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SHAPE CONSTANCY: FUNCTIONAL RELATIONSHIPS AND THEORETICAL FORMULATIONS[1]

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In the 1st section empirical findings concerning shape constancy are reviewed under 10 headings: the occurrence of compromise, conditions of observation, degree of orientation, observation attitude, familiarity and representativeness, differences between forms, individual differences, background effects, effects of movement, exposure time and intensity. The 2nd section deals with several theoretical accounts of shape constancy. The shape-slant invariance hypothesis is evaluated in the light of the experimental evidence and is judged to be equivocal. A line of investigation is proposed which might reconcile the experimental data with the requirements of this hypothesis. The final section of the paper considers the methodological precautions which need to be observed in experimentation on apparent shape and apparent slant.

When a form is projected by light on the retina, the differing orientations of the form with regard to the retina result in a set of different projective shapes. Under most conditions phenomenal shape is less affected by the orientation of the stimulus object with respect to the observer (*O*) than would be expected on the basis of the projective transformations which accompany variations in orientation. The term "shape constancy" has been introduced to designate this fact. Shape constancy is defined usually as the relative constancy of the perceived shape of an object despite variations in its orientation. This definition reflects the prevalent interest in the stability of the perceptual world. However, it is also possible to locate shape constancy within a wider range of events all characterized by a relative independence of perceived shape from retinal, projective shape. With this in mind, the phenomena relevant to this paper can be placed into two main classes:

Class 1. Under certain conditions projective shapes which are discernibly different yield similar perceived shapes.

Class 2. Under certain conditions projective shapes which are identical yield different perceived shapes.

Since Class 2 is mentioned infrequently in the literature, an example is in order. An ellipse with a minor-major axis ratio of 15:20 cm. presented at 45° from the line of regard. will produce the same projective shape as a frontal-parallel ellipse with a 10.7:20 cm. axis ratio or a circle at 15° 13′ from the line of regard. With normal, unimpeded observation, the three stimuli are easily discriminated as being different shapes despite the identity of their projective shapes.

The general plan of this paper is as follows: (*a*) A survey of the empirical findings concerning shape constancy is presented first.[2] (*b*) This is fol-

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[2] A number of publications concerned with shape constancy have been authored by Japanese investigators. Unfortunately, for the present writers, all but a few of these articles have been written in Japanese. However,

lowed by a discussion of several possible explanations of shape constancy with special attention devoted to the shape-slant invariance hypothesis. (*c*) In the final section some methodological considerations regarding the experiments in this area are presented.

Survey of Empirical Findings concerning Shape Constancy

The Occurrence of Compromise

All studies have concurred in the finding that apparent shape does not correspond with the objective dimensions of a slanted standard. Under optimal conditions of observation perceived shape will be intermediate between the objective and projective dimensions of the standard. The term "compromise" was introduced by Thouless (1931a) to describe this result. However, it should be recalled that the term describes only one instance of a more general class of shape perceptions which have the following common characteristic: the dimensions of the perceived shape cannot be precisely predicted from knowledge of either the projective shape or the objective shape. This latter statement takes cognizance of the fact that in some instances apparent shape is not intermediate between the objective and projective shape. On occasion the dimensions of the perceived shape, i.e., the comparison match, exceed the objective dimensions or fall short of the projective dimensions.

Conditions of Observation

Several investigators have shown that shape constancy is diminished by conditions which reduce the availability or effectiveness of perceptual cues to the orientation of the object (e.g., Eissler, 1933; Langdon, 1951, 1953, 1955b; Leibowitz, Bussey, & McGuire, 1957; Nelson & Bartley, 1956; Stavrianos, 1945; Thouless, 1931a; Yensen, 1955). There is some evidence that the effect of eliminating binocular cues on the judgment of shape will vary depending on the angle of inclination at which the standard stimulus is presented (Stavrianos, 1945, p. 55).

Various techniques have been employed for manipulating the availability of cues. Among the earlier methods are the restriction of observation to monocular viewing or squinting, and the gradual narrowing of the field of vision to the stimulus objects alone. A procedure introduced more recently involves the elimination of discernible surface texture.

Degree of Orientation

All of the experiments which have dealt with this variable indicate that the amount of constancy expressed in terms of Brunswik or Thouless ratios, or various other indices, does not remain constant over the arc of slant.

Eissler's (1933) results for six trained *O*s showed that constancy decreased as the angle of rotation from the frontal-parallel plane increased. This finding has also been reported by Sheehan (1938). Eissler also expressed his results in terms of "transformation" or amount of compensation which was given by the formula, $a-p/p$, where "a" is the match chosen by *O* and "p" is the projective shape. Transformation values increased with the angle of orientation.

Lichte (1952) obtained a linear function between the Brunswik ratio and the angle of rotation of the stimulus object from the frontal-parallel

most of these have been reviewed by Akishige (1958, pp. 147–149) in an article written in English and also by Okada (1961). In view of the indirect nature of our acquaintance with this work we have elected to omit these studies from our review.

plane. There was a regular decrease in the ratio with increases in the angle of rotation. This is in agreement with the results cited above. When Lichte replotted his data using the simpler measure, a−p, he found an asymptotic function with increasing angles of rotation. To explain this function Lichte (1952) suggested "that as the cues to the 'non-normal' orientation become stronger, more and more regression takes place, up to a limit set by the nature of the organism" (p. 55). When the present writers computed the quantity, a−p, from the data of other investigators, only one set of results was found which corroborated Lichte's finding. Thouless' (1931a) data indicated that the quantity, a−p, increases with increments in the angle of slant up to 60°, changing little with further increments in slant. Instead of an asymptotic approach to a limit most of the other experiments revealed an increase in the quantity, a−p, followed by a decrease. The results of Nellis (1958) and Leibowitz et al. (1957) showed that the quantity, a−p, increases with increments in the angle of orientation up to 60°–70° and then decreases at more extreme degrees of slant. A plot of Moore's (1938) findings for a 10-inch straight line revealed that a−p increases with increments in slant up to 30° and then decreases for a slant of 35°. A different kind of problem for Lichte is presented by Stavrianos' (1945) data, which indicated that the quantity, a−p, reaches a limit at an angle of 45° under full-cue conditions, but continues to increase with increases in angle of slant up to 55° under reduced-cue conditions. If the limit for full-cue conditions is "set by the nature of the organism," as Lichte claims, why should the value of a−p increase beyond this limit when cues to slant are eliminated?

Some of the confusions which prevail in the investigation of the relationship between shape constancy and angle of slant are exemplified in Lichte's study. Lichte confronted his *O*s with rectangular standard stimuli in the frontal-parallel plane. Each of the four standards was 5 inches high, and varied in width from 4.75 inches to 3.25 inches in .5-inch steps. The variable stimulus was a 5-inch square. The *O* was asked to rotate the variable stimulus "until it appeared equal in shape and width to the standard stimulus" (Lichte, 1952, p. 50). However, in view of the unaltering physical dimensions of the variable it was impossible for *O* to match the standard's physical shape. Nor was it possible to achieve identity of projective or phenomenal shape since any rotation of the variable produced a trapezoidal projective shape whose phenomenal shape may be assumed to have been trapezoidal also. The only alternative left to *O* was to match the apparent width of the turned variable which was phenomenally trapezoidal with the width of the standard which was phenomenally rectangular. This task is not entirely appropriate for a study of shape constancy.

In addition, the finding that the Brunswik ratio decreased with angle of rotation is an artifact of Lichte's peculiar assignment of values. In computing the Brunswik ratio, Lichte used the projective width of the variable setting as p, the objective width of the variable as r (real or physical value), and the objective width of the standard as a. To illustrate the artifactual nature of Lichte's "finding" suppose that the two widths appear equal when the projective width of the variable is 10% less than the projective width of the standard, i.e., a constant error of underestimation occurs. Bearing in mind the nature of the task and the assignment of values, then a reduction in the objective width of the standard will have three consequences: angle of rotation will be increased, the denominator of the Brunswik ratio will increase, and the numerator of the ratio will decrease. This means that the Brunswik ratio must decrease as angle of rotation increases; exactly what Lichte reported. However, this is a mathematico-experimental artifact and not a finding about constancy. A similar objection may be directed to Eissler's finding regarding the amount of compensation and angle of orientation.

The results obtained by Thouless (1931a) and Langdon (1953) are the reverse of those reported by Eissler, Sheehan, and Lichte. The main objective of Langdon's (1953, Experiment II) study was to investigate the presumed changes in constancy over the arc of inclination "under conditions which make it a reasonable assumption that the shape undergoing tilt continues to be perceived as physically unchanged" (p. 93). These conditions were achieved by oscillating the standard circular shape (solid or wire outline) continuously through an arc of 90° and obtaining judgments of shape during the oscillation. The comparison shapes were ellipses (solid shapes or wire outlines) in the frontal-parallel plane representing projections of the circle at various points on the arc of oscillation ranging from frontal-parallel to near the line of regard. The *O*'s task was to indicate when the oscillating circle and the ellipse appeared most similar in shape. The results "show an extremely high constancy toward the line of regard falling to a low point around 60°–50°, rising slightly thereafter and then declining once more as the frontal-parallel plane is approached" (Langdon, 1953, p. 102). Comparable results were obtained in a later experiment (Langdon, 1955b) using new points on the arc of inclination, intermediate between those used in the first study. However, one reservation must be expressed about Langdon's finding. We were unable to determine how Langdon arrived at the Thouless values reported in his papers. The contents of Langdon's Table VI (1955b, p. 25) should be sufficient for this task. Yet there does not seem to be any assignment of these data which will yield the mean values of constancy which are reported by Langdon. Our doubts on this matter are reinforced by the observation that the constancy values reported in an earlier experiment (Langdon, 1953, Experiment I, Table I, p. 95) are in error.

Clouding the picture further are the results of Moore (1938), Stavrianos (1945), and Leibowitz et al. (1957). Moore (1938) found that the Brunswik ratio decreased from .58 to .51 when the angle of slant increased from 20° to 25°. However, there was a decrease of only .03 as the angle was increased in steps of 5°–40°. Brunswik ratios obtained by Stavrianos (1945) for four angles of inclination ranging from 15° to 55° showed that some *O*s exhibited increased constancy with increased tilt while others showed the opposite trend. Stavrianos suggested that "individual differences may be responsible for the discrepancy between the findings of Thouless and those of Eissler with regard to the effect of increasing tilt on shape constancy" (p. 54). Brunswik ratios calculated by the writers from the data presented by Leibowitz et al. (1957, p. 659) showed that for binocular viewing the amount of constancy remained unchanged through five angles of inclination ranging from the frontal-parallel plane to 66° and then decreased as angle of inclination was increased. For monocular viewing the amount of constancy increased with increases in angle of inclination up to 56°, remained unchanged at 66°, and then decreased with further increases in angle. Finally, Nellis' (1958) curves show decreases in constancy as standard ellipses were turned from 30° to 75° from the frontal-parallel plane. However, the same *O*s showed "superconstancy" or "overcompensation" for the segment of the arc from 0° to about 30°. It should be added that Nellis did not treat her data in terms of constancy. Instead, she spoke of "compensation" which was defined as the ratio, log (a/p) (Nellis, 1958, p. 44). It was found that compensation increased as the angle of slant of the standard increased. Comparable findings are reported by Nellis for standard ellipses of different degrees of eccentricity, for slants on the horizontal and vertical axes, and for various slants of the background.

The only conclusion which is warranted by this summary is that the precise function relating constancy to angle of orientation is yet to be determined. It is not surprising that the results of experiments which differ along dimensions whose influence on apparent shape is unknown will fail to agree. In addition, the absence of a standard quantitative expression of constancy makes wide agreement unlikely.

Observation Attitude

Constancy is greatest when *O* assumes an objective attitude and attempts to report the actual physical shape of the standard. Klimpfinger (1933b) found that the adoption of an analytic, retinal-matching attitude may be as effective in reducing constancy as is the elimination of cues of orientation. These findings were confirmed by Gottheil and Bitterman (1951). A study by Angrist is also relevant. Angrist (1954) presented a white disc in a Dodge tachistoscope for .1 second, and asked *O* to judge its shape under instructions "to take the angle of regard . . . into account" (p. 34). She found that these instructions enhanced constancy as compared with earlier uninstructed judgments by the same *O*. However, as Angrist noted, the effects of instructions in her experiment were inextricably confounded with the effects of practice, and therefore her results are equivocal. A recent experiment by Epstein, Bontrager, and Park (1962) found an interaction of attitude with conditions of observation. While different attitudes affected shape constancy under conditions of unrestricted binocular vision, these same observation attitudes were ineffectual when the stimuli were viewed monocularly under reduced conditions. It might also be appropriate to point out that Klimpfinger (1933b) never compared the results obtained for different attitudes under identical conditions, and Gottheil and Bitterman (1951) instructed the *same O*s to assume different attitudes on successive occasions. In the study by Epstein et al., different *O*s were assigned to the different attitudinal conditions while all other conditions remained constant.

Thouless (1932), Sheehan (1938), Nellis (1958), and Leibowitz, Waskow, Loeffler, and Glaser (1959) have provided indirect evidence of the effects of attitude under conditions of unrestricted binocular vision. Nellis (1958) found that 8-year-old and 10-year-old children showed less constancy than adults. She proposed that these differences "reflect attitudes which are predominant at the different ages" (p. 85). However, earlier results reported by Klimpfinger (1933a) are not consistent with

Nellis' findings or interpretation. Klimpfinger found a regular increase in shape constancy from ages 3–14, which falls off rapidly and reaches the 9-year-old level for the adults (18–30 years), and drops to the 8-year-old level for adults 30–37 years of age.

Thouless (1932) and Leibowitz et al. (1959) found an inverse correlation between intelligence and constancy. The latter authors suggested that this relationship is the result of different attitudes adopted by *O*s at the different levels of intelligence. The more intelligent *O*s are assumed to adopt an analytic attitude (resulting in low constancy scores), while the less intelligent *O*s are presumed to adopt an objective attitude.

Familiarity and Representativeness

Geometrical forms often have important properties which cannot be specified physicalistically. Among these properties are familiarity and representativeness. Familiarity is some function of the number of previous exposures of the form. The representational character of the form is determined by the specific meaningful identity which is assigned to it. A nonsense form with an irregular, randomly curved contour is both unfamiliar and nonrepresentational. A regular geometrical form—e.g., a rectangle—is familiar from previous experience but is not necessarily representational. A rectangular playing card is *both* familiar and representational, i.e., it has a specific, meaningful identity.

The influence of familiarity on shape constancy has been studied by Borresen and Lichte (1962), Langdon (1953), Moore (1938), Nelson and Bartley (1956), and Thouless (1931b). Only Borresen and Lichte obtained evidence that constancy is a function of familiarity. In this study the irregular nonsense forms whose shape was to be judged were first familiarized. The familiarization procedure consisted of presenting the forms with varying frequencies at various angles of orientation. The *O*s were instructed to duplicate the shape of the standard when the standard "was considered as an object independent of its slant" (Borresen & Lichte, 1962, p. 94). A control group was not given familiarization training. Judgments of the shape of the five standards were obtained at two angles of orientation. Shape constancy was found to be an increasing function of the frequency with which the shape was presented in the familiarization period. However, the number of orientations presented during familiarization was not a significant determinant of constancy. This latter finding is surprising and should be examined further. We would expect that viewing the standard in various orientations would provide *O* with an index of the perspective transformations which the standard undergoes when displaced from the frontal-parallel plane. Such information should be of value in making shape judgments of the slanted standards. Another aspect of the experiment which warrants further study is the effect of instructions. The instructional injunction quoted above is ambiguous and may be interpreted by *O* as requiring that orientation be disregarded or conversely that orientation be taken into account.

Further evidence which suggests a relationship betwen familiarity and constancy is provided by a study of the apparent shape of afterimages. Ohwaki (1957) has reported evidence that the shape of the afterimage is not an exact representation of the retinal stimulation. Ohwaki's results suggest that the apparent shape may depend also upon *O*'s inspection of the stimulus or *E*'s (experimenter's) verbal description.

Studies of the influence of representativeness have not been reported. However, one experimental approach to this question might follow the lead supplied by McKennell (1960) in his study of apparent size. Under conditions of unrestricted viewing McKennell had *O* make three sets of size judgments: judgments from memory of the sizes of several representational objects, visual estimates of the sizes of the same representational objects, and visual estimates of the sizes of comparable white cardboard squares. The contribution of memory to the visual estimates of each representational object was determined by computing a partial correlation of the form $r_{1,2.3}$; the contribution of visual cues was determined by computing a partial correlation of the form $r_{2,3.1}$. An analagous experiment on apparent shape would involve a correlational analysis of the visual judgments of representational shapes, identical nonrepresentational shapes and estimates of the representational shapes from memory. Precautions would be necessary to assure that the representative and nonrepresentative forms were equivalent in other respects relevant to shape or slant determination, e.g., presence of inner detail.

Differences between Forms

There are some data which suggest that the variable of form interacts with slant in determining the amount of constancy. Thus Beck and Gibson (1955) obtained differences between quadrilaterals and triangles. They found a significantly greater number of exceptions from the required slant-shape relationship for the quadrilateral stimuli. Also Arnoult (1954), in a study of shape discriminations as a function of angular orientation, reported differences between two nonsense (nonrepresentational) forms. Finally, Moore (1938) reported that a slanted circle will show more constancy than a slanted line. However, no systematic study of this factor has been performed.

Individual Differences and Individual Consistency

A number of investigators have rereported the existence of individual differences in constancy (Langdon, 1953, 1955b; Lichte, 1952; Nellis, 1958; Sheehan, 1938; Thouless, 1932). Beveridge (1935–36) has reported racial differences in shape constancy. Among the factors which have been mentioned as influential in producing individual differences are: differences in attitude, shifts in apparent orientation, differences in sensory efficiency, practice effects, etc.

All investigators have agreed in the observation that individual consistency in the degree of shape constancy demonstrated under identical or similar conditions is very high. This finding has been reported by Thouless (1932), Sheehan (1938), Moore (1938), Weber (1939), Lichte (1952), and others.

The Effects of the Background

Several studies have been devoted to the perception of form in an unstructured field. The technique employed was to present the target in an otherwise totally dark room (Langdon, 1953, 1955b; Nelson & Bartley, 1956; Thouless, 1931b). Under these conditions, perceived shape approximates the requirements of retinal shape.

The remaining studies have investigated the effect of special background conditions. In considering these experiments, we have omitted the very effective illusions which demonstrate an influence of the "vector-field" on perceived shape (e.g., Campbell, 1937; Orbison, 1939). These studies are at best of marginal relevance since they deal with the appearance of drawings.

Nellis (1958) has studied the perception of elliptical shapes which were slanted at different angles out of the frontal-parallel plane and mounted on a background which was slanted also. The main finding was that "shape-compensation" log (a/p) decreased progressively with increases in the slant of the background. Nellis reported that the decrease is greater when the standard and background were slanted in the horizontal plane as compared with slants from the vertical plane. In addition it was found that the influence of background slant increased as the angle of slant of the standard increased.

Langdon (1955c) has also investigated the role of the spatial-surround-cues. Pairs of shapes, both stationary and rotating, were matched within a simulated Ames-type distorted room with a rotation of the frontal-parallel plane of 30°. The shapes were of two kinds. The first was calculated for normal (Euclidean) perceptual space, and the second pair was comparable only in apparent space. Langdon found that *O* could match an "ellipse" and a "circle" presented in the windows of a distorted room, when the two stimuli had been constructed in such a way as to be comparable for "equivalent space" (the space of the distorted room). According to Langdon, the ability of *O* to make such a match is evidence that shapes in the distorted room were seen in the dimensions of equivalent space. Langdon further maintained that *O*'s ability to match an equivalent-space ellipse with an equivalent-space *oscillating* circle is evidence that the shape-inducing effects of the distorted room were more powerful than the tendency of movement to restore the true shape of the stimuli. As reasonable as these conclusions may seem, they do not necessarily follow. It is quite possible that *O* can match the shapes of the equivalent-space ellipse and circle in the absence of the shape-inducing effects of the distorted room. Langdon's equivalent-space circle was actually an oblate ellipse, the left side of which is only very slightly wider than the right. As this oblate ellipse rotates clockwise away from the back wall of the distorted room, it projects the image of a prolate ellipse which becomes progressively narrower. Entirely aside from induced effects, we would expect *O*'s perception to be intermediate between the projective shape and the real shape. If the oblate ellipse is slanted far enough away from the frontal-parallel plane, this compromise perception ought to be of an ellipse which appears equal to the comparison ellipse. (Although the comparison ellipse was somewhat egg-shaped, it should be possible for *O* to make a rough match, if for no other reason than that the rotating oblate ellipse was also somewhat egg-shaped, its left side being somewhat longer and narrower than its right—just as was the case for the rotating ellipse.) There is, however, an even stronger reason for believing that Langdon has not demonstrated the shape-inducing effects of the distorted room. Langdon's conclusions rest upon the assumption that the distorted-room effects are so strong that shapes calculated to be comparable in their presence cannot be matched in their absence. If the shape-distorting effects are, in fact, this strong, then it should not be possible in their presence to match shapes calculated for normal perceptual space. Yet Langdon found that *O* can match a normal stationary circle with a normal ellipse in the distorted room.

Movement

As noted above, when all cues stemming from the object and its surrounding field are eliminated, perceived shape approximates projective shape. Under such conditions Langdon (1951, 1955b) has reported that a regular rotatory motion "is sufficient to restore constancy" (1951, p. 157). In a completely dark room Langdon (1951) presented two objects which could be seen by fluorescent coating. The objects were viewed successively with one eye. One object was a circular outline of wire which rotated mechanically on its vertical axis. The other object was one of 15 elliptical outlines which represented various frontal-parallel projections of the circle. The elliptical outline was presented in the frontal-parallel plane. The *O*'s task was to indicate when the rotating circle and the elliptical shape appeared equal. The measure of constancy was the excess angle of orientation over and above that required to produce a frontal-parallel projection equal to the comparison ellipse. Thus if the angular position of the circle was 49° at the time of apparent equality of shape with an ellipse equal to the frontal-parallel projection of a circle at 45°, then the degree of constancy is represented by the fraction 4/45 or .09. In this particular instance the two shapes will have appeared equal when the projective width of the circle is somewhat narrower than the frontal-parallel ellipse. This means that the circular form appears less elliptical, i.e., wider, than its projective requirements; a constancy-effect. Langdon found that constancy measured in this manner rose as a smooth linear function of increases in rotation speed up to an optimal velocity. Langdon's results have been stated in a concise manner by Yensen (1957):

> . . . the angle of inclination at which the subject matches a rotating circle, viewed in dark space, to a given frontal plane ellipse, is greater than the angular match for stationary shapes under the same conditions, and . . . this angle increases with increases in the rate of rotation of the rotating circle (p. 130).

Similar results have been reported by Langdon (1955a) for a specially constructed "solid." The solid was made to undergo progressive physical changes of shape while being compared with various stationary, two-dimensional projections under controlled conditions. Here again, the continuous movement and regular deformation of the shape resulted in more veridical perception.

Langdon sought to explain his results by noting that the stationary and rotating shapes have different "object-characteristics." The stationary shape appears insubstantial while "the intervention of motion . . . operates to 'create' the object as a real and subsisting entity" (Langdon, 1951, p. 164). In a later discussion Langdon (1955b) made a similar point, suggesting that the regular deformation produced by rotation endowed the moving shape with tridimensionality, and that this contributed to an enhancement of constancy. However, it should be noted that Langdon (1951) found that not all *O*s experienced tridimensionality and that differences in this respect did not "appear to affect their matching of the shapes" (p. 162). This observation was repeated in another context (Langdon, 1953, p. 100). In addition, Langdon does not present a clear statement of the reasons for maintaining that constancy should be enhanced when the standard has a solid appearance. A plausible explanation might be formulated on the basis of the considerations presented in Hochberg's (1957) summary of the Cornell Symposium on Perception (see pp. 79–81) and Gibson and Gibson's (1957) work on slant and shape perception as a function of continuous perspective transformation.

Yensen (1957) confirmed Langdon's results. However, he considered Langdon's interpretation of the experimental results to be incorrect. Yensen argued that Langdon's findings should not be interpreted as a restoration of constancy. Yensen's main objection stemmed from his results using as a frontal-parallel stimulus the "real" shape, i.e., a shape identical to the rotating stimulus (4×4 inch square), set in a frontal-parallel position. Yensen found that in this case a rate of increase in angular setting of the rotating square occurred which was highly comparable to the situation in which the match was made to a given frontal-parallel projection of the real shape, i.e., to a shape representing the width of the real shape at some angle of slant. Yensen (1957) reasoned that "constancy factors could not be operative in matches to the 'real' shape and so would not appear to be responsible for the increasing trend in matches to the slanted shape" (p. 131) in Langdon's experiments. Yensen's logic is unclear. The width of the frontal-parallel projection of the square decreases as the square rotates away from the frontal-parallel plane. Constancy means that the square appears wider than its frontal-parallel projection. The greater the constancy, the greater the angle of rotation at which the rotating square appears equal to the stationary square in the frontal-parallel plane. There is no a priori reason why this angle should not increase as the rate of rotation increases. Such an increase would affect mean angular settings by its effect on judgments made when the square is rotating from the line of sight toward the frontal-parallel plane. The greater the constancy, the earlier apparent equality will occur; hence the greater the angle (measured from frontal-parallel) at which *O* will indicate equality.

However, even if we accept Yensen's reasoning the significance of his results regarding the real shape remain open to serious question. There are two main objections: (*a*) The mean frontal-parallel plane projective width of the rotating shape matched to the real shape did *not* differ significantly for the four rates of rotation. Table IV (Yensen, 1957, p. 133) shows that the widths varied from 3.99 inches to 3.97 inches. (The real shape was a 4×4 inch square in the frontal-parallel plane.) Thus at all rates of rotation there obtained an almost identical high degree of constancy. (*b*) There were many differences between Langdon's conditions and those established by Yensen. Most deservant of mention is the fact that while Langdon's frontal-parallel comparisons (ellipses) represented various projective shapes of the rotating standard this was not so in Yensen's study. In Yensen's experiment the frontal-parallel shapes were rectangles; thus they could represent the various projective widths only, but not the projective shapes of the rotating square.

Exposure Time and Intensity

At least two studies (Leibowitz & Bourne, 1956; Leibowitz, Mitchell, & Angrist, 1954) have shown that exposure time may affect perceived shape. As exposure time was reduced from 1.0 seconds to .01 second, constancy was reduced for both a white disc and a half-dollar coin. An exposure of .01 second produced matches which corresponded with the projective shape of the object. Similar results were obtained by Leibowitz and Bourne (1956) for variations in luminance. The reciprocal relation between exposure time and intensity for very short exposure-durations (i.e., Bunsen-Roscoe law) suggests that some of the effect of exposure time might be due to the concomitant variations in intensity. However, Leibowitz and Bourne (1956, p. 280) presented evidence that exposure time has an effect on perceived shape in addition to its relationship to the total stimulus energy. In accounting for their findings the authors surmised that the effects of luminance "may be attributed to the impairment of acuity and intensity discrimination for 'additional' stimuli in the visual field" (Leibowitz &Bourne, 1956, p. 280). The effects of reduction in exposure time are similarly explained. Leibowtiz and Bourne's conclusion is recommended by the fact that the shortest exposure duration and lowest luminance resulted in a high degree of correspondence between judged shape and projective shape. This suggests that the reduction operation diminished the effectiveness of the cues for slant, and not the effectiveness of the projective shape. Had the latter been the case, then great variability would have been observed in *O*'s matches. Indirect empirical support of Leibowitz and Bourne's interpretation may be found in Clark's (1953) study of the influence of exposure time on the perception of slant. With only the retinal gradient of texture density as a stimulus for slant very brief exposures of a surface slanted 37° from the frontal-parallel plane resulted in persistent underestimations of slant. Perceived slant ranged from 8.1° to 14.9°.

Knowledge and Prägnanz as Explanations of Shape Constancy

It has already been shown that there is little direct evidence that prior knowledge influences shape constancy. Here it need be added only that an account in terms of knowledge or assumptions about the stimulus situation would, to paraphrase Koffka (1935, pp. 87–96), on the one hand, explain too much, and on the other hand, explain too little. While introduction of prior knowledge or assumptions might have helped to explain complete veridicality, these factors cannot help predict the percept which is not determined entirely either by the distal or proximal stimulus. In addition, this explanation could not account for the functional relationships described in the previous section.

Representing the opposite theoretical pole, the question might be asked whether shape constancy can be viewed as a product of the principle of Prägnanz, i.e., a presumed tendency to assimilate the slanted standard to a more stable frontal-parallel representation. Perhaps a slanted circle which produces an elliptical projective shape is assimilated to the more stable circular shape thus resulting in constancy. This interpetation conceivably could receive support from the observation that constancy appears to vary for differently shaped forms. However, a more parsimonious explanation of this finding might be made in terms of possible differences in the accuracy of apparent slant for different figures. For example, Clark, Smith, and Rabe (1956b) report findings which show that the slant of circles is more accurately perceived than the slant of rectangles. Stavrianos (1945, Experiment II) also obtained differences in the apparent slant-objective slant relationship for rectangles as compared with ellipses. In any event, sufficient reason for doubting the validity of the Prägnanz hypothesis is provided by a simple experiment performed by Thouless (1931a). The

*O*s judged the shape of an elliptical standard which was so proportioned and so slanted that the retinal projection was that of a circle. Thouless (1931a) reported the following:

> It will be found that not only is there no tendency for phenomenal regression to diminish as perspective shape approaches circularity, but even that under these conditions the index [of phenomenal regression] was greater than with any other perspective shape (p. 347).

However, if a preference for the more stable figure was a critical determinant, no constancy should have been obtained. The *O* should have perceived a circle. A very similar demonstration was reported by Moore (1938) who found that a prolate ellipse slanted to produce a circular projective shape showed as much constancy as a slanted circle.

Invariance Hypothesis

The first explicit formulation of the invariance hypothesis was made by Koffka (1935) in order to explain apparent exceptions to two principles which he believed to be basic to an understanding of perception. (*a*) The first of these principles is that "two proximal stimuli if more than liminally different cannot produce exactly the same effect" (p. 228). This appears to be contradicted by the fact that under certain conditions projective shapes which are discernibly different yield similar perceived shapes. (*b*) The second of Koffka's principles is that proximal stimulus situations which are the same must produce the same perceptual effects. This appears to be contradicted by the fact that under certain conditions projective shapes which are identical yield different perceived shapes. These apparent paradoxes may be resolved by noting that a perception produced by a given proximal stimulus pattern has at least two different aspects, shape and orientation. Gibson (1951) has put it this way:

> Perceiving a surface-form involves perceiving both the slant of the surface and the form of its edges; an impression of form is never obtained without some accompanying impression of the angle at which the surface lies, either frontal or inclined. The problem of shape constancy, so-called, is better formulated as the problem of seeing shape-at-a-slant (p. 405).

What is different in the percepts produced by two different proximal stimulus patterns is the shape-slant combination and not necessarily the shape or slant alone. Thus if two different retinal patterns give rise to the perception of the same shape, it will be a shape perceived at two different degrees of slant. Conversely, what is invariant for a given retinal shape is not a given shape perception but a certain combination of apparent shape and apparent orientation. Thus if the same retinal pattern gives rise to perceptions of two different shapes, the accompanying impressions of slant will be such that the shape-slant relationship is invariant. For example, one percept produced by a given proximal stimulus situation might indicate an underestimation of slant and corresponding underestimation of the length of the foreshortened axis of a slanted shape, while another percept produced by the same proximal stimulus situation would indicate an overestimation of slant and a corresponding overestimation of the foreshortened axis. These considerations have been summarized by Beck and Gibson (1955) in what may be designated as the "shape-slant invariance hypothesis": "A retinal projection of a given form determines a unique relation of apparent shape to apparent slant" (p. 126).

Experimental Evidence concerning the Invariance Hypothesis

The invariance hypothesis implies, that, for a retinal projection of a given form, a reduction in the accuracy of perceived slant will be accompanied by a corresponding reduction in the accuracy of perceived shape. When the slant of an object is correctly perceived, phenomenal shape should correspond most closely to objective shape; if *O* errs in his perception of orientation, this should be accompanied by deviations of phenomenal shape from objective shape. For instance, in an extreme case, a slanted object might appear to *O* to be in the frontal-parallel plane. In this event there should obtain an extreme discrepancy between apparent shape and objective shape; i.e., the apparent shape should approximate closely the retinal projection of the object.

Decreased Constancy Accompanying Reduction of Cues to Slant

A number of studies have shown that shape constancy is diminished by conditions that reduce the availability or effectiveness of cues to orientation.

Monocular Observation. Brunswik ratios calculated by the writers from the data presented by Leibowitz et al. (1957, p. 659) showed that under conditions of tachistoscopic exposure, constancy was consistently lower for monocular than for binocular observation. Similar results for unrestricted viewing time were reported by Thouless (1931a, 1931b), who found that the phenomenal shape of a disc lying on a table top became more elliptical when *O* switched from binocular monocular observation.

Elimination of Cues Provided by the Surroundings. In Thouless' (1931a, 1931b) experiment a high degree of constancy occurred even under the monocular condition because *O* could obtain slant cues from the relationship of the disc to the surface of the table. However, when the setting was darkened so that only the disc was visible, phenomenal shape equaled retinal shape. Using luminous, stationary outline shapes viewed monocularly, Langdon (1951, 1955b) found that the mean constancy value shifted from .153 to less than .02 when cues to slant emanating from the surroundings were eliminated by darkening the experimental room. Constancy values close to zero were obtained by Yensen (1957) for stationary outline rectangles viewed through a reduction tunnel which restricted *O*'s view to the targets.

Elimination or Reduction of Cues Provided by the Gradient of Texture. It has been demonstrated (e.g., Gibson, 1950a, 1950b) that the retinal gradient of texture is a stimulus-correlate for apparent slant. When Langdon (1953) eliminated the gradient of texture by employing as stimuli circular wire outlines in a fully lighted setting, he obtained a relatively low mean constancy value (.153). Yensen (1955, Experiment III) found that the apparent width of a standard slanted square viewed monocularly through a reduction tunnel was greater when the surface of the square had a determinate texture (provided by randomly spaced, black dots on a white background) than when the surface was uniformly white and hence lacked any discernible texture.

Reduction of Exposure Time and Intensity. Leibowitz et al. (1954, 1956) found that the phenomenal shape of a slanted disc progressively approached and finally equaled its projective shape as either exposure time or luminance was reduced. We may presume that this outcome was the result of a progressive elimination of cues for slant.

Slant and Shape Judgments Compared

Because none of the above studies obtained judgments of slant, their findings, as they bear on the invariance hypothesis, are inconclusive. A number of experiments in which *O* made both shape and slant judgments have revealed that conditions which reduce the accuracy of one of these kinds of judgment, e.g., slant, do not necessarily produce a corresponding reduction in the accuracy of the other kind of judgment, e.g., shape.

For purposes of exposition we shall divide the experiments in which both shape and slant judgments were obtained into (*a*) those in which one of the two kinds of judgment is unreliable and (*b*) those in which both kinds of judgment are reliable.

Experiments in Which One of the Compared Judgments is Unreliable. These experiments in turn may be divided into those which contradict the invariance hypothesis and those which support it.

1. Experiments which Contradict the Invariance Hypothesis—One of the earliest investigations (Eissler, 1933) of the shape-slant relationship yielded paradoxical results. The standards were rectangles and ellipses rotated around their vertical axes to deviations of 30° and 60° from frontal-parallel. The comparisons were a series of frontal-parallel shapes which were presented by the method of constant stimuli. After making a series of shape judgments for a given standard, *O* was required to make a verbal judgment of its apparent slant. Shape and slant judgments were made under full-cue and reduction conditions. In accord with the invariance hypothesis, shape constancy decreased as cues to slant were eliminated. A mean Brunswik ratio of .736 for binocular observation decreased to .473 for monocular viewing. A similar reduction in constancy occurred when perspective cues and shadows were eliminated by having *O* observe the stimuli through half-closed eyes or tinted glasses. However, slant judgments did not match shape judgments as required by the invariance hypothesis. In some cases a slanted object was seen as frontal-parallel or as only "slightly turned" and yet with good constancy, and in other cases fairly accurate estimations of orientation were accompanied by low constancy. Similar results were obtained by Klimpfinger (1933a, 1933b).

However, as has been noted by Stavrianos (1945) and Koffka (1935), any conclusions drawn from Eissler's results would be somewhat tenuous because (*a*) the evidence with regard to apparent slant rests on verbal reports made after each series of judgments rather than on quantifiable, contemporaneous judgments; (*b*) cases of accurate slant judgments without constancy were rare; and (*c*) more than a third of the cases of constancy without perception of nonnormal orientation belonged to a one-eyed subject, whose results differed in many ways from those of normal subjects.

Somewhat more reliable findings have emerged from several recent studies. Haan and Bartley (1954) had *O* make binocular observations of three luminous outlines: a circle and two ellipses. These objects were presented one at a time in a totally dark field at a distance of 17$\frac{1}{3}$ feet from *O*. Each outline was oriented at four different degrees of slant ranging from 0° to 67.5° away from vertical. Using a slant-board, *O* was able to reproduce the planes in which the standards lay with a fair degree of accuracy. Nelson and Bartley (1956) reported that the same *O*, in the same experimental situation, produced drawings of the standards which were very similar in shape to their frontal-parallel projections. However, we cannot be sure that these drawings indicate inaccurate shape perception. It is possible that *O* saw each standard as a shape-at-a-slant. When asked to draw this shape, *O* may have attempted to indicate perceived slant by foreshortening, i.e., by using the artist's device of representing slant around the horizontal axis by drawing an ellipse with a shortened vertical axis. This possibility is given substance by the results of an experiment by Clark, Rabe, and Smith (1956a).

Clark et al. (1956a) required *O* to adjust a pivoted rod to match the slant of each of a series of rectangles which were inclined 40° from frontal parallel. Since *O* was limited to monocular vision with head motionless, it is not surprising that the mean perceived slants were much smaller than the objective slant. What is surprising is that verbal judgments indicated that the stimuli appeared to be rectangles rather than trapezoids or any intermediate shape. Equally at odds with the invariance hypothesis were *O*'s drawings of the standards as trapezoids such as would have been projected by rectangles slanted a few degrees more than 40°. The drawings can be reconciled with the verbal reports on the assumption that *O* was trying to indicate slant by foreshortening. In a second experiment employing circular standards and permitting binocular as well as monocular viewing, Clark et al. (1956b) corroborated the paradoxical findings of their earlier study: although mean perceived slants were less than objective slant, all *O*s reported that they saw circles rather than ellipses.

2. Experiments which Support the Invariance Hypothesis—Qualified support for the invariance hypothesis is provided by Beck and Gibson (1955), who found that a nonveridical perception of slant was accompanied by a matching modification in the perception of shape. In order to eliminate all cues to slant except those provided by gradients of background texture, the stimuli were presented at a distance of 7 feet and *O* was limited to monocular vision with the head motionless. The standard was a triangle of indiscernible texture slanted outward from a roughly textured vertical background at an angle of 45°. Verbal reports indicated that all *O*s saw the triangle as being in the same plane as its background. Shape judgments were obtained by having *O* match the standard triangle with one of two comparison triangles mounted flat on the same background. One comparison had the same objective shape as the standard, while the other had the shape the standard would have if projected on the background. As required by the invariance hypothesis, all *O*s matched the standard with the comparison whose shape was its frontal-parallel projection. When stimulation for the slant of the standard was introduced by permitting binocular vision, there was an expected shift to the comparison which was objectively equal. Nevertheless, the projectively equal comparison continued to be selected in 23% of the cases. In several of the latter instances *O*s were asked to reproduce the slant of the standard by adjusting a vertical plate. Since they were able to do so with some accuracy, it is evident that their nonveridical shape matches constitute an exception to the invariance hypothesis. Beck and Gibson's findings failed to support a precise statement of the invariance hypoth-

esis. The results indicated only that there was a tendency to an invariant shape-slant relationship.

Epstein, Bontrager, and Park (1962) extended the Beck and Gibson experiment by presenting the background at 3° of slant and employing a comparison stimulus whose shape could be continuously varied. A more adequate measure of apparent slant was obtained by having each *O* rotate a circular disc to the same slant as the triangular target. For both moncular and binocular observation, the results showed less adherence to the invariance hypothesis than did the results of Beck and Gibson. This may be attributed to the fact that Beck and Gibson forced *O* to choose between one of two extreme alternatives, i.e., objective or projective. Faced with such a choice, *O* may have selected the comparison object which was most like the apparent shape although neither comparison stimulus was judged to be the same as the standard. In the experiment by Epstein et al. the continuously variable comparison enabled *O* to make more sensitive discriminations.

Additional evidence of a loose linkage between apparent shape and apparent slant was reported by Yensen (1955). In one study Yensen (1955, Experiment II) found that for the same actual slant the apparent width of a standard square was significantly greater when the standard appeared at a greater angle of slant than when it appeared at a lesser angle of slant (as a result of restricting observation to monocular viewing under low illumination). However, the confirmation of the invariance hypothesis must be qualified by the fact that some *O*s who reported the standard at 0° showed some degree of constancy, nevertheless.

With the exception of the experiment by Epstein et al. (1962), all the experiments summarized above suffer from the unreliability of either the shape or the slant judgment; one or the other judgment was obtained from a drawing or a verbal report or by means of a forced-choice technique.

Experiments in Which Reliable Judgments of Shape and Slant Were Obtained. Reliable judgments of both shape and slant under the same experimental conditions were obtained originally by Stavrianos (1945). In Stavrianos' first experiment, two standard rectangles were presented at four angles of inclination under three reduction conditions: normal binocular vision, binocular vision with reduction tubes, and monocular vision with reduction tubes. The *O*'s task was first to adjust the slant of a comparison rectangle (of different dimensions than the standard) until its slant appeared equal to that of the standard. Then, under "objective" instructions, *O* adjusted the shape of a frontal-parallel trapezoid of fixed base (different from that of the standard) until it appeared to be the same shape as the standard. The slant and shape variable stimuli were always viewed with full binocular vision. The results failed to support the invariance hypothesis.

1. For separate pairs of shape and slant judgments there was not a close relation between the deviations from the mean of slant judgments and the deviations from the mean of shape judgments.

2. A comparison of mean constant errors for shape and slant judgments failed to reveal the expected concomitant variation: (*a*) As depth cues were eliminated, there was an increasing underestimation of the slant of the standard, but the accuracy of shape judgments did not decrease. (*b*) Although significantly larger underestimations of slant occurred at intermediate angles of inclination of the standard, there was no general

tendency for underestimation of the foreshortened dimension of the standard to occur at those angles.

3. Variability in slant judgments was greater under the monocular conditions as compared to the normal condition, and this difference increased as angle of inclination from frontal-parallel increased. However, no consistent trends with regard to variability were evident for shape.

In Preliminary Experiments B and C, Stavrianos had found a constant error in shape and slant judgments which could be attributed to the inequality of the absolute size of the standard and the variable. When the data of Experiment I were corrected for these constant errors, the expected relationship between apparent shape and apparent slant was found for some *O*s for the monocular condition. In order to provide additional information about the shape-slant relationship under monocular conditions, a larger number of monocular judgments was obtained in Experiment II which differed from Experiment I chiefly in that ellipses as well as rectangles served as standards. When applied to the results of Experiment II only one of the methods of data analysis described above yielded support for the invariance hypothesis: for three of the five *O*s, the increased underestimation of slant which occurred at intermediate angles of inclination was accompanied by decreased constancy of shape.

Stavrianos explained her failure to obtain a precise relation between apparent shape and apparent slant on the grounds that slant judgments made under the conditions of her first two experiments did not accurately represent the slant registered by the observer when he made his shape judgments. "The perception of both tilt and shape when they are merely registered as background or as incidental parts of the total percept may differ from their perception when they occupy the observer's close attention" (Stavrianos, 1945, p. 72). The tendency for the predicted relationship between judgments of shape and slant to appear under the monocular condition may indicate that under that condition the observer found it necessary to focus more attention on slant when making explicit judgments of shape and more attention on shape when making explicit judgments of slant. Introspective reports indicated that this was, in fact, the case.

In the hope that a less complicated way of reporting shape perception would increase the similarity between the explicit judgment of shape and the registration of shape which occurred when slant was judged, Stavrianos performed a third experiment. In Experiment III the requirement of comparing shapes seen in two different fields was eliminated. The *O* made judgments of shape by selecting a square from a series of stimulus forms varying from rectangles taller than wide to rectangles shorter than wide. These stimulus forms were mounted together on a rectangular background, the slant of which *O* was required to match by adjusting the slant of a comparison rectangle. The results failed to support the hypothesis of a precise shape-slant relationship, although errors in slant adjustments were accompanied by approximately matching errors in shape judgments for some *O*s.

It is possible that even in Stavrianos' third experiment, the explicit judgment of shape was not the same as the implicit registration of shape which occurred when *O* judged the slant of the standard. It may be that the invariance hypothesis does not apply to experimental situations in which shape and slant are judged separately.

Attempts to Deal with the Problem of Explicit Judgment versus Implicit Registration

Beck and Gibson (1955, Experiment I) attempted to test the invariance hypothesis without requiring *O* to make separate judgments of shape and slant. The *O* made his match simply by selecting a comparison stimulus from a series of differently proportioned targets which were also slanted differently. Thus the judgments of slant and shape were "implicit in the same act of matching the standard object" (Beck & Gibson, 1955, p. 128). As standards, Beck and Gibson employed textureless, luminous shapes viewed monocularly, with motionless head, so that stimuli for slant were effectively eliminated. Comparison shapes were presented together on a single panel viewed under full-cue conditions. Each set of comparison objects included a number of shape-and-slant combinations which were projectively equal to the standard and a number of combinations which were not projectively equal. Beck and Gibson assumed that the invariance hypothesis would be supported by the choice of the former shape-slant combinations and contradicted by the choice of the latter. Between 82% and 92% of the matches were projectively equal to the standards. However, these results are somewhat equivocal since the choice of comparison shapes which are projectively equal to the standard gives no evidence that the observer was in any way registering or taking into account the slant of the comparison. He might have been matching projective shapes. In addition, choices of comparisons which were *not* projectively equal to the standard may be in accord with the invariance hypothesis. For example, *O* may have overestimated the slant of the comparison shapes, and hence he may have chosen a shape with a shorter vertical axis than that required to give the same retinal projection as the standard. Furthermore, choices of comparisons which are projectively equal to the standard may involve a contradiction to the invariance hypothesis. For example, *O* may have overestimated the slants and yet underestimated the vertical axes of the slanted shapes.

Essentially the same kind of objections apply to the attempts by Langdon (1953, 1955b) to avoid the problem of the relation between implicit registration and explicit judgment of slant. According to Langdon, the assumption of an invariant relation between shape and slant carries the implication that constancy is either constant throughout the arc of slant or varies as a simple function of the angle of slant. Thus it should be possible to test the invariance hypothesis without concerning oneself with slant judgments at all. One need only obtain shape judgments at a number of angles of orientation. When Langdon obtained such judgments for an oscillating circle as a stimulus, he found irregular variations of constancy over the arc of slant. Repeated findings of such irregularities in the relationship between constancy and angle of slant led Langdon to the conclusion that the development of any simple invariant shape-slant formula is improbable. However, Langdon has overlooked the possibility that the relationship between apparent shape and apparent slant may be simple while the relationship between actual slant and apparent slant may be complex. If Langdon were to measure apparent slant, he might find that it varies concomitantly with the irregular variations in apparent shape. We must conclude that until an adequate technique is developed for obtaining simultaneous slant and shape judgments, studies obtaining explicit judgments of shape and slant remain the most acceptable source of evidence regarding the invariance hypothesis.

Concluding Remarks about the Invariance Hypothesis

The review which has been completed above revealed that the invariance hypothesis rests on a precarious evidential base. Attempts to provide experimental confirmation of a precise relationship between apparent slant and shape have been unsuccessful. In addition, the force of the evidence which indicates a less rigid, general shape-slant relationship is mitigated by the experimental results which contraindicate the assumption that this relationship obtains.

Another consideration relates to the sufficiency of the invariance hypothesis as a basis for predicting perceived shape. It would seem that the adequacy of the hypothesis depends on the possibility that the various factors whose influence on shape constancy has been demonstrated may be shown to affect perceived slant. Only if these factors can be demonstrated to exert their influence on shape perception by determining apparent slant can they then be incorporated readily into the invariance hypothesis. If their influence is not channeled in this way, then they must be given independent status outside the shape-slant hypothesis. No systematic work on this question has been performed.

The effects of angle of orientation on shape constancy may serve to clarify this consideration. As has been previously noted, any variation in constancy over the arc of slant appears to pose a serious problem for Koffka's theory since the invariant relation implies that the amount of constancy remain the same throughout the arc of slant. Koffka (1935, pp. 233–234) commenting on Eissler's (1933) results attempted to explain these variations by referring to the actions of "internal" and "external forces." The former is a force set up by the "nonnormal orientation" of the stimulus; and it tends to reduce the apparent slant, thus encouraging constancy. This internal force does not increase in proportion to the angle of orientation. The distorted retinal image produces an external force which is assumed to increase more rapidly than the angle of orientation. Since the external forces become stronger than the internal forces as the angle of orientation increases, constancy should decline with the increasing angle. Koffka's interpretation has been criticized by Langdon (1953) on several points. Here we may note also, that regardless of the applicability of Koffka's reasoning to Eissler's findings, there would still remain the task of explaining the results reported by other investigators regarding this relationship.

However, an alternate explanation of the influence of orientation angle might be introduced which would be consistent with the invariance hypothesis. Perhaps the changes in constancy can be ascribed to shifts in the accuracy of slant perception as the angle of orientation increases. If the angle of orientation is progressively underestimated with increments in orientation, then the obtained decreases (e.g., Eissler, 1933) in constancy would be expected. Conversely, a consistent trend toward increasing accuracy of perception of slant with increasing objective slant would account for increasing constancy with increasing slant. Of course a linear relationship between the degree of accuracy and objective slant could not account either for the results showing changes in constancy over part of the range of slant only or the findings of irregular variations of constancy.

There is some evidence (Smith, 1956; Stavrianos, 1945) which can be brought to bear on this interpretation. Smith's experiment can serve as an illustration. Smith presented rectangular and circular stimuli at one of 6° of slant ranging in steps of 10° from 0° to 50° with only the gradients of outline convergence and distortion as stimuli for slant. At all angles the mean perceived slant was much less than the objective slants. However "for each condition, the percentage of error in perception, i.e., the difference between the actual and perceived slant, decreased regularly as the angle of slant increased for angles greater than zero" (Smith, 1956, p. 214). Other experiments which examined the relationship between perceived slant and objective slant over the full range of slant and under various conditions of observation might reveal that different apparent-objective slant relationships obtain under different conditions. Data of this sort would have implications for the invariance hypothesis, and might clarify the presently contradictory results regarding the effects of angle of slant on degree of constancy.

Evaluation of the Experimental Methodology

An analysis of the experimental procedures which have been used in studying shape constancy and the shape-slant relationship suggests the need for considerable improvement. The following points deserve to be noted:

1. Many of the investigations failed to obtain information concering the perceived slant of the targets. Nor were conditions created which would allow the experimenter to make a reliable assumption about the phenomenal orientation of the stimuli.

2. Crude response measures were often employed. Thus Thouless (1931) and Nelson and Bartley (1956) asked *O* to draw the apparent shape of the target. In addition to the obvious ambiguities which are inherent in the drawing response, e.g., differences between *O*s in ability to draw what is seen, there is another flaw in the procedure which is peculiar to the shape constancy situation. Suppose *O* is shown a circle slanted from the frontal-parallel plane on its horizontal axis and he is instructed to draw what he sees. If normal conditions of observation prevail, and the angle of slant is not too great, *O* will probably see a circle *which is slanted.* How is *O* to represent this percept in his drawing? Many *O*s will attempt a crude perspective representation and draw an ellipse with an elongated horizontal axis. If the experimenter accepts this product without further inquiry, he will conclude erroneously that constancy is incomplete. This shortcoming of the drawing as an indicator of perceived shape may be stated more generally: an unambiguous representation of perceived shape-at-a-slant is difficult to obtain.

Another illustration of an inadequate response measure is Beck and Gibson's (1955, Experiments II and III) forced-choice technique. The *O* must choose either the comparison which meets the projective requirements or the one which satisfies the objective requirements. In this case, the results may be only a misleading artifact of the technique. The *O* may choose the comparison which is *most like* the apparent shape although *neither* comparison stimulus is judged to be the same shape as the standard. Lacking the opportunity of making sensitive discriminations in the response system, *O* gives results which may be interpreted erroneously as the absence of differentiation in the perceptual system. The same problem may arise when complete reliance is placed on *O*'s verbal designation. In this case minor differences in apparent shape may be assimilated into undifferentiated broader language categories, e.g., the category of circles which may include slightly eccentric ellipses.

3. On occasion the range of comparison stimuli was not sufficiently broad. No allowance was made for exaggeration of objective shape or overstatement of projective shape. Also, as Gottheil and Bitterman (1951) point out, often no provision was made for perfect constancy. Thus, if the standard is a slanted circle and the comparison series is comprised of a set of ellipses, it may be possible to make a perfect projective match; but it is impossible to make a perfect objective match. Along these lines is the case in which *O*'s efforts to match the comparison to the standard along one dimension, e.g., width, requires that the comparison assume a phenomenal shape different from the standard (Lichte, 1952; Yensen, 1957). Under these conditions *O* is confronted needlessly with a conflict between the tendency toward a match representing phenomenal equality of shape and the performance required by the experimenter.

4. Several investigators failed to specify the instructions which were given to *O*. As a result, it is not always possible to compare the findings of different experiments with confidence that the *O*s were actually performing the same task. In addition, the instructions supplied by some experimenters were vague and did not make clear to *O* which of the several possible matches was desired. In these instances, it is possible, that different *O*s were matching for different aspects of shape, and also that the same *O* was not consistent on the several trials or under the several conditions for which he was tested. The results of Joynson's (1958a, 1958b) studies of perceived size and Joynson and Newson's (1962) study of perceived shape show that these concerns are justified. Joynson and Newson gave their *O*s instructions which were intentionally vague. The *O*s were told to select from a series of comparison triangles "the one that looks most like the one you are going to see" (Joynson & Newson, 1962, p. 3). The *O*s responded in various ways. Type R *O*s (62%) made no distinction between objective and nonobjective (phenomenal or projective) equality and tried to match for "the real shape." These *O*s produced matches which were close to objective equality regardless of the inclination. Type RN *O*s (38%) were spontaneously aware of the different possible interpretations of the instructions, i.e., objective or nonobjective. The frequency with which these *O*s made nonobjective judgments (phenomenal or analytic) increased as the angle of inclination increased. When a nonobjective interpretation was assigned to the instructions *O* disregarded the slant and typically produced "compromise" judgments. However, Type RN *O*s who matched for objective equality showed an even higher degree of constancy than the Type R *O*s. This occurred because the Type RN *O*s were more deliberate in taking the inclination into account.

5. Experiments differ from each other along dimensions whose effect on apparent shape has in most cases not been subjected to independent systematic investigation. These uncontrolled and unassessed differences create difficulties in interexperiment

comparisons. Some of the procedural differences were these:

a. In some studies (e.g., Angrist, 1954; Eissler, 1933; Klimpfinger, 1933a, 1933b; Leibowitz & Bourne, 1956; Leibowitz et al., 1957; Sheehan, 1938; Thouless, 1931) the standard shape was slanted and was to be matched by a frontal-parallel comparison shape. Other experimenters (e.g., Langdon, 1951, 1953; Lichte, 1952; Yensen, 1957) presented the standard in the frontal-parallel plane to be matched by a comparison stimulus at a particular slant.

b. Different means of producing the slant of the slanted stimulus have been employed. Most important is the fact that in some cases the stimulus object was rotated about its horizontal axis (e.g., Moore, 1938; Stavrianos, 1945) and in other cases along its vertical axis (e.g., Langdon, 1951, 1953; Lichte, 1952). Muto's (1954) and Nellis' (1958) findings showed that this apparently trivial procedural aspect may be important.

c. The distance of the stimulus objects from *O* ranged from 75 cm. to 6 m. Some evidence that the distance of the target may be important was reported by Langdon (1953) and Gruber and Clark (1956). The latter investigators found that as distance increased, perceived slant decreased.

d. The size of the similarly shaped test objects employed by different investigators has varied considerably. The possible confoundings which may result from inattention to this variable are suggested by Stavrianos' (1945) finding that the relative amount of the vertical horizontal illusion decreases as the horizontal extent of the stimulus form increases. In addition, Stavrianos found that the mean estimated tilt for a large rectangle (180×250 mm.) was greater than that of a small rectangle (80×150 mm.). Both of these by-products of the size of the stimulus will influence apparent shape.

e. In several cases (e.g., Beck & Gibson, 1955; Epstein et al., 1962; Stravianos, 1945) *O* was able to view both the standard and the comparison simultaneously. In other experiments the situation was arranged to make simultaneous observation impossible. This was accomplished by separating the stimuli by a sufficient enclosed angle (e.g., Langdon, 1951) or by presenting the stimuli successively (e.g., Leibowitz et al., 1954). Fragmentary evidence reported by Moore (1938) and by Joynson and Newson (1962) suggests that these conditions may lead to differences in the amount of constancy.

6. Different quantitative measures of constancy were used. Therefore, it is misleading to compare the results of different investigators simply in terms of "amount of constancy." An advance toward a systematic analysis of shape constancy would be achieved if a single measure were agreed upon. Of those which have been employed, the Thouless-Brunswik formulae seem to have little to recommend them. In addition to the objections which Koffka (1935, pp. 226–227) and Brunswik (1940) have raised, there are the following restrictions on the usefulness of these formulae.

The application of the formula is restricted to the case in which the comparison stimulus is in the frontal-parallel plane. It is only in this case that the value for the apparent shape, i.e., *a*, can be assigned safely. In the case of a comparison which is slanted also, the assignment becomes problematical. The value may be designated by the objective dimensions of the match, but it also may be designated by the projective dimensions of the match. An uncritical decision in favor of the former implicity *assumes* the validity of the shape-slant hypothesis and shape constancy. If the projective dimensions are selected, then the perplexing circumstance is created in which a perfect objective match will yield less than 100% constancy.

An implicit assumption underlying the use of the formula is that a shape viewed normally in the frontal-parallel plane will be perceived veridically. However, in this special case where $r=p$ the use of the Thouless-Brunswik ratio to express the outcome can be misleading. Thus, a perfect match would yield a ratio equal to zero, and only matches which exceeded the objective dimensions of the standard would yield positive values falling between 0 and 1.0.

One alternative would be to express constancy as the amount of compensation (Nellis, 1958). The degree of compensation is the ratio of the dimensions of the shape chosen to match the standard to the projective dimensions of the standard. This may be written as a/p, or, if one prefers, log (a/p). This formula is not subject to Koffka's criticisms concerning restriction of range and constancy values beyond unity. Nor is it inapplicable in the special case where $r=p$ since a logrithm of 0 indicates that the organism has done no work, i.e., has not compensated for any difference between a and p. However, it does suffer from the first of the two restrictions noted above.

Conclusion

The perceptual constances have played an important role in the development of perceptual theory. They have served the purposes of diverse and opposed theoretical formulations. Despite this prominence there is surprisingly little in the way of well established functional relationships in this area. With the possible exception of size constancy theoretical speculation has far outdistanced (or disregarded) the experimental evidence. An illustration of this state of affairs is to be observed with regard to the constancy of shape. The only remedy for this condition is more experimentation with the aim of identifying the determinants of shape constancy and describing their interaction. Hopefully, a theory formulated on this basis will be more adequate to the tasks which are required of it.

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