EXPLORATORY EXPERIMENTS ON THE STIMULUS CONDITIONS FOR THE PERCEPTION OF A VISUAL SURFACE [1]

JAMES J. GIBSON AND FREDERICK N. DIBBLE

Cornell University

It is possible that the simplest visual perceptions are those of *surface* and *edge* (1). These impressions can be obtained when the eyes are fixated, i.e., without having to consider the effect of the succession of overlapping retinal images normally obtained when the visual environment is scanned. They can probably be explained without reference to the stimulation arising from the posture and the movements of the eyes, head, and body—the factor of equilibrium and orientation in space perception. The vestibular-kinesthetic-tactual complex of stimuli has to be considered, of course, but the visual stimulus might be considered first. This approach to space perception is simplified above all by deferring consideration of the meaning of percepts until their psychophysical basis has been established. The question to which this approach leads, then, is what are the proximal stimuli, in terms of image-variables, for the "elementary impressions" of surface and edge?[2]

A phenomenal surface has the qualities of hardness, distance, slant, and illuminated color (2, p. 368 f.).[3] A phenomenal edge has properties of "two sidedness," or relative distance (a jump in depth from one to the other side), of length, curvature, and direction. An edged or bounded surface has the property of shape or form along with its slant, and size or area along with its distance. For all these properties psychophysical experiments may be possible which will establish the stimulus variables to which they correspond.

According to what will here be called the *texture-hypothesis*, the stimulus for a visual surface is a fully differentiated, sharp, or textured retinal image. This, however, is a crude statement. It can be somewhat refined by the statement that a surface occurs in perception *when the gradients of luminous intensity in the image between small regions of different intensity are maximally steep* (3).

This phraseology implies that a visual surface is a thing. A surface in visual experience is assumed to be something distinct from the filmy or foglike impression obtained when the

[1] Preliminary work on this problem over a period of two years was carried out by the authors. The main experiment to be reported was performed by Dickens Waddell and Walter Carel, to whom especial acknowledgment is due for undertaking to atropinize their own eyes in the interests of the experiment. The research is part of a project carried out under Contract AF41(128)-42 between Cornell University and the Air Force School of Aviation Medicine.

[2] The impression of what the writer has called a "corner," with its qualities of convexity or concavity, will not be discussed here although it also might be considered a basic spatial impression (1, p. 93).

[3] The word *hardness* is not an adequate term for the quality signified. It suggests tactual and kinesthetic meanings which are not intended, such as the softness of fur and the hardness of marble. What is meant is only a kind of visual definiteness which probably goes with the capacity of the eye to accommodate for the surface in question. In this sense, fur and marble are equally hard. Katz described it as something which seemed to stop the eye, as contrasted with the penetrable character of a film or fog (4).

retinal image is homogeneous. Actually, however, it should be considered an open question whether a surface is best studied as an entity or as a variable of visual perception. The question is whether the characteristic quality of hardness, already referred to, is a matter of all-or-nothing, or whether it is at one end of a discriminable dimension with something like "softness" at the other end. The other qualities of surfaceness are surely variables.

The statement of the texture-hypothesis in terms of gradients of luminous intensity suggests the latter interpretation. Since the steepness of such gradients is a variable quantity, the hardness of the impression should be a variable quality. A hard surface would go with the greatest sharpness of texture and a soft film with the least.

A phenomenal edge was characterized as having a definite increase in depth or distance from one side to the other. The texture-hypothesis, by extension, can account for this fact. According to this explanation, depth (along with all other tridimensional qualities) depends in the first instance on the *relative density* of the texture. To this is added the relative disparity of the texture when vision is binocular and the relative displacement of the texture when the head moves (1). The step in relative distance is explained by the step in density, disparity, and motion. The understanding of such a phenomenon is of great practical as well as theoretical importance, for it is approximately what one sees at the edge of a cliff, at the bottom of the windshield when driving a car, and at the line of the cowling when landing an airplane.

It should be noted that this explanation assumes that an edge occurs only between two textured surfaces. If any irreversible jump in phenomenal depth could be demonstrated to occur when the margin in the retinal image is one of intensity or wave length only, the hypothesis would fail to that extent.

The Experiments

The adequacy of the texture-hypothesis may be tested in a general way by making controlled observations with devices which produce the retinal images supposedly necessary for phenomenal surfaces and edges. The experiments to be reported are exploratory in this sense. They were performed with only a few *O*s and invite repetition by others.

Appearance of an extended surface under variable illumination.—A 20-ft. stretch of wall made of a coarse-textured plasterboard and painted a light gray could be made to fill nearly the whole of *O*'s visual field if he were seated about 3 ft. in front of it. The wall was illuminated by a bank of ceiling lights controlled by a rheostat. Even though this device was much simpler than that of Metzger (6), a number of his observations could be checked with it.

At full illumination, the experience was not only surfacelike in the sense of hard, as Metzger has reported, but also visibly textured in a way different from plywood, cloth, or concrete. The texture of this type of plasterboard could be identified and described. In addition to hardness, the perception also involved a definite distance, a zero slant to the line of sight, a gray color, and an impression of definite illumination. These reports are consistent with Metzger's, but suggest that the variable of phenomenal texture equality is not the same thing as his hypothetical microstructure. Our surface had a coarse physical texture; his plaster wall had a fine texture. It would seem, then, that the phenomenal quality of texture or pattern must be distinguished from the condition of the retinal image supposed to produce a surface.

When the illumination of the wall was gradually reduced, a level was reached at which all the properties mentioned were no longer reportable. The texture seemed to melt, the impression of hardness softened, the definite distance became foggy, and the impression of color was no longer separable from the impression of illumination. When the illumination was raised, these properties of a surface seemed to become definite again. They appeared to be in some degree linked together, although it is possible that different absolute thresholds for different properties might be determinable with a more elaborate setup.

Whether a continuous dimension from hardness to softness could have been discriminated in this situation is not possible to decide after the fact. A regular psychophysical experiment is needed.

The results are consistent with the hypothesis that the hardness of a surface is related to the steepness of the gradients of luminous intensity in the retinal image.

Effect of artificially focused and unfocused retinal images.—A large lighting fixture or globe, made of milk glass, was mounted in front of *O*'s eyes so as to fill the entire field of view. The shape of the outermost section was that of a flattened hemisphere. When moderately illuminated from outside, the visual field was homogeneous and no surface was visible. The translucent surface in front of the eyes, approximately 20 cm. distant, was sufficiently near flat so that a lantern slide could be projected on it from outside and the image would be in focus at the center but increasingly out of focus toward the periphery of the field. Photographic slides were prepared of various textured surfaces (a ploughed field, wallpaper, line patterns) and the projector was focused for the central region of this screen. In addition to the peripheral blur, the central image could also be gradually blurred by altering the projector lens.

When the projector beam was switched on, *O*'s impression of a luminous fog gave way to an impression of something a short distance in front of his eyes. Presumably the eyes accommodated and converged for the central portion of the photographic image. The percept could not, however, be called a surface comparable to the wall described above. Distance was definite, there was a certain hardness at the center of the field, and the quality of texture was reportable but no other surface properties were evident. The *O* did not mistake the image for a real surface, although this illusion is sometimes possible in experiments with an image on a flat translucent screen (2). The field became vaguer and perhaps softer toward the periphery as the gradients of intensity in the image became shallower.

When the center of the image was made to blur, the periphery became even more blurred. The impression of softness then increased over the whole field.

These results are consistent with the general idea that a sharply textured image makes for a surfacelike experience, but they also suggest that this formula is insufficient. The phenomenal texture observed was neither continuously extended, as in looking at a wall, nor bounded, as in looking at an object. Perhaps the alternatives of being either extended or bounded are part of the essential stimulus conditions for the impression of a visual surface.

Observations with a bounded region in the retinal image.—The texture-hypothesis in its crude form might lead one to predict that any bounded region of the visual field would be a surface when its image was differentiated or "speckled" and a film when its image was undifferentiated. The facts, however, contradict such an inference. An ordinary object on a background appears hard rather than filmy in everyday experience even when the structure of its surface is so homogeneous, or its distance is so great, that the corresponding retinal image must be homogeneous in effect. Likewise a rotating color disk has a homogeneous retinal image but yields the impression of a hard surface. Katz noted facts of this sort (4), and the contradiction can be shown experimentally.

A simple device for inducing a surrounding field of one kind of color and texture with a sharply bounded region of another color and texture is a large screen with an aperture or window in it. Under the name of a "reduction-screen" having an aperture of small visual angle, this setup is well known in the experiments on color perception.

Several cardboard aperture-screens were constructed with circular holes at the center varying in diameter from 1 cm. to 30 cm. The *O* fixated the aperture at a distance of 50 cm., usually with monocular vision and a motionless head. Behind the screen any of a number of different surfaces with different textures could be set up, at a further distance of 100–200 cm., in such a way as to fill the aperture.

Exploratory observations demonstrated that under some conditions, especially with the larger apertures, *O* saw a hard surface at some distance behind the screen, with a definite surface color and a definite texture. The perception was similar to that of looking out a window at, for instance, a surface of grass. Under other conditions, especially with the smaller apertures, *O* saw a soft penetrable color in the aperture itself, i.e., film color, or what has been called a "reduced color" (4). The phenomenon was not like that of a window but merely like a vague hole in a surface. Presumably in this event *O* was accommodating for the nearer rather than the farther surface. There were, however, more alternatives than these. Under some small-aperture conditions *O* saw a hard surface "on" the screen instead of a film "in" the aperture. This result seemed to be more likely when the aperture was much darker or much lighter than the screen, although the conditions for this, as for the other impressions, cannot be specified since the number of variables in the situation was large. In such cases the aperture

was sometimes reported to look like a disk of black or white paper pasted on the screen. It had no visible texture, but it nevertheless appeared to be a surface *with respect to hardness*.

This result seems to contradict the texture hypothesis. Evidently the hypothesis cannot be interpreted to mean that phenomenal hardness depends on retinal texture in the case of a sharply bounded region of the visual field. However, it is possible that the steep intensity gradient at the *contour* may have been the effective stimulus for the impression in this case rather than the texture within the contour. This interpretation becomes more likely if one remembers that a texture is itself composed of many small regions of the field and that it is the sharp margins or contours of these elements of texture which hypothetically produce the hardness of a continuous surface. It would not be surprising if the rule that held for a small region of the retinal image also held for a larger region of it. The suggestion is that the stimulus conditions for texture and for contour are fundamentally alike.

When the conditions of this setup were such as to arouse the "window" type of experience, a clear impression of edge was obtained. As might be expected, the jump in distance appeared more definite with binocular than with monocular vision, and when the head moved than when it was motionless. If fixation of a single eye with a motionless head were long continued, however, there seemed to be a tendency for the farther surface to come forward into alignment with the nearer surface, although retaining its surface qualities. The depth at the edge was then ambiguous. A few comparisons suggested that this result might be more likely when the texture of the two surfaces was different, e.g., when one was patterned and the other unpatterned. The situation obviously demands systematic investigation.

Effect of a variable aperture on the judgment of surface or film.—In order to investigate further the transition between the impression of surface and that of film, one of the variables in the aperture-screen setup was selected for more systematic study—the variable of aperture size. An iris diaphragm of the type used in cameras was mounted at the center of a large screen. Both the screen and the diaphragm were painted black. Since the aperture was continuously variable from a diameter of 2 mm. to about 50 mm. and the screen was set at a variable distance of 10, 20, or 30 cm. from *O*'s eye, a range of aperture sizes was obtainable from approximately 1 degree of visual angle to 24 degrees. The *O* sat with head fixed in a headrest, fixated the aperture, and reported its appearance. All vision was monocular. Five *O*s were used, all graduate students with training in this type of observation.

Behind the screen at a distance of something over 2 m, was set a textured surface of high reflectance. For two *O*s this consisted of cotton sheeting; for three others it was plasterboard with a coarser texture. In order to control accommodation, the eyes of all *O*s had been dosed with atropin (5% solution of homatropin) 40 min. before the experiment and the distance of the critical surface was adjusted for each *O* so that it was necessarily in focus. The effect of this procedure was to force accommodation for the surface and prevent accommodation for the aperture screen. It can probably be assumed that the transitions from surface to film were not accompanied by changes in accommodation, but were produced solely by a decrease in the size of the retinal image. The room was fully illuminated. At the larger apertures *O* simply saw a white textured surface through a circular hole in the black screen, the edges of the hole being blurred because of the far accommodation.

The intention of this experiment was to determine the minimum angular extent of a given texture which is required to see a surface. The aperture was either decreased from its maximum or increased from its minimum at any given distance until *O* reported a transition from surface to film or from film to surface. Ten ascending and ten descending judgments were obtained at each of the three distances from the screen. Each *O* was allowed to determine for himself the criterion for making his judgment, and each had been given a considerable degree of practice in making the distinction.

The results of the experiment were not quite as expected. Although the judgment was difficult to make, every *O* could do so and his angular threshold could be determined for the ascending and descending series and for the three different distances. Each individual *O* showed some consistency but the different *O*s gave widely different thresholds. The lowest threshold obtained for an *O* was in the neighborhood of 2 degrees and the highest in the neighborhood of 20 degrees. These differences were not related to the coarseness of the texture used. The suggestion was that each *O* had developed a different subjective standard of what he called a surfacelike impression. The only fact that emerged clearly was that the impression of a surface becomes more likely when the aperture is increased in size, and less likely when it is decreased. The implication is that this impression is not an entity but a variable, and that there is no clear point of difference between the impression of surface and that of film. It is possible that the accommodation response of the eye is a matter of all-or-nothing, but that

the retinal stimulation usually correlated with the response is a variable.

The aspect of stimulation being varied here was area, or number of adjacent visible elements of texture. Steepness of intensity gradients for these elements was held constant. The results indicate that the quality of hardness is a function of the *extent* of a differentiated image as well as its intensitive differentiation.

The contour of the aperture was always blurred in this experiment rather than sharp as it was in the previous setup, i.e., a shallow intensity gradient rather than a steep one. Accordingly, it is noteworthy that the film in the aperture was never reported to look like a hard surface on the screen as it sometimes was previously.

Discussion

Two conclusions, at least, are suggested by these exploratory observations, although many questions still remain in doubt. In the first place it is probably a mistake to assume that a phenomenal surface is an elementary impression of visual space. It is not a thing at all, but a variable of things. The hardness of a surface lies on a dimension having the quality of softness at the other extreme.

In the second place the visual hardness of a surface does not seem to be in psychophysical correspondence with texture as such. The texture-hypothesis as usually formulated is inadequate. A sharp contour in the retinal image seems to yield hardness whether it delimits a small speck of light or a large patch of light. The formula of the steepness of gradients of luminous intensity between regions of the image, however, gives promise of being valid.[4] The size of the regions referred to is unspecified, and is a matter for empirical study. The investigator must learn to think of the retinal image in terms of light rather than of objects which reflect light if he is to explain our perceptions of the latter. From this point of view the speckled image of a so-called texture and the contour image of a so-called figure differ only in that the former has many elements instead of one.

The problem of the stimulus conditions for an edge is similar to that for surface character except that more variables are involved. Perhaps edge is best conceived as a variable, not an entity. A true phenomenal edge bounds a phenomenal surface and it may be the case that one can never elicit the former without the latter.[5] Only a beginning has been made in the study of edge character during the present experiments, but they do suggest ways in which an investigator can go about making systematic experiments. There seem to be three basic ways of producing retinal images which arouse an edge. First is a setup which bisects the visual field, i.e., produces an unclosed edge in experience. Second is a setup which yields what might be called the *window phenomenon*, a closed edge with depth increasing from outside to inside the contour. Third is a setup which yields a closed edge with depth increasing from inside to outside

[4] Gradients of intensity are suggested in this statement as a first formulation although, in addition, gradients of wavelength might have to be considered. The ineffectiveness of a difference in hue without a difference in brightness to produce a visual contour (5), however, suggests that this complication may be minor. The *amount* of intensity difference as well as the gradient of this difference between adjacent regions may also have to be considered.

[5] The quality of *edge* is, in fact, a sort of upper threshold for the quality of slant. It is probably the impression which slant approaches as a limit when it increases from zero slant (a surface perpendicular to the line of sight) to an infinite slant (a surface parallel to the line of sight). As one fixates the flat face of an object, a cube for instance, and walks around it, the surface gets increasingly slanted (and the form gets increasingly foreshortened) until suddenly the surface disappears and becomes an edge. This relationship will be further discussed in a subsequent report.

the contour. This is allied to the classical *figure-ground phenomenon.* All these setups involve the impression of two planes of distance. The evidence suggests the hypothesis that under some circumstances an edge may degenerate into a mere margin or contour, in which case the two planes of distance become indistinct. The phenomenon of figure-on-ground has apparently been studied heretofore under these circumstances.

Surface character can be studied without the complicating effect of edges or of any boundaries save those of the visual field itself. The wall experiments demonstrate this possibility. The most interesting surfaces, however, are those exemplified by the flat face of an object and the ground behind the object (and various combinations of these). Experimentation with these requires the control of a large number of variables. In order to do so, it is wise for the experimenter first to spend some time taking an unprejudiced look at the visual world about him.

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