig. 7 is actually the perspective figure for the square in position *A* of Fig. 1, where this ratio was 0·69.

to the parallelism of the 'real' object. In some cases, this tendency may result in a phenomenal divergence. A striking example of this is to be found by looking through a telescope or through binoculars at a wall with parallel top and bottom receding from the observer. Under these conditions, the top and bottom of the wall appear to diverge considerably as they go from the observer. The explanation of this appears to be that when looked at in the ordinary way the wall appears to converge, but much less so than does the retinal stimulus, regression having taken place to the 'real' character of parallelism. When looked at through a magnifying instrument, the wall appears nearer and the amount of phenomenal regression which takes place is not that proper to its actual distance but the greater amount proper to its apparent distance, so that the regression is beyond parallelism to divergence. Another way of stating this is that regression is taking place towards the non-existent object with divergent sides which, if it occupied the apparent position of the wall as seen through binoculars, would cast on the retina an image with the degree of convergence of that actually formed (this degree being, of course, considerably less than that from a parallel-sided object in the same position).

A more convenient method of showing the same phenomenon is by an isometric or other parallel-sided projection of a cube (Fig. 8). If we

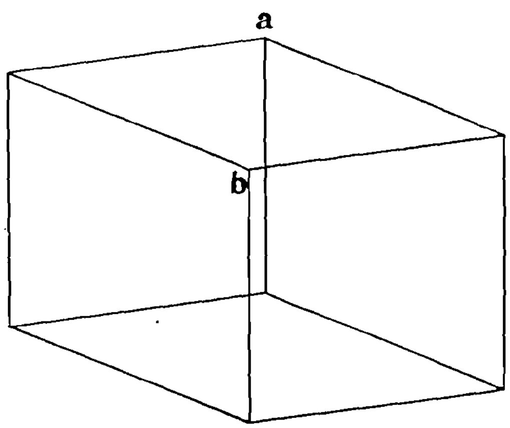

Fig. 8. Isometric projection of cube.

see this as a solid figure with the corner *a* towards us (a mode of perception favoured by the fixation of *a*), the two pairs of edges perpendicular to the vertical edge through *a* appear to diverge. A similar effect is seen in the other two pairs of edges if the phenomenal figure is reversed and *b* is seen towards us.

This may be explained by saying that this figure is a true perspective projection of an obliquely truncated pyramid with actually divergent sides[1]. This, however, is not a complete answer to the problem. If, as is commonly believed by writers on perception, the phenomenal object is entirely determined by the characters of the retinal projection, this figure should give a parallel-sided perception, whatever might be the shape of the object of which it is the projection. On the other hand, the phenomenal object is not a function only of the character of the object seen, since, if we look at an actual cube, the edges receding from us seem to converge somewhat. We can make a series of figures like Fig. 8 with the sides actually converging and select a member of the series in which the actual convergence exactly neutralizes the phenomenal divergence for one of the two ways of perceiving it. It is then seen as a parallel-sided figure. Similarly we can have a series of almost cubical solids with increasing actual divergence of sides and select one which appears parallel sided in perception. This would not be the one giving a parallel-sided retinal projection but one giving a retinal projection with sides still convergent but less so than that of the true cube. As with the perception of shapes, brightnesses and sizes, we are dealing with a compromise effect. The phenomenal character is a compromise between the character of the peripheral stimulus and that of the object (either 'real' or intuited).

V. Summary.

Experiments were performed on the shapes of objects viewed obliquely, the apparent brightnesses of differently illuminated surfaces of different reflectivity, the apparent sizes of objects at different distances, and the apparent convergence of parallel lines receding from the observer. In all of these cases it was found that what was seen was intermediate between what was given in peripheral stimulation and the 'real' character of the object. To this effect of the character of the 'real' object on the phenomenal character we may give the name 'phenomenal regression to the real object.' We may use as measure of this effect the index

$$(\log P - \log S)/(\log R - \log S),$$

[1] More precisely, of an infinite series of such solids of which the figure in which *a* and *b* are in the same plane (*i.e.* the projection itself) is a limiting member. There is the further psychological problem of why the phenomenal object should be a particular member of this series, and of why it should be so difficult to see the diagram as a plane figure with parallel sides since this is as much a member of the series of figures of which this could be a projection as any other. Possibly there is a tendency to approximate the phenomenon as nearly as possible to the cube.

in which P is a numerical measure of the phenomenal character, R of the 'real' character, and S of the stimulus character.

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