Psychological Bulletin
1964, Vol. 62, No. 3, 180–196

EXAMINATION OF GIBSON'S PSYCHOPHYSICAL HYPOTHESIS[1]

WILLIAM EPSTEIN AND JOHN PARK
University of Kansas

The experimental evidence regarding Gibson's psychophysical hypothesis is examined. The presentation is divided into 2 sections dealing with static and transforming stimulation, respectively. Under the former heading the stimulation for surface, slant, and depth is considered. Under the latter heading the investigations of motion perspective, continuous perspective transformations, and size-transformations are examined. 2 general conclusions emerged from this examination: the psychophysical hypothesis has not been unequivocally confirmed and Gibson's theory requires revision to make explicit several recurrent implicit premises.

One of the major contemporary theoretical accounts of perception is Gibson's (1950b, 1959, 1963) psychophysical theory. Unlike other theories, for example, Gestalt and transactionalism, Gibson has attempted to develop a S-R account of perception; one which does not introduce intervening variables such as sensory organization or neo-Helmholtzian assumptive worlds. The central proposition of Gibson's (1959) theory is the generalized psychophysical hypothesis:

> for every aspect or property of the phenomenal world of an individual in contact with his environment, however subtle, there is a variable of the energy flux at his receptors, however complex, with which the phenomenal property would correspond if a psychophysical experiment could be performed [p. 465].

The objective of this paper is to evaluate the evidence for this hypothesis.

The similarity between Gibson's hypothesis and the older discredited constancy hypothesis is evident. Gibson's hypothesis, however, is less vulnerable. Unlike the earlier hypothesis, Gibson's position does not presume a picture theory of the proximal-perceptual relation. Gibson requires retinal correlates, not retinal replicas. A more important source of strength is Gibson's conceptualization of the stimulus. In the earlier view the stimulus was a static, nonchanging, local correspondent of the distal source. As long as this view prevailed it was a simple matter to contradict the constancy hypothesis by demonstrating the equivocality of the distal-proximal and proximal-perceptual relationships (Koffka, 1935, pp. 75–105). This type of critical analysis is not so readily applicable when Gibson's (1959, 1960) view of the stimulus is taken into account. In Gibson's (1959) view the effective stimulation for perception must be sought "in a textured optical array, supplemented by the transformations relating a simultaneous pair of them, and by the transformations relating a sequence of momentary arrays [p. 474]." The stimulus is ordinal—a pattern or gradient of stimulation. The order may be sequential as well as spatial. Sequential ordinal stimulation refers to the lawful transformations of stimulation which occur when either the subject or the object is in

[1] This article was written with the support of Research Grant MH 04153-04 to the first author by the National Institute of Mental Health of the United States Public Health Service.

motion. It is important to note that in Gibson's view (see especially 1957 and Gibson & Gibson, 1957) the change in stimulation is a stimulus to which the subject can respond. On other occasions, the subject may respond to the aspect of stimulation which remains invariant in the flux of stimulus transformations. The invariants uniquely specify the source of stimulation, and the perceptual apparatus is geared to extract these invariants, thereby achieving veridical perception. Thus, in Gibson's view, stimulation undergoing change is more informative than static stimulation since an instance of static nontransformation can rarely specify its source. Gibson's conceptualization of stimulation provides him with the grounds for rejecting the frequent assertion that the distal-proximal and proximal-perceptual relationships are fundamentally ambiguous. Once this assertion can be denied the way is opened for a retinal account of perception.

In one sense the greater portion of all experimentation on perception could be considered to have bearing on Gibson's hypothesis. However, our treatment will be restricted mainly to those studies having the following two characteristics: (*a*) The main objective of the experiment was to examine psychophysical correspondence. (*b*) The experiment has sought to manipulate the type of visual input, that is, optic array, which Gibson has stressed. For this reason we have excluded discussion of other studies which might be considered relevant, for example, the work reviewed by Epstein, Park, and Casey (1961) and Epstein and Park (1963). The discussion will be divided into two parts, dealing with static and transforming stimulation, respectively.

Psychophysical Correspondence under Conditions of Static, Nontransforming Stimulation

This section will review the experimental studies of the perception of surface, slant, and distance.

Stimulation for the Perception of Surface

"According to what will here be called the *texture-hypothesis,* the stimulus for a visual surface is a fully differentiated, sharp, or textured retinal image [Gibson & Dibble, 1952, p. 414]." Evidence for this hypothesis is adduced by Gibson from a series of experiments with the *Ganzfeld.* In an experiment similar to Metzger's (1930) prototypal research, Gibson and Dibble (1952) seated the subject before a gray wall of coarse-textured plasterboard which filled nearly the entire visual field. With full illumination, the wall appeared surfacelike and visibly textured. As the illumination of the wall was gradually reduced, the texture vanished, and the impression of hardness was replaced by that of a fog. In a similar manner the impression of surface vanished when Gibson and Waddell (1952) produced homogeneous visual stimulation by means of translucent eyecaps. These results are in accord with the findings of other investigators (Cohen, 1957; Hochberg, Triebel, & Seaman, 1951; Metzger, 1930) and appear to support the hypothesis that the perceived hardness of a surface is related to the steepness of the gradients of luminous intensity in the retinal image.

While it appears reasonably certain that texture is sufficient for the perception of a surface, there is evidence that it is not necessary. Gibson and Dibble (1952) found that a homogeneous textureless surface viewed through a small aperture appeared to be a hard surface in the plane of the reduction screen rather than a film in the aperture. The authors suggest that the effective stimulus may have been the steep intensity gradient at the contour. Cohen (1957) found that a steep gradient of intensity between a homogeneous disc and a homogeneous field produced the impression of a figure having a hard surface and lying on a foggy ground.

Stimulation for the Perception of Slant

Gibson (1950a) proposed that "slant at any point may be given by the rate of increase of density of the texture at that point [p. 371]." This hypothesis has had to be revised in the face of evidence that rate of increase of texture density is not a sufficient stimulus for the veridical perception of slant. Since a gradient of texture density merely specifies a family of tridimensional arrangements, it is understandable that the corresponding percept may be variable. In addition, slant is generally underestimated when texture gradient is the chief or only cue.

Underestimation has been found by Gibson (1950a), Gruber and Clark (1956), and Clark, Smith, and Rabe (1956). The stimuli were textured surfaces presented at several degrees of slant, or projections of lantern slides made by photographing textures at several slants. The textures employed were various: bricklike, mottled, or composed of irregular light dots on dark grounds. Outline perspective, binocular cues, and motion parallax were eliminated. Perceived slant increased as the steepness of texture gradient increased. Hence it was concluded that a retinal gradient of texture density can, in isolation from other factors, determine perceived slant. Nevertheless, slant was underestimated (see Gruber & Clark, 1956). Although the amount of underestimation was considerably less, some underestimation occurred even for regular textures consisting of repeated evenly-distributed elements with linear perspective and familiar shape. These results may have been caused in part by the tendency of perception to conform to the slant of the reduction screen.

These experiments failed to observe the distinction between optical slant and geographical slant. Optical slant is dependent only on the geometrical relation of a surface to the eye, whereas geographical slant is dependent on the relation of the surface to other parts of the world or to gravity. By creating an incongruency between the reference-axes of the eye itself and the reference-axes of their experimental room, Gibson and Cornsweet (1952) produced a situation in which the two kinds of slant could be perceived separately. The subject's head was rotated 45 degrees to the left around its vertical axis and set at a 45-degree angle to the walls of the room. The subjects were able to determine accurately the point at which a rotating textured surface reached each of two normal positions: perpendicular to the line of sight (a judgment of optical slant) or parallel to the walls of the room (a judgment of geographical slant). The results indicate that the two kinds of slant can be perceived independently, and that optical slant corresponds to the gradient of density of texture at the fovea, while geographical slant does not.

Gibson, Purdy, and Lawrence (1955) investigated the role of texture density by means of an optical tunnel, a device composed of a set of plastic sheets, alternately black and white, with circular apertures, set one behind the other so as to project onto the retina a set of concentric rings of alternating high and low intensity. When subjects with motionless heads and monocular vision viewed a tunnel having a zero gradient of density, they reported seeing something ambiguous, something which fluctuated between flat and deep. When subjects were given another presentation of this same pseudotunnel using both eyes and a third presentation using both eyes without a biting board, they reported a surface with extended depth which approached the actual depth of the pseudotunnel. When the peripheral-to-central gradient of disparity was reversed by a pseudoscope, the subjects saw a striped, convex, truncated cone protruding from a background. It appears that an unambiguous appearance of slant results from a zero gradient of density only when it is supplemented by some other stimulus such as a gradient of disparity or deformation. Gibson, Purdy, and Lawrence (1955) concluded that a gradient of texture density cannot by itself compel a perception of corresponding slant because the gradient merely specifies a family of tridimensional arrangements rather than a particular distal stimulus situation. For example, a gradient of increasing texture density may be produced either by a slanted surface having equal-sized elements at constant distances from one another or by a frontal-parallel surface having elements with progressively diminishing sizes and separations. What a given gradient of density determines, according to Gibson, is "a relationship between apparent slant and apparent spacing of texture elements [Gibson et al., 1955, p. 12]."

What little evidence there is regarding this hypothesis comes from an experiment by Beck (1960). He presented a set of optical tunnels which had constant-sized apertures and elements unevenly spaced so as to duplicate the increasing (or decreasing) density gradients which would be present in the cross sections of rays projected by equally-striped, tapered tunnels (or cones) converging to various angles. With fixed monocular vision, these texture gradients produced impressions of noncylindrical tapered objects. However, these impressions were quite variable. Hence it appears that a texture gradient in isolation is able to produce a complex impression of slant and recession, but it is not able to uniquely determine slant and recession. A particular impression of slant and recession presupposed "a presumption, attitude, or expectation," for example, that the stripes along the surface of the pseudotunnel were spaced equally. A linkage between apparent slant and apparent texture-spacing is indicated by the fact that adding binocular parallax resulted in a change of subjects' judgments from an equally striped, tapered tunnel to an unequally striped, parallel tunnel. However, some exceptions were found to the proposed linkage between apparent slant and apparent texture-spacing. Beck also found that the introduction of binocular disparity did not always eliminate the ambiguity of fixed monocular vision.

That texture gradient is not adequate as a cue to slant is also confirmed by Smith and Smith (1957), who required subjects to make judgments of the degree of curvature of a perfect semicylinder with a textured surface and hidden ends. Under monocular conditions the mean judgments were nearly flat. This result was explained by the authors as due to the tendency to see the display in the plane of the aperture. It may also be noted that form and size constancy were placed in opposition to the texture gradient because the texture was composed of dots of different sizes and shapes (circular and elliptical). Greater curvature was seen with binocular vision for all textures.

The curvature of a semicylinder was also judged in a further study by Smith and Smith (1961), who presented singly and in combination a large number of cues to slant: linear perspective, light and shade, texture gradient, form transformations, monocular movement parallax, binocular disparity, and interposition. When the edges of the cylinder were obscured, all these cues in combination were not sufficient for veridical judgments. "These results indicate that the gradient theory . . . may be . . . psychologically insufficient for accounting for veridical perceptions of slant in all situations [Smith & Smith, 1961, p. 147]." It is clear that the availability of a set of variables, for example, a combination of binocular disparity, texture gradient, and motion parallax, which uniquely specifies the source, does not insure veridical perception. The fact that perceptions were veridical when the edges of the cylinder were shown may indicate that recognition of a familiar object (a cylinder) was important.

According to Gibson (1951) outline figures produce ambiguous percepts. Because a given retinal shape may be produced by an indefinite number of forms at appropriate orientations, it seems logical that simple retinal form-stimulation should elicit unstable percepts in the absence of other cues. Gibson maintains that texture gradient is necessary for the reliable perception of slant, even though it is not sufficient. Contrary to Gibson's view, experiments by A. H. Smith and his associates indicate that an adequate stimulus for perceived slant is the retinal gradient of outline convergence. Clark, Smith, and Rabe (1955) limited the subject to monocular vision, with motionless head, and required him to judge the slants of outline forms which were presented in succession and at relatively great distance in order to eliminate any cue arising from accommodation. It was found that a trapezoid appeared unslanted and rectangular when slanted so as to project a rectangular retinal image. A trapezoid presented in the frontal-parallel plane (or at 20 degrees) appeared to have the same slant as a rectangle slanted at 20 degrees (or at 40 degrees) so as to project the same retinal image. As physical slant increased, mean perceived slant generally increased, although the mean perceived slants were underestimations (probably due to the absence of other cues for depth). In spite of Gibson's (1951) finding that outline forms are ambiguous, no observer in the experiment under consideration reported that the stimulus forms changed in their apparent shape or slant. The discrepancy in results may be due to the fact that Gibson's figures were drawn on grounds presented in the frontal-parallel plane; Clark, Smith, and Rabe (1955, 1956) set off their outline figures from their backgrounds. With Gibson's figures there would be a conflict between the slant percept produced by an outline figure and the unslanted percept required by the orientation of the ground. There is considerable evidence that the slant of a figure tends to be assimilated to the slant of its ground (Beck & Gibson, 1955; Epstein, Bontrager, & Park, 1962; Metzger, cited in Koffka, 1935, p. 124).

In a further study, Clark, Smith, and Rabe (1956) found that when outline perspective was the only cue, the accuracy of slant perception was greater than when texture gradient was the only cue. Accuracy of perceiving slant did not improve when the gradient of outline deformation was supplemented by adding texture to the stimulus form or to the background or to both. When the ground was textured, perception was less accurate.

Stimulation for the Perception of Depth

Gibson maintains that depth perception does not occur without the perception of a surface (and hence without a gradient of texture, which is required for the perception of a surface). To test this hypothesis, Weinstein (1957) inked out all texture from a set of Gibson's (e.g., 1950b, pp. 184–185) photographs of a large open field with stakes driven into the ground at various distances from the camera. Judgments of the sizes of the stakes made by the subjects using the impoverished pictures were not significantly poorer than judgments made by the subjects using the normal photographs with a texture gradient present. Using the same type of impoverished pictures, Smith (1958) obtained relatively good size constancy. According to Smith, it would not have been possible for the subject to make size judgments of the distant stake in the impoverished photographs if he had not assumed a level ground-plane common to himself and the test objects. Without such an assumption, the image of an object at the same position in the light pattern could give rise to a percept of a small near object on a hillside or of a larger, more distant object on a level plane. The subjects in Smith's experiment were told to assume that a plowed field extended from their position for a long distance. They were also told that their view would be that of the camera. With these assumptions, and an awareness of the angle of elevation of the eye, they had sufficient information to make size and distance judgments.

Natsoulas (1963) has pointed out that the visual depth experienced in the *Ganzfeld* situation contradicts Gibson's requirement that the visual perception of depth be produced by certain attributes of the textured optical array, especially variations in density, disparity, and motility. Gibson rejects this kind of finding on the ground that, like all experiences taking place in response to impoverished, ambiguous, or equivocal patterns, it is unreliable, varying from observer to observer and from time to time in the same observer. The theory need not explain these experiences because they are a function of something other than stimulation and are not veridical. Natsoulas points out that the experience of depth in the presence of the *Ganzfeld* is not unreliable; it is an unvarying accompaniment of the *Ganzfeld* situation. Gibson, Purdy, and Lawrence (1955) found variability in their subjects' reports because the stimulus field was not entirely homogeneous. Among other things, there was the gross inhomogeneity between the surface of the first sheet of plastic and the optical tunnel seen through the aperture in this sheet. As Cohen (1957) has demonstrated, an inhomogeneity anywhere in the field can reduce the tendency to see a surfaceless fog in other parts of the field. When all inhomogeneities have been eliminated from the field, almost all subjects have reported a surfaceless fog extending away in depth (Cohen, 1957; Hochberg, Triebel, & Seaman, 1951). Not only do experimental results of this kind make it appear that Gibson is wrong with regard to the necessary stimulus conditions for the perception of distance; such findings also contradict the fundamental assumption of this theory that perception, when it is reliable and stimulus determined, is also veridical.

Psychophysical Correspondence under Conditions of Transforming Stimulation

As was the case for static stimulation there are two related questions which need consideration: (*a*) Do transformation sequences yield consistent, relatively unvarying percepts, and (*b*) are these percepts in good correspondence with the objective properties of the source of stimulation? In this section we will consider these questions with regard to motion perspective, perspective transformations, and size transformations.

Motion Perspective

Motion parallax has long been recognized as a depth cue. However, beginning with Helmholtz' (1925, pp. 295–296) well-known description, the emphasis has been on the relative angular velocities of isolated objects at various distances from the subject. This emphasis is reflected in the experimental investigations (e.g., Graham et al., 1948) which typically have used only two objects and two velocities in an otherwise uniform field of view. This approach is also consistent with the traditional "air theory" (Gibson, 1950b, p. 6) of space, as contrasted with the "ground theory" which emphasizes the variations in stimulation which are correlated with a continuous background surface. When the ground or terrain is taken into account there is a continuous flow or gradient of retinal velocities. This gradient involves a continuous transformation of the angular separations between points in the field or, more simply, a transformation of pattern. Gibson uses the term "motion perspective" to distinguish these conditions from those which prevail in the two-velocity case. Motion perspective is presumed to be a stimulus correlate of perceived relative distance in the same way that gradients of optical texture are presumed to be correlates of perceived recession of a surface (Gibson, Olum, & Rosenblatt, 1955). Thus motion perspective is assigned the status of a stimulus for depth. This contrasts with its frequent designation as a "clue" which is effective only when other information makes the assumption of spatial extension reasonable (e.g., Ittelson's, 1960, neo-Helmholtzian analysis).

In order to examine Gibson's interpretation, experiments are needed which isolate motion perspective. Will motion perspective in isolation consistently yield an impression of depth which is compatible with the variability of retinal velocity? An early experiment by Gibson and Carel (1952) produced negative results. The source of stimulation was a battery of scattered lights having a uniform overall density. The battery was in the subject's frontal plane and appeared so when motionless. The lights could be moved across the field with a velocity which decreased from the bottom of the battery to the top. The display was exhibited in the dark, and observation was monocular. The gradient of retinal velocity thus produced should be sufficient to yield the perception of a surface which recedes from the subject from bottom to top. This expectation was not confirmed. A consistent impression of recession, slant, or relative distance was not induced.

Negative results were also obtained by Smith and Smith (1957, 1961) under different conditions. They investigated the conditions necessary for the veridical perception of the convexity of a cylindrical textured surface. Rotation of the cylinder on its horizontal (long) axis was not sufficient to cause the cylinder to appear curved if it appeared flat when motionless.

Subsequent experiments by Gibson, Gibson, and Smith (1959) have also failed to produce unequivocal results. A series of three experiments was conducted with the shadow projector described by Gibson (1957) and Gibson and Gibson (1957). Experiment I was a two-velocity experiment in which subjects were asked to describe what they saw in response to the differential translatory velocity of two circular spots or two superimposed textures composed of elements of indefinite size and contour. Theoretically, the perceived distances of the two spots or textures should be inversely proportional to the optical velocities. The results of the experiment did not confirm this expectation. The magnitude of apparent separation varied greatly between subjects. However, even more damaging was the fact that the direction of the difference in depth was not consistent between subjects, that is, almost 25% of the subjects reported that the spot or surface carrying the lesser velocity appeared nearer. The authors speculate that "perhaps it was (the) lack of solid continuity or rigid connectedness between the nearer and farther surface which prevented the ideal possibility . . . from being realized [Gibson et al., 1959, p. 46]."

For this reason Experiment II was conducted with a continuous flow of velocity produced by a single randomly textured surface slanted 45 degrees away from the translucent window of the shadow projector which was moved back and forth parallel to the screen. This situation is similar to the one produced by Gibson and Carel (1952). The main result of Experiment II was that most subjects reported a rigid moving plane surface slanting away from them at the top of the field. However, estimates of the slant varied from 12.5 degrees to 60 degrees. Again the magnitude of the apparent separation was highly variable.

Smith and Smith (1963) tested the prediction that the inconsistencies observed by Gibson et al. (1959) would be eliminated by using a combination of two-velocity parallax and a continuous gradient of velocity flow. The results did not support the prediction. The direction of apparent depth agreed with the requirements of the velocity ratio; however, the magnitude of separation in depth of the surfaces was indeterminate. Also, contrary to the results of Gibson et al. (1959, Experiment II) the continuous flow of velocities did not yield the perception of a slanted surface.

The results of the experiments reviewed above do not confirm Gibson's assertion of a strict psychophysical relation between a continuous gradient of optical motion and perceived depth. The experiments failed to provide evidence that motion perspective in isolation is adequate to specify depth, slant, or the relative order of surfaces in depth. It will be recalled that the studies of texture gradients in isolation (Beck, 1960; Gibson, Purdy, & Lawrence, 1955) also yielded inconsistent percepts. Apparently perception is not correlated with individual gradients of stimulation in a 1:1 manner. In light of this observation it seems more promising to study various gradients in combination, for example, motion perspective and textural density, instead of single gradients in isolation. Smith and Smith's (1961) study of the perception of cylindricality illustrates the possibilities of this approach.

Several general remarks are in order concerning the expectation that psychophysical correspondence would be observed when only a single gradient is available.

1. This expectation implicates certain assumptions concerning the properties of the environment. For example, with regard to the expected correlation between apparent recession and optical density, there is the assumption that the elements which constitute the texture of the environment are the same physical size and shape throughout. This is probably a safe assumption insofar as we deal with man-made surfaces. However, when natural terrain is considered there is no compelling reason to believe that this is consistently the case. Many surfaces are admixtures of uniform physical texture and texture composed of elements of variable size and shape. The "ecological validity" (Brunswik, 1956) of the various optical gradients is not known. In fact Gibson and Flock (1962), in a discussion of the illusory closeness of mountains, have offered as an explanation the fact that "in the neighborhood of a mountain, the distant earth-shapes may be much larger than the nearer ones and the usual optical gradient will then be altered [p. 502]." This is presumed to produce the apparent nearness of the mountain despite the contradictory information provided by the concurrent gradients of disparity and motion perspective.

Gibson (1959) feels that the occurrence of illusions and errors in perception will not be explained in the same way as veridical perception. Supplementary theoretical principles are required. As yet the details of this theory have not been advanced. However, a hint of what Gibson's theory would be like with these corollaries added is given by his comments on the apparent distance of mountains (Gibson & Flock, 1962):

> There are many possible types of stimulus-information for distance in a natural optic array, some of them based on constant laws of geometry and optics, others based on probable but variable conditions of geological features, atmosphere, and illumination. Illusory perception will depend on the combination of circumstances which holds for the particular situation, and also probably on the degree to which the attention of the observer has been trained to register the reliable information in the array [p. 503].

This statement sounds very like those made by Brunswik (1956) regarding the learning by the observer of the ecological validity of cues. In fact, it is hard to see how Gibson's system, in its final and complete form, will be able to retain its individual identity.

2. Assumptions of a different sort are implied when other gradients are considered. Two examples will illustrate: (*a*) When the objects under observation are not in the same line of sight, the prediction that differential retinal velocity produced by actual movement in the field will yield veridical apparent relative distance seems to require, in the case of a moving subject, the correct registration by that subject of the relative rates of his movements when viewing the objects whose distances are to be compared. A correct perception of the magnitude of the separation between the objects would involve a correct perception of the absolute rate of movement. This is necessary if the perceptual system is to partial out the various sources of differential retinal displacement. Such correct registration would be a considerable achievement if the subject is undergoing passive locomotion. (*b*) Another example concerns the gradient of relative size. It is evident that this gradient in isolation is ambiguous for the same reason that the visual angle subtended by a single object is ambiguous. The continuous diminution of the angles subtended by a series of objects does not uniquely specify recession since it is equally compatible with a frontal-parallel series of objects which are actually regularly compressed in physical size. The ambiguity is eliminated if the subject assumes that the objects are the same size. Gibson (1950b) seems to recognize this when he writes of the "retinal gradient of size-of-similar objects." Recent experiments by Epstein and Baratz (1964) have shown that the apparent relative distance produced by relative visual angle may indeed be governed by such assumptions.

Continuous Perspective Transformations

The projection of a form or pattern on a non-frontal-parallel surface constitutes a perspective transformation of the form or pattern. In this sense the retinal projection of any form, pattern, or surface which is not in the subject's frontal-parallel plane will constitute a perspective transformation. When either observer or object is in continuous motion the result is a continuous sequence of perspective transformations.

Most studies of the effect of transformation have presented the static end products of transformation, concealing from the subject the antecedent transformation sequence. This set of conditions must represent an atypical case. Behavior in the natural environment is marked by continual shifts of the head and body leading to continuous transformations of the retinal pattern. A predilection for static stimulation also is evident in those few instances where changing stimulation has been studied. As an illustration, Wallach and O'Connell (1953) in interpreting the kinetic depth effect (KDE) treat the continuous sequence of shadow transformations as a series of independent static projections tied together by memory traces. It will be clear from the earlier discussion that Gibson takes exception to the traditional emphasis on static stimulation. According to Gibson the emphasis should be reversed.

Only a small portion of the evidence on this question has direct Gibsonian origins. Moreover, the implications for Gibson's theory have often not been made explicit by the original investigators. Therefore, their agreement with our conclusions cannot always be assumed. The studies reported by Gibson dealt with slant depth of surfaces. The experiments which derive their impetus from Wallach and O'Connell's (1953) work on the KDE have involved the internal depth and coherence of complex forms, for example, a bent parallelogram. Finally, Langdon's (1951, 1953, 1955) investigations of shape constancy also have implications for Gibson's view.

Slant Depth. Several experiments reviewed in this section used a device called a shadow transformer invented by Gibson and Gibson (1957). A continuous sequence of shadow transformations is produced on a translucent screen by a rotating object placed between the screen and a point source of light which is positioned so as to produce polar projection.

Gibson and Gibson (1957) presented the shadow sequences produced by turning two regular (closed-square, open-square pattern) and two irregular (closed amoeboid, broken amoeboid) forms through 4 degrees of semirotation. There were two main questions: (*a*) Would the sequence of transformations yield the perception of a rigid surface of changing slant? (*b*) Would judgments of the amount of slant correlate positively with the variations in the length of the transformation sequence, that is, the degree of semirotation? The results for all four forms were affirmative on both counts. A separate control group was shown only the motionless end point of a 60-degree transformation. For this group the irregular forms yielded judgments of "no slant," whereas the regular forms were perceived as slanted. However, the amount of slant was greatly underestimated and was considerably less than the slant produced by the 60-degree transformation sequence. Gibson and Gibson concluded that a perspective transformation sequence is sufficient to produce an accurate perception of slant and rigidity regardless of the familiarity or texturedness of the form which carries the motion.

This conclusion cannot be accepted without reservation. The appropriateness of the control condition is questionable. There is little reason to expect that exhibiting the end points should be equivalent to displaying the form in the numerous aspects of its transformation arc. The logical requirement is that no single static aspect or combination of discrete static aspects yield a perception of slant. Therefore, what is required is that a random sample of discrete static transformations be presented. If the subject fails to report changing slant, then we may conclude that a continuous and lawful sequence is essential. The second objection concerns an important difference between the control and experimental conditions which may account for the results. Under the experimental conditions, the subject may safely infer that one and the same object is being presented in various aspects. On the other hand, when isolated static aspects are presented the subject cannot be certain of the continuing identity of the shadow-casting object. The apprehension of physical identity is crucial since without it the shadow transformations could just as well be perceived as continuous deformations in the plane of the screen.

That these arguments need to be taken seriously is indicated by the results of Sidorsky (1958), White (1962), and Epstein and Mountford (1963). Sidorsky (1958) found that subjects could accurately judge their own apparent rotation in the medial plane when presented with static perspective transformation of a grid-patterned surface as viewed at different pitch angles. Epstein and Mountford (1963) presented the static end products of various amounts of transformation of rectangular representational and nonrepresentational forms. Judged slant was found to vary systematically with the degree of transformation. A general rule may be that any deformation of contour or surface texture which represents a deviation from modal regularity will produce a depth displacement.

White's (1962) experiment is especially interesting. White puts the question this way:

> If the moving presentation is effective merely because it provides more looks at the pattern which are not completely redundant, then the order in which these looks are presented should not make any difference in the accuracy of judgment. If, however, the *transitions* between looks are important, then disrupting the order in which the looks are presented should impair the accuracy of the judgment [p. 75, italics added].

In order to examine this question White showed subjects a motion picture which displayed either an orderly sequence of transformations of an unfamiliar 3D rigid form tumbling about a fixed center, or a scrambled series in which the same frames were randomly ordered. At the conclusion of the movie the subject was asked to select a still picture of the standard form in a new orientation from a set of four similar forms. There was no difference between the judgments based on the ordered and scrambled series. It seems that insofar as accuracy of identification is concerned the regularity of the sequence is not critical.

The results of these experiments have bearing on two salient aspects of Gibson's view. First they raise questions concerning the evidential basis for Gibson's reiterated insistence that the sequence itself is a stimulus, for example, "the *form* of the change of form of the stimulus is what determines the perception [Gibson & Gibson, 1957, p. 137]." Second, doubts arise concerning the criterial validity of the regular perspective transformation sequence. The fact that a source may be mathematically specified by a given sequence in an unequivocal manner cannot be taken to imply that the subject uses this relationship.

Internal Depth. The experimental investigations of the perception of internal depth through motion have been reviewed by Metzger (1953, Ch. 13) and Braunstein (1962).[2] The following discussion will focus on the KDE. Under certain conditions, a sequence of transforming shadows will appear as a rigid form, having internal depth and turning in depth. This has been labeled KDE by Wallach and O'Connell (1953). The above definition is incomplete since it does not specify two important conditions for demonstrating KDE. (*a*) The familiar cues for relative distance must be absent. In contrast with Gibson and Gibson's (1957) situation, this requirement implies the use of parallel rather than polar projection. (*b*) None of the static aspects of the transformation sequence should yield a

[2] Of historical interest is Miles' (1931) discussion of the movement interpretations of the silhouette of a revolving two-blade electric fan. Miles traces the irregular history of this problem back to a description by Nicholson (1802) of a theater exhibition in London.

perception of depth. None of the better-known studies of KDE have provided satisfactory evidence that the second requirement was fulfilled. There is good reason to doubt whether this criterion can be met with figures which have many interior angles and lines. In fact, Fried (1960) tested Wallach and O'Connell's (1953) figures, and concluded that only the single bent rod appeared flat in its various static transformations.

The basic fact of KDE is plainly consistent with Gibson's views. A continuous sequence of transformations is shown to be sufficient to determine the perception of a rigid turning form. However, Gibson's theory demands more than this. First, it requires that variability of perception be small. Second, that the perceived form be in good correspondence with the actual shadow-casting form. Finally, perceived turning should also be in good agreement with the actual turning. Data on these questions can be found in the work of Wallach and O'Connell (1953, pp. 211–212), White and Mueser (1960), Green (1961), and Epstein (in press).

Wallach and O'Connell (1953) asked 20 subjects to make judgments of the form of the shadow-casting object immediately following the kinetic presentation. For the wire helix, subjects were instructed to fashion a piece of wire into the shape of the shadow-casting figure. The reproductions were better than those made by the same subjects while they looked directly at the turning figure. For the 110-degree parallelogram, subjects were asked to select a match from a set of four alternatives which included a copy of the standard and three variants. Seventeen of 30 subjects chose the exact copy as their match. It would appear, therefore, that the perception of internal depth based solely on kinetic stimulation is accurate.

This conclusion was confirmed and extended in an experiment by Epstein (in press). Judgments of internal depth and amount of turning were found to be in good agreement with the actual oscillation and objective depth of a 120-degree bent parallelogram. Accuracy did not vary significantly as the length of the transformation sequence varied from 15 to 85 degrees. Apparently, a sequence produced by oscillation through an arc of 15 degrees is sufficiently informative, and lengthening the transformation sequence contributes nothing to accuracy. It remains to be determined whether this is true independently of the locus of transformation, for example, 40–55 degrees instead of 0–15 degrees. There is the possibility of an interaction of length and locus. Also of interest would be to determine whether identical optical transformations have equivalent perceptual effects regardless of their source, for example, passive movement of the subject compared with movement of the object.

The experiments of Wallach, O'Connell, and Epstein have utilized as their shadow-casting objects figures composed of connected lines varying in length and orientation. However, KDE may also be obtained by rotating a display which consists of an arrangement of unconnected straight lines. For example, four vertical pegs arranged at the corners of a square will appear as a rigid spatial arrangement turning about its center. White and Mueser (1960) studied the subject's ability to reconstruct the arrangement of pegs under variations of the shape and number of pegs constituting the display, the speed of rotation, and the exposure duration. Under all conditions, excepting the static presentations, subjects reported immediate perceptions of a stable rigid arrangement rotating in depth. However, most subjects were unable to reproduce the arrangement with greater than chance accuracy. Additional evidence that accuracy is low for unconnected arrangements may be inferred from the results of Green's (1961) Experiment VI.

It appears that accuracy is enhanced by two properties of the display: complexity, for example, interior angles, and connectedness. Should an explanation of this observation be forthcoming it will probably be intimately related to the answer to a more basic question. Why does the sequence of shadows appear as it does, instead of appearing as a continually deforming two-dimensional pattern? It is not sufficient for Gibson to reiterate that sequences are stimuli for depth and solidity. This may (or may not) be an empirical fact; however, it cannot be adduced as the explanation of the specificity of perception. Nor is it sufficient to demonstrate that the subject can discriminate between two similar transformation sequences, one produced by turning a rigid surface and the other by an elastic surface which has been made to contract (Fieandt & Gibson, 1959).

The answer appears to rest in Gibson's implicit adherence to a variant of the Gestalt principle of *Pragnanz*. According to this principle the 3D rigid appearance is a reflection of the subject's preference for the simpler percept. Or in the alternative terminology of information theory: "Other things equal, that perceptual response to a stimulus will be obtained which requires the least amount of information to specify [Hochberg, 1957, p. 83]." Gibson is cited by Hochberg (1957, p. 83) as one of those who subscribed to this principle. If we are correct in ascribing the minimum principle to Gibson, then this is certainly an instance where the psychophysical hypothesis has been discarded. Perception no longer is strictly a function of stimulation. Rather it is mediated by a selective principle built into the perceptual system. The inclusion of a selective principle robs Gibson's thesis of its attractive simplicity. It also carries the implication that a sequence of transformations which requires less information to specify as a continually deforming two-dimensional pattern will be perceived as such, instead of as a turning rigid form. It is obvious that this outcome would be incompatible with the unamended Gibsonian interpretation. Some evidence that two-dimensional deformations are perceived under these circumstances has, in fact, been reported by Metzger (1959).

The Perceptual Constancy of Turning Shapes. The question of shape constancy has been discussed in great detail elsewhere (Epstein & Park, 1963). Here we will mention only Langdon's studies as they bear on the relationship between transforming stimulation and perception. In normal observation the contour of an object is not given as an instance of static nonchange, or as a series of discrete transformations. Instead the contour is usually represented by a continuous family of perspective transformations. While this is true for the numerous states of the same contour, it need not be true for the differences between the contour shapes of different objects, or the differences between the contours of objects which are actually undergoing physical change. One implication of this analysis is that the traditional formulation of the constancy problem is misleading since it focuses on the relation between discrete static transformations and perceptual stability. A second implication is that continuous transformation should enhance shape constancy. Although Langdon has not followed the route we have just taken, he has conducted a series of experiments which examine the second implication.

For the present analysis the main finding of Langdon's (1951, 1953,

1955) experiments is that the rotation of shapes, under conditions such that a stationary presentation yields no constancy, will be sufficient to restore constancy. The degree of perceptual constancy was positively correlated with speed of rotation or rate of change of shape. These results were obtained both with simple outline figures, for example, a wire circle, and complex "solids," for example, a wire cube. Langdon criticizes the kind of explanation which Gibson might advance and offers an alternative. In any event, Langdon's results provide evidence for Gibson's view that the stimulation most useful for achieving a stable visual world is not constant nonchanging stimulation, but is instead stimulation undergoing continuous change.

Size Transformations

Continuous displacement of a frontal-parallel surface in a radial line from the subject yields a size transformation of the retinal image. Diminution of distance produces a symmetrical expansion of the image, and increasing distance results in a symmetrical contraction. If the surface moves back and forth, then one transformation sequence is a sequential inversion of the other.

While size transformations have long been recognized as cues for relative distance there has been little experimental work on this topic. Some of the early work (e.g., Bourdon, 1902) has been reviewed by Woodworth (1938, Ch. 26) and Boring (1942, Ch. 8). We have uncovered only three recent studies addressed to this question (Ittelson, 1951; Schiff, Caviness, & Gibson, 1962; Smith, 1951). There is some disagreement about whether the perceived radial motion produced by size transformation is regulated by the subject's assumptions about the target. Ittelson (1951) provides evidence that assumptions about, and prior experiences with, the transforming target are important determinants. Smith's (1951) experiment, on the other hand, failed to support this view. However, both of these investigators do provide clear-cut evidence that under appropriate conditions size transformations will yield perceived radial motion. In addition, the studies concerning prediction of time of collision (Carel, 1961) have shown that this effect is lawfully related to the amount of transformation.

The recent experiment by Schiff, Caviness, and Gibson (1962) illustrates the experimental investigation of this cue. Twenty-three monkeys were observed responding to four stimuli: expansion of a circle projected on a screen, contraction of the circle, darkening and lightening of the screen. Two very different modes of behavior were observed as responses to the size transformation. The expanding circle led to alarmed withdrawal, as if to avoid collision. The contracting circle led to exploratory responses. The results for the brightness variations showed that this variable cannot account for the effects of size transformation. Schiff et al. (1962) conclude that size transformations are sufficient stimuli for radial motion. They do not consider the possibility that size transformations merely produced changes in perceived size without affecting perceived distance, and that sudden, rapid changes in perceived size produce withdrawal or approach responses.

Conclusion

In concluding we wish to consider briefly several general questions.

1. The possibility that the constancy hypothesis is sufficient. There were two steps required for the successful resurrection of the constancy hypothesis as an account of veridical perception. First it must be proved that some variable of

stimulation unequivocally specifies the distal source. Secondly it must be shown that the total variance in perception can be attributed to variance in the proximal stimulation.

While Gibson has offered persuasive arguments concerning the specificity of stimulation he has only rarely (e.g., Gibson, Olum, & Rosenblatt, 1955) attempted the mathematical analyses which are demanded. Several unpublished theses by Gibson's students (Hay, 1961; Purdy, 1958) have made admirable efforts to achieve this objective, and they deserve careful study. However, certain physical properties of the environment (such as rigidity) have been accepted as primitive and hence have escaped analysis. What makes this procedure unsatisfactory is not the implausibility of the assumptions. The assumptions are not extravagant, nor is it by itself improper to postulate certain premises in writing geometrical relationships. Our discomfort arises from the fact that some of the properties which are assumed are the very ones which Gibson's theory is intended to explain.

Concerning the psychophysical hypothesis it can be said that Gibson has not proved his case. The experimental data simply do not support the hypothesis of perfect psychophysical correspondence. Nor does the evidence support the contention that perception is "in contact with the environment," that is, veridical, in cases of psychophysical correspondence.

The question of veridicality has a long history in philosophical analysis, and we would wish to avoid the question. However, an evaluation of Gibson's thinking would be incomplete without a discussion of this matter. We are uncertain about the value of introducing the conventionally defined relation of veridicality into a theory of perception. It is clear in Gibson's case that the account of perception is contained in the psychophysical hypothesis which relates percepts to proximal stimulation, and need not involve any assumptions concerning the distal-proximal or distal-perceptual relationships. The introduction of veridicality considerations leads Gibson to distinguish between perceptual events on bases other than the subject's response, or an analysis of stimulation. For example, suppose Subject X looks into an optical tunnel and reports that he sees a solid tunnel. Subject Y is shown a real tunnel which provides identical stimulation, and he too reports that he sees a tunnel. Applying the label "veridical" to Y's report and "nonveridical" to X's report hardly seems a useful exercise.

2. Is a correlational theory sufficient? In reviewing Gibson's *The Perception of the Visual World* Boring (1951) advanced the following criticism:

> What Gibson calls a "theory" is thus only a description of a correlation, a theory which tells *how* but skimps on *why* . . . eventually science must go deeper into the means of correlation, must show in physiology *why* a gradient of texture produces a perceived depth, not merely that it does [p. 362].

Prentice (1951) in his review has made the same criticism of Gibson.

Putting aside the question of whether Gibson needs more physiology or more psychology we would agree that he needs more theory. In our view Gibson has tried to capture too much empirical terrain with too little theory. The consequence has been the unintended development of implicit theoretical propositions which are applied when the explicit theory is confronted by an emergency. These hidden theoretical principles can be employed only at the peril of internal inconsistency. Gibson's theory needs deliberate revision.

REFERENCES

BECK, J. Texture-gradients and judgments of slant and recession. *Amer. J. Psychol.*, 1960, 73, 411–416.

BECK, J., & GIBSON, J. J. The relation of apparent shape to apparent slant in the perception of objects. *J. exp. Psychol.*, 1955, **50**, 125–133.

BORING, E. G. *Sensation and perception in the history of experimental psychology.* New York: Appleton-Century, 1942.

BORING, E. G. Review of J. J. Gibson, *The perception of the visual world. Psychol. Bull.*, 1951, **48**, 360–363.

BOURDON, B. *La perception visuelle de l'espace.* Paris: Reinwald, 1902.

BRAUNSTEIN, M. L. The perception of depth through motion. *Psychol. Bull.*, 1962, **59**, 422–433.

BRUNSWIK, E. *Perception and the representative design of psychological experiments.* Berkeley: Univer. California Press, 1956.

CAREL, W. *Summary 1961.* (General Electric Advanced Electronics Center Publ. No. R6ELC60) Ithaca: Cornell University, 1961.

CLARK, W. C., SMITH, A. H., & RABE, A. Retinal gradients of outline as a stimulus for slant. *Canad. J. Psychol.*, 1955, **9**, 247–253.

CLARK, W. C., SMITH, A. H., & RABE, A. The interaction of surface texture, outline gradient, and ground in the perception of slant. *Canad. J. Psychol.*, 1956, **10**, 1–8.

COHEN, W. Spatial and textural characteristics of the *Ganzfeld. Amer. J. Psychol.*, 1957, **70**, 403–410.

EPSTEIN, W. Perceptual invariance in the kinetic depth effect. *Amer. J. Psychol.*, in press.

EPSTEIN W., & BARATZ, S. Relative size in isolation as a stimulus for relative perceived distance. *J. exp. Psychol.*, 1964, **67**, 507–513.

EPSTEIN W., BONTRAGER, H., & PARK, J. The induction of nonveridical slant and the perception of shape. *J. exp. Psychol.*, 1962, **63**, 472–479.

EPSTEIN W., & MOUNTFORD, D. Judgment of slant in response to an isolated gradient of stimulation. *Percept. mot. Skills*, 1963, **16**, 733–737.

EPSTEIN, W., & PARK, J. N. Shape constancy: Functional relationships and theoretical formulations. *Psychol. Bull.*, 1963, **60**, 265–288.

EPSTEIN, W., PARK, J., & CASEY, A. The current status of the size-distance hypotheses. *Psychol. Bull.*, 1961, **58**, 491–514.

FIEANDT, K. v., & GIBSON, J. J. The sensitivity of the eye to two kinds of continuous transformations of a shadow-pattern. *J. exp. Psychol.*, 1959, **57**, 344–347.

FRIED, C. Studies on the kinetic depth effect as a means for presenting three-dimensional information: I. Methodology and selection of forms for study. *USA Ordn. Hum. Engng. Lab. tech. Memo.*, 1960, No. 2-60.

GIBSON, ELEANOR J., GIBSON, J. J., & SMITH, O. W. Motion parallax as a determinant of perceived depth. *J. exp. Psychol.*, 1959, **58**, 40–51.

GIBSON, J. J. A critical review of the concept of set in contemporary experimental psychology. *Psychol. Bull.*, 1941, **38**, 781–817.

GIBSON, J. J. The perception of visual surfaces. *Amer. J. Psychol.*, 1950, **63**, 367–384. (a)

GIBSON, J. J. *The perception of the visual world.* Boston: Houghton Mifflin, 1950. (b)

GIBSON, J. J. What is form? *Psychol. Rev.*, 1951, **58**, 403–411.

GIBSON, J. J. Optical motions and transformations as stimuli for visual perception. *Psychol. Rev.*, 1957, **64**, 288–295.

GIBSON, J. J. Perception as a function of stimulation. In S. Koch (Ed.), *Psychology: A study of a science.* New York: McGraw-Hill, 1959. Pp. 457–501.

GIBSON, J. J. The concept of the stimulus in psychology. *Amer. Psychologist*, 1960, **16**, 694–703.

GIBSON, J. J. The useful dimensions of sensitivity. *Amer. Psychologist*, 1963, **18**, 1–15.

GIBSON, J. J., & CAREL, W. Does motion perspective independently produce the impression of a receding surface? *J. exp. Psychol.*, 1952, **44**, 16–18.

GIBSON, J. J., & CORNSWEET, J. The perceived slant of visual surfaces: Optical and geographical. *J. exp. Psychol.*, 1952, **44**, 11–15.

GIBSON, J. J., & DIBBLE, F. N. Exploratory experiments on the stimulus conditions for the perception of visual surface. *J. exp. Psychol.*, 1952, **43**, 414–419.

GIBSON, J. J., & FLOCK, H. The apparent distance of mountains. *Amer. J. Psychol.*, 1962, **75**, 501–502.

GIBSON, J. J., & GIBSON, E. J. Continuous perspective transformations and the perception of rigid motion. *J. exp. Psychol.*, 1957, **54**, 129–138.

GIBSON, J. J., OLUM, P., & ROSENBLATT, F. Parallax and perspective during aircraft landings. *Amer. J. Psychol.*, 1955, **68**, 372–385.

GIBSON, J. J., PURDY, J., & LAWRENCE, L. A method of controlling stimulation for the study of space perception: The optical tunnel. *J. exp. Psychol.*, 1955, **50**, 1–14.

GIBSON, J. J., & WADDELL, D. Homogeneous retinal stimulation and visual perception. *Amer. J. Psychol.,* 1952, **65**, 263–270.

GRAHAM, C. H., BAKER, K. E., HECHT, M., & LLOYD, V. V. Factors influencing thresholds for monocular movement parallax. *J. exp. Psychol.,* 1948, **38**, 205–223.

GREEN, B. F., JR. Figure coherence in the kinetic depth effect. *J. exp. Psychol.,* 1961, **62**, 272–282.

GRUBER, H. E., & CLARK, W. C. Perception of slanted surfaces. *Percept. mot. Skills,* 1956, **16**, 97–106.

HAY, J. C. The importance of optical motions for visual space perception in man. Unpublished doctoral dissertation, Cornell University, 1961.

HELMHOLTZ, H. Physiological optics. In, *Handbuch der Physiologischen Optik.* Vol. 3. (3rd ed. trans. by J. P. C. Southall) New York: Optical Society of America, 1925.

HOCHBERG, J. E. Effects of the Gestalt revolution: The Cornell symposium on perception. *Psychol. Rev.,* 1957, **64**, 73–84.

HOCHBERG, J. E., TRIEBEL, W., & SEAMAN, G. Color adaptation under conditions of homogeneous visual stimulation (*Ganzfeld*). *J. exp. Psychol.,* 1951, **41**, 153–159.

ITTELSON, W. H. Size as a cue to distance: Radial motion. *Amer. J. Psychol.,* 1951, **64**, 188–292.

ITTELSON, W. H. Visual space perception. New York: Springer, 1960.

KOFFKA, K. *Principles of Gestalt psychology.* New York: Harcourt, Brace, 1935.

LANGDON, J. The perception of changing shape. *Quart. J. exp. Psychol.,* 1951, **3**, 157–165.

LANGDON, J. Further studies in the perception of changing shape. *Quart. J. exp. Psychol.,* 1953, **5**, 89–107.

LANGDON, J. The role of spatial stimuli in the perception of shape. *Quart. J. exp. Psychol.,* 1955, **7**, 19–36.

METZGER, W. Optische Untersuchungen am Ganzfeld: II. Zur Phanomenologie des homogen Ganzfelds. *Psychol. Forsch.,* 1930, **13**, 6–29.

METZGER, W. *Gesetze des Sehens.* Frankfurt am Main: Kramer, 1953.

METZGER, W. Was ist wirklich Neu in der Theorie des raumlichen Sehens? *Proc. XV Int. Congr. Psychol., Amsterdam,* 1959, 258–261.

MILES, W. R. Movement interpretations of the silhouette of a revolving fan. *Amer. J. Psychol.,* 1931, **43**, 392–405.

NATSOULAS, T. On homogeneous retinal stimulation and the perception of depth. *Psychol. Bull.,* 1963, **60**, 385–390.

NICHOLSON, W. Narrative and explanation of the appearance of phantoms and other figures in the exhibition of the phantasmagoria: With remarks on the philosophical use of common occurrences. *J. nat. Phil. Arts,* 1802, **1**, 147–151.

PRENTICE, W. C. H. Review of J. J. Gibson, *The perception of the visual world. Amer. J. Psychol.,* 1951, **64**, 622–625.

PURDY, W. C. The hypothesis of psychophysical correspondence in space perception. Unpublished doctoral dissertation, Cornell University, 1958.

SCHIFF, W., CAVINESS, J. A., & GIBSON, J. J. Persistent fear responses in rhesus monkeys to the optical stimulus of "looming." *Science,* 1962, **136**, 982–983.

SIDORSKY, R. C. Absolute judgments of static perspective transformations. *J. exp. Psychol.,* 1958, **56**, 380–384.

SMITH, O. W. Judgments of size and distance in photographs. *Amer. J. Psychol.,* 1958, **71**, 529–538.

SMITH, O. W., & SMITH, P. C. Interaction of the effects of cues involved in judgments of curvature. *Amer. J. Psychol.,* 1957, **70**, 361–375.

SMITH, O. W., & SMITH, P. C. On motion parallax and perceived depth. *J. exp. Psychol.,* 1963, **65**, 107–108.

SMITH, P. C., & SMITH, O. W. Veridical perceptions of cylindricality: A problem of depth discrimination and object identification. *J. exp. Psychol.,* 1961, **62**, 145–152.

SMITH, W. M. Sensitivity to apparent movement in depth as a function of "property of movement." *J. exp. Psychol.,* 1951, **42**, 143–152.

WALLACH, H., & O'CONNELL, D. N. The kinetic depth effect. *J. exp. Psychol.,* 1953, **45**, 205–217.

WEINSTEIN, S. The perception of depth in the absence of texture gradient. *Amer. J. Psychol.,* 1957, **70**, 611–615.

WHITE, B. W. Effect of temporal ordering on visual recognition. *Percept. mot. Skills,* 1962, **15**, 75–81.

WHITE, B. W., & MUESER, G. E. Accuracy in reconstructing the arrangement of elements generating kinetic depth displays. *J. exp. Psychol.,* 1960, **60**, 1–11.

WOODWORTH, R. S. *Experimental psychology.* New York: Holt, 1938.

(Received October 25, 1963)