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WHAT GIVES RISE TO THE PERCEPTION OF MOTION?[1]

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The assumption that displacement of the retinal image over the retina is the basis for all perception of motion is rejected. The reasons for the plausibility of this assumption are considered. It is part of the traditional theory that retinal sensations are entailed in visual perception. But it involves a misconception of how the eyes work. Another theory of the information for perceiving motion is proposed in terms of the ambient array of light. The registering of subjective bodily movements by vision is contrasted with the detecting of objective environmental motions. A number of century-old puzzles are resolved by this approach and a set of novel experiments is suggested.

Experimental studies of the perception of motion in the past, especially of visual motion, have failed to resolve the old puzzles or to yield any kind of general explanation. The root of the trouble may be a persistent misconception of what gives rise to the perception—an erroneous but plausible assumption about the stimulus.

What is the effective stimulus that always elicits a sensation or perception of motion? The physical motion of an object in the world, one might answer, but this is obviously not sufficient unless the object is illuminated or luminous, and unless it lies within the field of view of the observer. The motion must be specified somehow in the light to an organism and it must also enter an eye. When it is specified in the light and does enter the eye the animal almost always detects it, as the study of behavior shows. This is what is meant by saying that animals are very sensitive to "motion." But physical motion is not the same as optical motion.

A mobile object is not the only cause of motion detection. Because of motion parallax, the observer will also see a kind of motion when he himself moves or is moved in the environment, all objects being stationary. In this case, the human observer describes the motion of objects as only "apparent." Distinguishing between the "motion" of objects and the "movement" of the observer (Gibson, 1954), it is clear that both cases will cause an optical motion of some sort in the light to the eye. This light, and only this light, contains the effective stimulus.

In the past, however, we have assumed that the retinal image was the proximal stimulus for vision. We have analyzed light-stimulation in terms of the retinal image, not in terms of the array of light to the eye (as we shall see, the two are not equivalent). For this reason, it has long been assumed as if it were self-evident that some *displacement of the retinal image over the retina* must be the effective *stimulus for an impression of motion.*

[1] This summary is based on a series of investigations over the last 10 years on the perception of motion and space carried out with the support of the Office of Naval Research under Contract NONR 401(14) with Cornell University. A bibliography of the published studies may be obtained from the author. This is the third summary of the project to be published in *Psychological Review* (Gibson, 1954, 1957). It is hoped that each summary makes some theoretical advance over the previous one.

I will call this the *retinal image displacement hypothesis*.

This hypothesis is clearly incorrect, for a retinal displacement does *not* elicit any sensation of motion during the saccadic *scanning* movements of the eyes between fixations, nor during the spontaneous correctional or tremor movements of the eyes during fixations. The first fact is an old puzzle (why does the world not seem to move when the eyes move?) and the second is a new puzzle arising from the discovery of an optical way to "stabilize" the retinal image on the retina during a fixation. In the absence of any other hypothesis to take its place, however, a number of ad hoc theories has arisen to explain the failures of the retinal image displacement hypothesis. One theory is that a retinal sensation *does* occur during an eye movement but that it is canceled out in the brain.

I shall argue that the hypothesis should be discarded, but let us first consider the reasons for its plausibility and persistence.

1. Some displacements of the retinal image relative to the retina *do* seem to yield sensations of motion. During pursuit fixation of a moving object in the environment, the image of the environment moves across the retina and the phenomenal world behind the object is often said to exhibit an "apparent" motion. (But at the same time, the object is also seen to move although its image is *not* displaced regularly over the retina, so there is a paradox here.) During after-nystagmus, the vertigo arising after cessation of prolonged artificial body-rotation, the phenomenal world has a disconcerting apparent motion—a motion said to result from the slow phase of the after-nystagmus but not from the fast phase. During a forced movement of the eyeball, as when it is pushed by a finger, there is an apparent motion of the environment, and much has been made of this observation during a century of theorizing, from Helmholtz to Von Holst.

2. It is true that an abrupt displacement of a spot of light in an otherwise homogeneous field of darkness will elicit a sensation of displacement (e.g., Hick, 1950). A rapidly moving spot of light yields the impression of a *streak*. But a slow motion of the spot cannot be observed, and a stationary spot may be seen in illusory motion after it has been fixated for some time in the dark—the so-called autokinetic phenomenon.

3. The hypothesis of retinal image displacement for the sensation of motion is analogous to other assumptions about the effective stimuli for other sensations. The location of a luminous spot on the retina is supposed to yield a sensation of location. The intensity of a stimulus on the retina is supposed to yield a sensation of brightness, and the wavelength of the stimulus a sensation of color. The form of the stimulus is supposed to yield a sensation of form and the angular extent of the stimulus a sensation of extendedness. A brief pulse of stimulation on the retina is supposed to yield a brief flash of sensation. Accordingly, a motion of the stimulus over the retina should always yield a sensation of motion. It is assumed not only that these stimuli yield the corresponding sensations but also that the sensations depend upon the respective stimuli. All of these assumptions can be challenged (Gibson, 1966) but they have seemed to support one another because they were mutually consistent. They are all part of the classical theory that a two-dimensional retinal image delivers two-dimensional visual sensations, to which depth must be somehow added.

4. The retinal image displacement hypothesis is taken to be consistent

with the fact that the aftereffect of inspecting an environmental motion is localized on the retina—the negative afterimage of motion that results from looking at a slowly rotating disk, or a Plateau spiral, or a moving belt behind a window (or a waterfall). It is said to be analogous to the negative afterimage of hue or brightness in being a patch of disembodied motion in the visual field like the patch of filmy color constituting an afterimage. But this way of describing the aftersensation may be inadequate, as will be evident later; it may prove to be not so much a patch of motion as an aftereffect of the optical change that occurs at the *boundaries* of the disk, window, or waterfall.

5. The whole history of research on stroboscopic motion (Boring, 1942, Ch. 15), including Wertheimer's (1912) theory of the phenomenon, implies the hypothesis that displacement of a stimulus over the retina is the necessary condition for a perception of motion. Wertheimer was only concerned to explain why this displacement could be discontinuous instead of a dense sequence of momentary stimuli at a dense series of adjacent retinal points as commonsense and physics would suppose. He assumed a neural process of "short-circuiting" in the brain, never doubting that the retinal image was projected to the brain. It is possible, however, that stroboscopic motion can be subsumed under change of pattern in the image and does not have to be thought of as displacement of a stimulus.

6. The whole history of research on the just noticeable speed of motion and the discrimination of different speeds implies the assumption that a sensation must occur with a sufficient displacement of the stimulus over the retina and must increase with increasing displacement per unit of time. Many of these experiments in the psychophysical tradition have been reprinted or summarized by Spigel (1965) in his book of readings on the perception of motion. The present author's criticism of these experiments is also reprinted in this book (pp. 125–146). I objected that the supposed absolute threshold of the sensation of motion differs with different arrays of stimulation, and that the supposed differential threshold depends on how far apart the standard and the variable motions are in the field of view. Angular speed of motion has thus not yielded to psychophysical measurement, for the experiments that attempt to isolate it are unsatisfactory.

In general, psychologists and physiologists have not been able to conceive any other possible visual stimulus for motion than "the successive stimulation of adjacent retinal loci," as Spigel phrases it (1965, p. 2). I too once asserted that since the retinal image is a two-dimensional projection of focused light on a sensitive anatomical surface, "when we say that it undergoes motion we must always mean motion with reference to that surface [Gibson, 1950, p. 31]." This assertion now seems to me wrong. The effective proximal stimulus, more exactly the effective stimulus-information, can be conceived in a wholly different way. I shall argue that motion *of* the retinal image is a misconception and that motion *in* the retinal image, a change of pattern, is not displacement with reference to the retina.

THE MISCONCEPTION UNDERLYING THE RETINAL IMAGE DISPLACEMENT HYPOTHESIS

For centuries we have thought of the retinal image as a picture projected and focused on a screen, the image being mobile and the screen fixed. The image is supposed to be freely transposable over the retina. But actually it is the other way round. The image is perfectly stationary, being anchored to the world, and the retina moves relative to the image. The retina is *continually* moving behind its image. Exploratory eye movements are necessary with highly foveated eyes like ours in order to bring the fovea successively to bear on details of the total image. Tremor of the eyes, moreover, is incessant and vision fades away when it is artificially canceled. In this cancellation experiment the term "stabilized retinal image" is a misnomer, for the normal image is always stable and the experiment only causes the image to vibrate in synchrony with the retina.

If the image is thought to be freely transposable over the retina we are faced with the puzzle of how it can be equivalent for vision when it excites a different set of receptors in the retina. But this is to state the question wrongly, for it is the retina that sweeps and vibrates in the course of its normal functioning. The puzzle is not one of a transposable image but of a mobile retina. In short, a retinal image from the natural environment *cannot* be displaced over the retina for it is the retina that is displaced over its image—the extended or potential image which the eye explores by sampling (Gibson, 1966, Ch. 12).

The problem is not just one of which moves relative to the other—the retina or the image. In truth, to put the matter radically, the natural retinal image is not an image at all. We are accustomed to visualize it in terms of photography, as a frozen sample of the structure of the ambient light at one station point at one moment of time. This bears enough similarity to a flat photographic image on a plane surface to perpetuate the misconception. But actually each eye samples the field of view of the head, the head turns to sample the whole array of the ambient light, and the body moves from one vista to another in the environment. All higher animals do so, not just man. The retina sweeps over a potential image in time, revealing a new crescent of the array and abandoning an old one. It is not an image projected on a plane but on a sphere. The eye-head system can look around so as to produce a microcosm of the environment inside the eye "like a panoramic painting of the world shrunken to the interior of a 1-inch sphere [Gibson, 1966, p. 259]." And, even further, this panorama is merely one of a continuous family of transformations corresponding to each of the possible paths of locomotion in the environment. If we are going to say that what a man sees as he gets about in the world depends on his retinal images we have got to stop thinking about them as flat snapshots projected and focused on a sensitive anatomic screen in a small spherical darkroom.

It should now be evident that the retinal image as we habitually conceive it is not equivalent to the array of light coming to the eye, and not even equivalent to the sector of the array *entering* the eye. For the problems of vision, image optics will not suffice and ecological optics will have to be formulated. The latter is at a higher level of analysis than the former.

THE POSSIBLE CAUSES OF MOTION STIMULATION

If we discard the retinal image displacement hypothesis as a basis for motion detection what alternatives do we have? We may have to give up the theory that retinal sensations are the data for perception. What other information is available? There is good evidence to show that some visual perceptions of objective motion occur in the absence of visual sense data, perceptions that are "amodal" in that they do not have the defining attributes of the visual mode (Michotte, Thinés, & Crabbé, 1964). One can detect occluded motion if the information for occlusion is available (Reynolds, 1968). As for the detection of subjective movement, psychologists have struggled in vain for a century with the puzzle of whether kinesthesis is one mode of sensation, or is multimodal, or perhaps amodal (Boring, 1942). The assumption that there is a fixed number of senses is probably untenable. So perhaps the time is ripe for a theory of perception and proprioception based on higher-order information instead of on sensory data.

To make a fresh start, consider the possible sources of optical motion in the light to an eye for a living animal in a natural environment. (The kinds of optical motion from an apparatus in a laboratory or a display intended to produce motion will be considered later.) What kinetic events have corresponding optical events that could induce an experience of motion or movement if the light entered an eye? There are two main types of such an event: motion of an object in the environment and movement of the observer. The latter may be subdivided into four categories, however, so that the list of sources comes to five: motion of an object, locomotion of a whole animal in the environment, movement of the animal's head on its body, movement of an eye in its head, and movement of an extremity of its body.

Other kinds of motion as described by astronomy and physics need not be considered. The motion of the environment in space does not concern us because it is not given in light except by obscure information. Motion of the environment relative to an animal is impossible, although a rotation of it can be simulated with a so-called optokinetic apparatus. The motion of a physical particle is only given in light when the array has been highly magnified. Let us examine the five types to determine what they entail in the way of optical information.

Objective Motion

Any surface or object in the environment that reflects (or emits) light can move in a variety of ways relative to the permanent environment and can thus alter the perspectives of its texture and its edges in the ambient light. Rigid objects can move, in accordance with Newton's laws, in ways that are analyzable by three dimensions of translation and three axes of spin. Viscous or elastic surfaces can move in ways that are very difficult to analyze, the turbulent flow of liquid and the motions of the skin of an animal being examples.

What are the optical motions corresponding to the six parameters of rigid material motion? They are by no means copies or representations. They can be treated mathematically as families of perspective transformations by methods of projective geometry (Gibson, 1957, but see also the modified and extended analysis of Hay, 1966[2]). This treatment, however, is limited to the consideration of the plane faces or facets of an object, the geometrical polygons, and their transformations in the optic array. What about a polyhedron, a many-faced solid object? When it turns, so that unprojected faces become projected, and vice versa, there is information for the back faces as well as the front faces. Another mathematical treatment than one con-

[2] In 1957, I assumed that there are six families of perspective transformations corresponding to the six Newtonian motions, but this is not correct. Transformations specify motions, as Hay has shown, but the correspondence is not this simple.

fined to perspective transformations is required. There has to be an analysis of occlusion and disocclusion.

This approach, moreover, leaves out of account the background of a solid object, not only its back side. Objects are not ordinarily seen against the sky or in darkness. The hiding or screening of one surface by another and its opposite, the revealing or uncovering of it, are typical of object motions in a terrestrial environment. Motion of an object toward the observer involves not only more of its figure but less of its ground, and motion away from the observer involves the opposite. Even a frontal motion of an object does not yield simply a frontal displacement in the visual field, as we have assumed. There is a progressive occlusion of the background at the leading edge and a progressive disocclusion at the trailing edge, apart from the "motion." Quite possibly this is the essential information for the perception of what we call its motion.

Evidently the occlusion transformation (if it may be called that) must be analyzed and experimentally isolated as well as the projective transformations and size transformations.

The optical motions corresponding to the types of viscous or elastic motion of a surface have been little studied. There is not even a classification of such motions. Fieandt and Gibson (1959) set up one such optical transformation, corresponding to "stretch," and Gibson and Pick (1963) considered one kind of transformation in the light coming from a human face, but the problem has scarcely been touched.

In general, the optical information for environmental events other than simple displacements has been neglected (although the array from a motion picture screen carries an enormous amount of it). One reason for this neglect is probably our preoccupation with retinal displacements.

Locomotion of the Observer

Whenever the station point of an eye in a head on the body of an individual is displaced relative to the illuminated environment, actively or passively, a transformation of the whole array of ambient light results, termed *motion perspective* (Gibson, Olum, & Rosenblatt, 1955). This is not to be confused with differential displacements of parts of the retinal image over the retina, the supposed cue of *motion parallax* (e.g., Gibson, Gibson, Smith, & Flock, 1959). An observer can explore this total transformation of the ambient array just as he can explore the total nontransformation of the frozen array that exists when the station point of the eye remains motionless. Motion perspective has been analyzed for the surface of the earth from horizon to horizon, as it applies in aviation, and gradients of velocity have been analyzed for the slant of a plane surface (Flock, 1964). But the ordinary environment contains edges, and locomotion therefore involves occlusion-transformations at edges. These kinetic edge effects may well be more important than gradients of velocity as information for perception. The slightest shift in the station point of an eye makes them evident. When long continued, they constitute the transitions from one vista to another as the traveler moves through the world. But, as noted, they still await a precise mathematical description.

The point to be emphasized about motion perspective, including edge-effects, is that it does *not* elicit a perception of objective motion but a detection of subjective movement. With an introspective attitude, to be sure, a human observer can report an *apparent* centrifugal flow of the visual field ahead when he drives a car but he is ordinarily simply aware of his locomotion in the rigid world. Is this awareness *visual* or is it *kinesthetic?* No answer can be given. I have called it *visual kinesthesis,* but a better statement is to say that it is nonmodal or sensationless, that is, that the classical sensations are irrelevant for it.

Motion perspective in any case provides information. It affords control of active locomotion. It also permits the registering of passive locomotion. Volition, together with classical muscle-joint proprioception, accompanies it in the first case but not in the second. But the global flow of motion perspective is information in its own right; it provides the *only* valid information for a bird in a headwind as to its motion or nonmotion with respect to the earth.

It is important to realize that motion perspective caused by locomotion entails change in the *whole* of the textured ambient array whereas the alteration of perspective caused by an objective motion entails only change in *part* of the ambient array, the remainder being frozen. If this part-whole difference can be picked up by a visual system, the difference between motion in the world and locomotion of the self would be specified by the input of the system, and an explanation in terms of a special brain process to correct the retinal sensation would not be required.

Head Turning and Head Rotation Relative to the Body

In vertebrates, head turning is exactly linked with compensatory eye turning so as to keep the eyes in a fixed posture relative to the ambient array for as much of the time as possible (Gibson, 1966, Ch. 4 & 9). Nevertheless, when the head turns or is turned its field of view sweeps across the ambient array and a new sample is available for the binocular system. In primates the head's field is approximately a hemisphere. The same thing happens when the head is rotated on an axis parallel with the shoulders, in looking up or down. The shift of the field of view relative to the whole sphere of available light can be noticed by introspection; there is a kind of uncovering and covering up of one's surroundings. But this shift or sweep is not seen as a visual motion except in postrotation vertigo; ordinarily one is simply aware of the head turning (or being turned) in a stationary world. The input from the neck (or from the semicircular canals, with passive turning) confirms this head turning with information from a different source. When the head is tilted to one side, however, or passively rotated on a saggital axis, a visual sensation of motion is easier to notice. This head movement does not yield a new sample of the ambient array; instead there is roughly the same sample with a rotation of each retina behind its retinal image. The subjective visual field tilts and it is *almost* as if the world were tilting. When the available array is reduced to a vertical luminous line in darkness the line *does* appear to tilt, the Aubert phenomenon, although not as much as the actual tilt of the retina relative to the image of the line. An illusory visual sensation seems to arise with tilts of the head but not with sweeps or shifts of the field of view, and it seems to be enhanced by impoverishing the optic array.[8]

Note that the information to specify head rotation is not contained in the

[8] There is considerable experimental literature on the classical problem of the perceived uprightness of the phenomenal world despite the tilt of the retinal image, but this is not quite the same as the problem of its *stability,* which is here considered. For an introduction to the former controversy, see Gibson (1952) and the references given.

optic array (unless the station-point of an eye is displaced relative to the environment). Head rotation is specified only by a shift or rotation of the *borders of the field of view,* borders corresponding to the nose and eyebrows. What moves is a sort of *window* opening on the optic array. The occlusion and disocclusion of the structure of the array can be noticed easily if one holds a tube in front of one eye and then looks about. The world does not move but the window does. If, however, a lens or an inverting lens-system is inserted in the tube so as to alter the occlusion transformation an illusory motion of the world results.

Eye Movements Relative to the Head

The established types of eye rotation are the small saccades or tremor movements during fixation, the large saccadic eye movements, vergences, pursuit movements, compensatory nystagmus during head turning, and after-nystagmus. They all entail displacement or sweep of the retina behind the potential retinal image, but two of them are accompanied by illusory visual sensations and the rest are not. These two are the apparent motion of the background during pursuit and the apparent motion of the environment during vertigo, to which must be added the apparent motion of the environment during a *forced* movement of an eye. In line with the new conception of stimulus information, we need an explanation of why the apparent motions arise. We need no explanation of why they do *not* arise during the majority of eye movements, for motion of the retina is ordinarily registered as eye movement, that is, as sensationless proprioception.

In the theory of sensation-based perception there has to be a position sense of the eye, a feeling of the gaze-line relative to the skull (and thus relative to the skeleton and thus relative to the substratum). Only by means of such a position sense could input of retinal points be corrected so as to yield visual directions-from-here. But, despite all efforts, the position sense has not been demonstrated to exist. The eye has no joint, as the elbow has to register the position of the forearm, and the eye muscles seem to register strain rather than angular position, so that the perception of visual direction remains a puzzle. However, if the ambient optic array (or the potential retinal image) is recognized as a fact of optics to which the ocular system conforms, no special position sense of the eye need be assumed. The animal does not have to "feel" to "know" where his eye is pointing for he can, as it were, "see" where it is pointing (although this need not be a reportable visual sensation). If eye movements can be registered relative to the array they do not have to be registered relative to the skull, skeleton, and ground (Gibson, 1966, Ch. 12).

Returning to the illusory sensations of motion, the explanation may be that, under some conditions, the displacement of the retinal stimulus relative to the retina becomes *obtrusive.* A subjective or introspective attitude is one such condition, an abnormal oculomotor adjustment is another, and a reduction of the information in the ambient optic array is probably a third. Under such a condition the distinguishing of an objective motion from a subjective movement may become difficult. The input of the receptors, or the simpler receptive units, of the retina will become evident when the information sought by the exploratory visual system becomes obscure.

Movement of an Extremity of the Body

Many of the higher animals have limbs that are visible, that is, enter the field of view of the head. Movements of the extremities relative to the main body constitute a large part of the animal's behavior. The classical sense of movement, kinesthesis, is supposed to register and provide for voluntary control of such movements. This afferent input comes principally from the joints of the skeleton (Gibson, 1966, Ch. 6). But clearly an input will also occur from the eyes if the movement of the foot, paw, or hand is in the field of view. The skills of the primate come largely from looking at the hands. The visual feedback is covariant with the articular feedback. The information for positions and connected sets of positions (movements) is the same in both perceptual systems.

The visual motion of an extremity is somewhere between a subjective movement and an objective motion. It partakes of both proprioception and exteroception. The hand moves both with reference to the body and with reference to the world. Its projection is continuous with the body in the optic array and yet it is almost a figure on a ground like the projection of an object in the environment. The transformations arising from this quasi-object include all those that arise from a true object; occlusions of the environment, perspective transformations, and those corresponding to elastic motions. When the human infant watches his moving hand he is probably differentiating the set of those optical motions, thereby improving both his perceptual skill and his proprioceptive skill. Experimental studies of this phenomenon with infant monkeys have been carried out (Held & Bauer, 1967).

When an adult is performing manipulation his eyes move in all possible ways, fixating, scanning, pursuing, altering convergence, and compensating for movements of his head. The enormously complex motions of the retinal image relative to the retina are not registered at all in this situation. But the information in the optic array from the hands, the tools, and the stationary background of the environment, that is, the occlusions, the perspective and topological transformations, are registered with precision by the retino-neuro-muscular system. The optic array itself is the frame of reference with respect to which these informative optical motions occur.

A THEORY OF THE OPTICAL INFORMATION FOR PERCEIVING MOTION AND DETECTING MOVEMENT

A distinction has been drawn between perception and proprioception that cuts across the modes of sensation. There is information in ambient light for both objective motion and for two types of subjective movement, locomotion of the observer and movement of his limbs. Two other types of subjective movement, head turning and eye turning (the movements of the visual system itself), are not specified by transformations in the array or changes of its structure but by changes in the *sampling* of the array.

To be explicit, (*a*) when a figure in the array transforms with occlusion effects the motion of an object is specified. (*b*) When the total array transforms with occlusion effects the movement (locomotion) of the observer is specified. (*c*) When a certain familiar elastic protrusion enters the array the movement of a limb is specified.

These optical motions are registered by exploratory adjustments of the head-eye-retina system. (*d*) When the borders of the ocular orbits sweep across the array head turning is specified. (*e*) When the retina sweeps over the potential retinal image in one of the several ways possible for the oculomotor system an eye movement is specified. These five hypotheses together constitute a new theory that resolves puzzles of long standing.

According to this theory, reportable visual sensations of motion may or may not accompany the pickup of these types of information. They are merely symptomatic of information pickup in any case, not the basis of it. The important kinds of information that the retina seems to register are continuous *transformations* of form and texture and *disruptions* of texture (the occlusion transformation).

IMPLICATIONS FOR RESEARCH

Most of the known experiments and demonstrations concerned with visual motion presuppose the retinal image displacement hypothesis and the general theory of sensations (e.g., Spigel, 1965). Experimenters have engaged in a misguided effort to scratch the retina with a focused pencil of light in much the same way that they would scratch the skin with a stylus. The new theory suggested calls for new experiments.

1. An obvious need is for clarification of what is meant by optical transformations. Even more important are the disruptions of optical texture, the kinds of discontinuity or rupturing that can occur in an array. Methods of displaying such stimulus information are by optical shadow-projection, by animated film projected on a screen, and by computer-generated displays.

2. Points of light in otherwise homogeneous darkness do not serve to simplify the conditions for motion perception, as previously assumed, but only to reduce the information in an array. Textured and structured light is needed if the optical motions in the light are to be controlled and systematically varied.

3. The practice of requiring the subject to fixate a stationary point so as to keep the retina stationary in space during a presentation of motion does not achieve the intended purpose of isolating a displacement over the retina, for whatever moves relative to the fixation spot will constitute either change of pattern or will involve occlusion effects.

4. The ingenious optical procedure of "stabilizing" the human retinal image (actually of moving a beam of light so as to match the spontaneous movements of the eye during fixation) should be recognized as complicating, not simplifying, the normal activity of the retina. Similarly, the neurophysiological results of applying motions to the stationary retina of a paralyzed eye (e.g., Hubel & Weisel, 1962) are highly suggestive but cannot be expected to reveal the neurophysiology of a mobile eye in an intact visual system.

5. The neurophysiological puzzle of how the form of a retinal image can be recognized when the form of the physiological image in the receptors of the retina is altered by an eye movement (the problem of Gestalt transposition) becomes an unnecessary difficulty in the new theory. Neither a form on the retina nor a displacement of it over the retina need be registered —only the *information* in the structure and transformation of an array. The conception of a physiological image, a picture transmitted to the brain, can be finally discarded. Experimenters can permit a moving eye and a changing array without having to worry about the eye-camera analogy.

6. New experiments are possible on the aftersensation of motion obtained in a patch of the visual field occupied by a moving belt, or a slowly rotating disk or an expansive or contractive motion coming to the eye from a Plateau spiral. The aftersensation has been described as an image filled with motion in the opposite direction, but it might just as

well be an aftereffect at the contour of the patch arising from the disruption of optical texture at the contour. Rotation involves a *shearing* of the inner texture relative to the surrounding texture; expansion or contraction involves *destruction or creation,* respectively, of the inner texture at the boundary. The crucial factor might prove to be not the "motion" as such but the kinetic discontinuity.

7. The perception of the speed of motion of an object on a background might prove to depend on the rate of occlusion of the background at the edges of the object. For an object on the earth, this optical information is invariant with changes in the size and distance of the object. The constancy of perceived speed for such an object would thus be explained directly, whereas the kind of speed given by extent of retinal displacement per unit of judged time, speed as defined in physics and conceived in empty space, runs into all the difficulties of the theory of how sensations are corrected by depth perception (Reynolds, 1968). The explanation of Brown's velocity transposition phenomenon, elaborating the suggestion of Smith and Sherlock (1957), might be attempted along the same lines, although this involves the complexities of window motion as distinguished from terrestrial object motion.

8. In general, new conceptions of motion perception go along with new conceptions of space perception, although evidence for the latter has not been considered in this review. The information in light for the perception of surfaces and surface layout, and the nature of this perception, has been considered elsewhere (Gibson, 1966, Ch. 9–12).

9. The apparatus that can be used by a psychologist for systematically varying the information in a kinetic display is rapidly becoming more versatile. The technologies of film and television are adaptable to experiments. Moreover, the methods being tried in a new branch of art, kinetic art, are themselves experiments of a sort. The "abstractions" that arise from a changing optic array are much more interesting and more diverse than those from a painting. The perception psychologist can seize the opportunity to isolate information *about* events and episodes without having to make representations *of* events and episodes.

The kinetic "image" projected on a screen, opaque or transparent, is a method of controlling the light to the eye of an observer. It need not be thought of as a replica, copy, or representation of the environment, as an *image,* but as a *carrier of information,* in this case event-information. One can use an aperture or a window with a disk or a belt behind it instead of a projection screen; or cause a patch to move along a slot in a screen, as Michotte did in his many experiments; or put drawings on a phonograph turntable; or use a cathode-ray tube, or a television tube; whatever device is employed should be thought of as a way of experimenting with the information in light.

In summary, these nine suggestions for future experiments are based on a new conception of what gives rise to the perception of motion. It is not the motion of light over the retina, as we have been tempted to assume, but something that happens in ambient light. This is not easy to specify and measure, but it is surely a change in the structure of the array and it is open to investigation.

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