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THE EQUIDISTANCE TENDENCY AND ITS CONSEQUENCES

Problems in Depth Perception

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For this demonstration, two playing cards were used that appeared at different distances as a consequence of a difference in retinal size (Gogel, 1956b, pp. 4–6). A small disc was successively placed directionally closer to either the apparently nearer or the apparently farther card or midway between the cards in direction. Both the cards and disc were viewed (with the right eye only) under conditions in which depth cues other than the relative size of the playing cards were reduced or eliminated. The average results indicate that the disc appeared closer in depth to the card to which it was directionally closer and appeared approximately midway between the cards in depth when it was midway between them in direction. In a further experiment (Gogel, 1956b, pp. 7–14), the apparent path of movement of a monocularly observed disc attached to a monocularly observed rotating trapezoidal window was analyzed using the generalization that the strength of the equidistance tendency would vary as a function of the changing directional orientation of the disc with respect to the various parts of the window. This latter experiment not only demonstrates that binocular observation of some of the objects is not a necessary condition in order for the equidistance tendency to be effective, but it also supports the concept that the equidistance tendency applies to parts of objects as well as to objects *per se.* All objects, contours, and all parts of objects in the visual field both exert and are subject to a visual equidistance effect with respect to all other objects, contours, and parts of objects, with the strength of this equidistance tendency between any two visual inhomogeneities being inversely related to their difference in visual direction. It follows, for example, that all parts of a figure slanted in depth would tend to appear in the frontoparallel plane in the absence of strong cues to slant.

III. A Simple Method of Demonstrating the Equidistance Tendency.

The equidistance tendency can be demonstrated very simply by using a scene in which many objects and surfaces are visible. The only apparatus required is a luminous figure; for example, a disc of light and a partially reflecting, partially transmitting mirror to reflect the image of the disc into one eye only, while observing the scene binocularly. According to the equidistance tendency, the distance position of the disc will appear to be near objects in the binocularly viewed scene to which the disc is directionally adjacent, which can be demonstrated by rotating the mirror to move the disc to the directional vicinity of different objects in the scene. Some of the conditions that will contribute to the success of the demonstration are as follows. First, no portion of the surface generating the disc should be visible except the disc itself. Second, all cues as to the physical distance position of the disc (such as its accommodative value) should be removed. For example, the purpose of using only one eye in the observation of the disc is to prevent stereoscopic cues with respect to the binocularly viewed scene from determining the perceived distance position of the disc. Third, the binocularly viewed objects or contours in the scene that are physically at different distances should appear at different distances. Fourth, the directional adjustment of the disc should be such that the disc is directionally adjacent to only one object at a time in the binocularly viewed scene. The last condition is useful in avoiding the complication involved in predicting where the disc will appear in depth when several objects that are at different apparent distances are all in the directional vicinity of the disc and thus make approximately equal equidistance contributions to its perceived distance position.

IV. Modifications by the Equidistance Tendency of Judgments Involving Depth Cues.

A. *Modifications of Judgments Involving Stereoscopic Cues.*—It was noted that the equidistance tendency sometimes can modify depth perceptions even in situations in which stereoscopic cues to the apparent depth of the objects are available. This has been demonstrated in a study by Gogel, Brune, and Inaba (1954) in which the equidistance tendency was shown to affect a depth perception involving stereoscopic cues. The conditions of the experiment were such that the strength of the equidistance tendency was at a maximum relative to that of the stereoscopic cue. That the equidistance tendency can modify a stereoscopic judgment under other viewing conditions is suggested by an experiment by Harker (1962) in which a binocularly observed grid was oriented at various stereoscopic slants. The slant of the grid in depth would be expected to induce cyclorotation of the eyes, resulting in a reduction in the apparent tilt of the grid. The equidistance tendency also would be expected to act in the direction of reducing the apparent tilt by tending to make all parts of the grid appear at the same distance. Harker found that only some of the reduction in perceived tilt could be attributed to cyclorotation with the remainder attributed to the action of the equidistance tendency. Simon (1936), in a series of experiments, found that a binocularly observed outline circle physically slanted in depth would change its apparent orientation under reduced conditions of observation. Simon suggests that the perceived orientation (and perceived distance) of such objects would be along an ellipsoid with the observer at a focal point. Clearly the observations upon which this conclusion is based are very similar to those expected from the equidistance tendency and probably represent a modification by the equidistance tendency of judgments involving stereoscopic cues. It is clear from these experiments that, under certain conditions, stereoscopic judgments can be modified by the equidistance tendency.

Several studies concerned with after-effects also may support (at least inferentially) the notion that the equidistance tendency can modify stereoscopic judgments. Kohler and Emory (1947), Bergman and Gibson (1959), and Howard and Templeton (1964) found that the prior presentation of inspection figures physically arranged in depth and viewed binocularly affected the perceived depth involved in subsequently presented test figures. Kohler and Emory relate their results to satiation theory. Bergman and Gibson describe their results as a negative after-effect. A physically slanted textured surface with either steady or moving fixation appeared less slanted with continued observation. A subsequently presented surface in the same locality had an error in perceived slant that was opposite to that found with the original presentation. Howard and Templeton explain their results by assuming that the inspection stimulus appeared less three-dimensional than it actually was (the equidistance tendency) and consequently that the subsequent stimuli appeared distorted in depth in a direction opposite to that of the distortion in the inspection display. Since at least some of the effects found in these studies are attributable to the equidistance tendency, it is not only likely that the equidistance tendency, under certain conditions, can modify stereoscopic judgments, but also that equidistance effects occurring in one presentation can extend to other presentations.

B. *Modifications of Judgments Involving Size Cues.*—The equidistance tendency may be effective even under circumstances in which it opposes the size cue to relative distance (Gogel, 1956a, Exper. III). An experiment by Gogel and Harker (1955) supports the same conclusion. It was found that the perceived depth between two playing cards of different retinal size increased with an increase in their lateral separation. Under the conditions of the experiment, the size cue would have tended to make the cards appear at different distances, while the equidistance tendency would have made them appear equidistant. The increase in the perceived depth with increased lateral separation of the cards could therefore be attributed either to an increase in the strength of the size cue with increased directional separation or to a decrease in the strength of the equidistance tendency with increased directional separation. In a later experiment (Gogel, 1956a, Exper. IV) using the larger lateral separation, an additional object was introduced so that the perceptual effect of the equidistance tendency resulting from this additional object would oppose the perceived depth normally occurring between the cards. The additional object clearly modified the depth perception that occurred between the cards. It appears likely, therefore, that the increase in apparent depth with increased lateral separation that occurred in the previous experiment (Gogel and Harker, 1955) was a consequence of a decrease of the strength of the equidistance tendency and not the result of an increase in the strength of the size cues. It seems that, even though opposed by the size cues that occur from familiar objects, the equidistance tendency can modify the resulting depth perception.

In the study by Bergman and Gibson (1959), the inspection figure consisted of a textured surface (burlap) viewed through an aperture in order to eliminate any perception of the edges of the surface. The texture of the slanted surface provided a gradient of size changes (size cues) for the perception of slant. There was a tendency for this surface when viewed either monocularly or binocularly to appear frontal with continued observation. From the viewpoint of the present paper, this result represents a modification by the equidistance tendency of the depth perception resulting from size cues alone or from size and binocular disparity cues together.

A well-known demonstration that can be used to illustrate the capability of the equidistance tendency to modify the perceived depth normally resulting from size cues occurs with the Ames monocular distorted room. This room, while nonrectangular in shape, provides retinal stimuli equivalent to that of a rectangular room and is perceived as rectangular. Two windows usually are located on the far wall of the room with the left window more distant and proportionately larger than the right. Since the two windows have the same retinal size and shape, they are perceived to have the same size and to be at the same distance. If a familiar object (for example, a face) is presented directly behind each window, the two faces will appear to be of different sizes. The usual explanation for the apparent difference in the size of the faces is that the familiarity that would indicate that the two faces are the same size is in conflict with the assumption that the room is rectangular (Ittelson and Kilpatrick, 1961). This conflict need not have occurred, however. The observer (in agreement with the known sizes) might have perceived the faces to be of the same size and, therefore (in agreement with their differences in retinal size), might have perceived them to be at different distances behind the windows. The perceptual conflict is a consequence of the faces appearing at the distances of the apparently, but not physically, equidistant windows. Clearly, the equidistance tendency is the factor that determines that each face will appear at the distance of its directionally adjacent (framing) window. Thus, the conflict appears only because the equidistance tendency is effective in modifying the normal depth perception that would occur as a result of the different retinal sizes (the relative size cue) between the two faces.

It is interesting to note that, according to the above interpretation, the distorted room is entirely unnecessary in producing the conflict. A rectangular room with rectangular windows and with two faces presented at different distances behind the windows would produce a retinal stimulus identical to that of the distorted room with the faces directly behind the windows. Hence, both the display involving the rectangular room and the display involving the distorted room must be perceived as identical. With either the distorted or rectangular room, if all distance cues as to the depth between the faces are absent except the cue of familiar size, the equidistance tendency would result in faces of apparently different sizes appearing at the distance of the apparently equally distant windows. It is the modification of the perceived depth between the faces by the equidistance tendency, with respect to the windows, that is necessary for the perception that the two faces are of different size.

V. Other Instances of the Effects of the Equidistance Tendency.

Visual conditions in which the equidistance tendency would have some perceptual effect occur frequently. Therefore, it would be expected that phenomena which can be attributed to this tendency would have been noted either explicitly or implicitly in a variety of situations. This is indeed the case, as the following instances demonstrate. Judd has reported (1898) that white threads presented against a black background and located at different distances from an observer seemed to be equidistant when viewed monocularly, whereas when viewed binocularly, they were clearly perceived to be at different distances. In discussing the apparent depth between diplopic images and a binocularly fixated object, Judd states, "And we may assert it as a general principle that in monocular vision objects tend toward a single plane, the plane determined by binocular factors" (1898, p. 293). Katz (1935, pp. 71–74) notes that the apparent location and orientation of film color is at least partially determined by the location and orientation of the aperture through which it is viewed. Simon (1936) discusses some of the early observations on perceived distortions which relate to his own experiments (mentioned above) and, it would seem, also relate to the equidistance tendency. In an experiment concerned with the cue of motion perspective, Gibson and Carel (1952) report that a stationary display of lights in a reduced-cue situation are perceived as occupying a frontoparallel plane. The results from a number of experiments concerning the perception of slant (Beck and Gibson, 1955; Bergman and Gibson, 1959; Clark, 1953; Clark, Smith and Rabe, 1955, 1956a, 1956b; Gibson, 1950b; Gibson size of an afterimage is directly proportional to its perceived distance from the observer. According to this assertion, Emmert's law is a special case of the size-distance invariance hypothesis (Epstein, Park and Casey, 1961; Price, 1961) and thus would be subject to the evidence for and against this hypothesis. The second possible answer to the problem of how the perceived size of the afterimage is determined can be considered by returning to the example of an afterimage appearing at the distance of a directionally adjacent (or directionally identical) vertical surface. It has been asserted (Gogel, 1964) that the perceived size of objects is determined by the perceived size (S') per unit of visual angle (θ) of objects in its apparent depth vicinity. Suppose, for example, that the visual angle (θ_A) of the height of the afterimage is half as large as the visual angle (θ_B) of the height of the vertical surface and that the perceived size (S'_B) of the height of this surface is 6 feet. Under these conditions, the afterimage would have a perceived height (S'_A) of 3 feet; i.e., $S'_A/\theta_A = S'_B/\theta_B$. The contributions of the equistance tendency in this example would be to make the afterimage appear at the depth vicinity of the surface and thus determine that the S'/θ value of the surface would become that of the afterimage. It is very difficult to provide an instance in which the perceived size of an afterimage cannot be attributed to the action of relative values of S'/θ with respect to the surrounding environment rather than to its perceived distance from the observer. The S'/θ values of perceptually adjacent objects will determine the perceived size of the afterimage without the need to involve the concept of perceived distance from the observer. For the statement of Emmert's law in terms of either perceived or physical distance or in terms of the S'/θ values of objects in its perceptual depth vicinity, however, the equidistance tendency is a necessary postulate.

C. *Application to the Moon Illusion.*—Conclusions that apply to the perceived sizes of afterimages should also apply to the perceived size of the moon and hence to the moon illusion (King and Gruber, 1962; Kaufman & Rock, 1962b). The perceived size of the moon should be capable of being systematically changed by making it via the equidistance tendency appear at the distance of objects with different values of S'/θ. For example, the following demonstration should be possible. Suppose a "moon" [this might be an optically generated disc of light as in the experiments by Kaufman and Rock (1962b) and Rock and Kaufman (1962)] is presented along a line of sight directly above a rectangular object, for example, a playing card 11 feet from the observer. No other objects except the playing card and moon are visible, and all cues to a perceived depth between the moon and card are removed. In this case, according to the equidistance tendency, the moon usually would appear at the distance of the playing card. Since the moon appears at the distance of the card and subtends about one-half the width of a playing card when the card is at 11 feet, the moon would appear to be about 1 inch in diameter. Suppose, however, that, without changing its physical size or distance, the rectangular object is made to appear as a window, with consequently about a 12–fold increase in S'/θ. Under these conditions, the moon (still appearing at the distance of the rectangular object) would appear to be about 1 foot in diameter. Thus, the moon could be made to have any perceived size depending upon the joint operation of the equidistance tendency and the concept that the moon will assume the S'/θ value of objects with which it appears equidistant.[1] The moon illusion is the observation that the moon at the horizon usually looks larger than it does when it is at the zenith. But it is clear from the above discussion that the horizon (or zenith) moon can be made to look any size by making it appear at the distance of objects with various values of S'/θ. It follows that the direction of the moon illusion is a happenstance of the particular visual conditions usually experienced, since the appropriate manipulation of the visual conditions should make it disappear or cause its reversal.

The above explanation of the moon illusion is consistent with the results of the recent research on the moon illusion by Kaufman and Rock (1962a, 1962b), King and Gruber (1962) and Rock and Kaufman (1962) in which evidence is presented against the angle-of-regard hypothesis of the moon illusion summerized by Boring (1943). Unlike the S'/θ aspect of the explanation asserted in the present paper, however, Rock and Kaufman (1962) use the size-distance invariance type of explanation; i.e., it is concluded that, in general, the perceived size of the moon is deter-

[1] Boring (1943, p. 57) provides an illustration of this phenomenon when he notes that the apparent size of the horizon moon shrinks when viewed between the thumb and forefinger.

mined by its perceived distance. This conclusion partially results from observing the size of the horizon moon when the terrain between the observer and the moon is modified. There is no reason, however, for expecting terrain modifications to affect the apparent distance of the moon unless there is some factor that makes the moon appear at some particular distance; i.e., at the distance of some portion of the terrain. It is asserted that this factor is the equidistance tendency. Since the horizon or objects on the horizon are usually directionally closest to the moon, the moon usually tends to appear at the horizon distance. Thus, either the explanation in terms of S'/θ or the explanation in terms of the size-distance invariance hypothesis requires the operation of the equidistance tendency. The explanation in terms of S'/θ can be classified as a type of explanation which Rock and Kaufman call "the context effect," and which they reject as necessary for understanding the illusion. This rejection seems to be on the basis of the previously mentioned effect of terrain modifications on the perceived size of the moon illusion, and also because the moon illusion occurs over water or desert where there are no other objects of particular perceived sizes (Kaufman and Rock, 1962a; Rock and Kaufman, 1962). But it is not unreasonable that terrain modifications could change the value of S'/θ in the visual field at the apparent-distance position of the moon, and it is difficult to imagine a visual field containing no values of S'/θ while still maintaining the perceived distances required for the size-distance invariance explanation. Regardless of whether perceived distance or S'/θ is the appropriate explanation, however, the moon illusion, like Emmert's law, requires the equidistance tendency as a part of its explanation.

VII. Possible Explanations of the Equidistance Tendency.

The requirements that must be met by any attempt to explain the equidistance tendency are specified by the range of phenomena demonstrating the tendency. From the point of view of the present paper, any explanation must encompass the following phenomena.

A. The equidistance tendency occurs between any visual inhomogenities (between any contours or parts of a figure or surface).

B. The strength or effectiveness of the equidistance tendency is inversely related to directional separation (in any orientation).

C. The equidistance tendency occurs between objects viewed monocularly or between objects viewed binocularly or between objects some of which are viewed monocularly and some binocularly.

D. The presence of strong depth cues can reduce or eliminate the effectiveness of the equidistance tendency.

E. Under certain conditions, the equidistance tendency can modify depth perceptions resulting from cue systems such as binocular disparity and relative or familiar size.

F. The equidistance tendency can act as a resultant effect occurring between one object and a complex visual field.

Roelofs (1960, 1961) presents an explanation of the process by which monocularly observed objects appear at approximately the same apparent distance as binocularly observed objects. This explanation asserts that the monocularly presented image in the one eye fuses binocularly with an unstimulated but corresponding area in the other eye. Since the resulting fusional process will tend to be with respect to corresponding points, the monocularly observed object will tend to appear at the same apparent distance as the binocularly observed fixated object. It is difficult, however, for the present writer to see how this explanation can be applied to cases in which the equidistance tendency occurs between objects either completely monocularly or completely binocularly observed.

Bergman and Gibson (1959) describe the results of their study as indicating the occurrence of a negative after-effect. The tendency for the slanted surface to appear in a frontoparallel plane is attributed to a perceptual shift toward a norm and is called normalization. The effect of the normalization is assumed to persist over time and results, for example, in subsequently presented frontoparallel surfaces appearing tilted in the opposite direction. It is possible, therefore, that the concept of normalization might provide a basis for understanding the equidistance tendency. There are several reasons, however, for considering this to be unlikely. One difficulty in applying the concept of normalization to the equidistance tendency is that normalization is sometimes difficult to define. Why, for example, is a frontoparallel plane more representative of a norm than a plane slanted in depth at 45°? Also, it is not obvious why the effectiveness of a normalization would be inversely related to directional separation as is required by the equidistance tendency. Furthermore, since the equidistance tendency can occur in visual fields containing a large number of different objects at different distances, an explanation in terms of normalization would require the concept of a large number of competing normalization tendencies. The range of phenomena involved in the equidistance tendency is such that an explanation of the tendency in terms of any simple concept of normalization is not apt to be successful.

Several of the discussions of the equidistance tendency (Gogel, 1956a; Roelofs and Zeeman, 1957) suggest that the tendency can be treated as a factor possessing both magnitude and direction. It would seem reasonable, therefore, that the equidistance tendency can be additive or subtractive with respect to other cue tendencies in the perceptual localization of an object in apparent depth (Gogel, Brune and Inaba, 1954). Also, equidistance tendencies can subtract or add in determining a final equidistance vector. Thus, in the present paper, it is assumed that the equidistance tendency adds a depth factor to any visual field containing more than a single point of light, and that as a depth factor it enters quantitatively in competition or agreement with other depth factors in the determination of a final apparent position of an object in depth.

VIII. Some Unsolved Aspects of the Equidistance Tendency.

It has been reported that the tendency for surfaces slanted in depth to appear in a frontal orientation changes with increasing time of observation (Bergman and Gibson, 1959; Clark, 1953; Simon, 1936; Smith, 1964). It is therefore possible that the strength of the equidistance tendency changes with observation time. In the absence of opposing cue systems, the effect of the equidistance tendency may be rapid. This is suggested by the ability of the equidistance tendency to determine the perceived path of movement of an object attached to the rotating trapezoidal window with the entire display viewed monocularly (Gogel, 1956). The rapidly changing directional alignments in the study with the rotating window required that the effect of the equidistance tendency be rapid in order for it to determine apparent depth. Without opposing cues or tendencies, any amount of equidistance tendency seems to be quickly effective. When other cues of depth are present, possibly the relative effectiveness of the equidistance tendency (relative to that of other cues) increases within some interval of observation time. Additional research is required to clarify the temporal characteristics of the equidistance phenomena both for simultaneous and successive presentations.

Additional aspects of the equidistance tendency should be considered. The notion that the equidistance tendency between two objects is a vector of a particular magnitude would suggest that increasing the number of objects at a constant distance would increase the strength of the equidistance tendency toward this distance. In a similar fashion, the strength of the equidistance tendency between objects might increase with an increase in their visual area. Also, the meaning of the term directional separation requires clarification. Is the significant directional separation to be defined physically, retinally, or perceptually? In most experimental situations, a distinction between the three types of definitions would not need to be made. It is possible, however, to construct experimental situations in which the three types of directional separation are not identical.

IX. Concluding Remarks.

The equidistance tendency may be expected to modify the perception of depth in any situation in which cues to depth are either partially or completely reduced. The effect of the equidistance tendency on any object will depend upon the adequacy of the specific cues that relate this object to the remainder of the visual field. Depth relations in the remainder of the visual field may be clearly perceived. Unless the depth cues relating a particular object to the rest of the visual field are effective, however, the equidistance tendency will modify or determine the apparent depth position of this object. Illustrations have been given of the distortion in perceived depth that can occur in experimental situations as a result of the equidistance tendency. The equidistance tendency might also be expected to influence perceptions in real-life situations. Consider, for example, the perception of the distance to a tall distant object, such as a water tower, whose base is obscured by intervening hills. The tower appears at the distance of the highest hill until this hilltop is reached, at which time it appears at the distance of the next highest elevation. Other examples of the action of this tendency in normal situations are possible. It is clear that the moon illusion is only one of many real-life situations in which the equidistance tendency is involved. It is evident from the present paper that the range of phenomena that can be classified under the equidistance tendency is large and that the perceptual consequences of the equidistance tendency must be considered in a variety of both experimental and naturally occurring situations.

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