THE USEFUL DIMENSIONS OF SENSITIVITY [1]

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WHAT I am going to talk about is the relation of sensing to perceiving. We have all believed that we understood the process of sensation fairly well and that only the process of perception gave us difficulties. But I am going to suggest on the contrary that a straightforward theory of perception is possible and that it is our understanding of sensation which is confused.

First let us make sure that there is really a problem in how to treat sensing and perceiving. Some psychologists now maintain that there is no difference between them in fact. The distinction has broken down; they say it has no validity and we should forget it. I think that what they mean is this. An individual can make discriminations in many ways. We can say either that he is *sensitive to* many variables of stimulation or that he can *experience* many kinds of differences between things but what has importance, the argument goes, are only the facts of discrimination, not whether they are called sensory or perceptual. There is something valid in this argument. I would call it the experimentalist's position—stick to the facts and cut the cackle! It is enough to determine just what differences an animal, a child, or a man can respond to and what others he cannot. This limited aim of psychology might be called simple psychophysics (not metric psychophysics) and it is good experimental science. But it provides no explanation of how the individual keeps in touch with the environment around him. The problem of perception, then, the problem of contact with the environment, still remains.

The variables of sensory discrimination are radically different from the variables of perceptual discrimination. The former are said to be dimensions like quality, intensity, extensity, and duration, dimensions of hue, brightness, and saturation, of pitch, loudness, and timbre, of pressure, warm, cold, and pain. The latter are dimensions of the environment, the variables of events and those of surfaces, places, objects, of other animals, and even of symbols. Perception involves meaning; sensation does not. To see a patch of color is not to see an object. To see the extensity of a color is not to see the *size* of an object, nor is seeing the form of a color the same as seeing the *shape* of an object. To see a darker patch is not to see a shadow on a surface. To see the magnification of a form in the field is not to see an approaching object, and to see the expansion of the whole field is not to observe one's own forward locomotion. To have a salty taste is not to taste salt, and to have a certain olfactory impression is not to smell, say, a mint julep. To feel an impression on the skin is not to feel an object, nor is having sensations of strain and pressure to feel the weight of an object. To feel a local pain is not to feel the pricking of a needle. To feel warmth on one's skin, is not to feel the sun on one's skin, and to feel cold is not to feel the coldness of the weather. To hear sound is not the same thing as to hear an event, nor is to hear an increasing loudness to hear the approach of a sounding object. Finally, let us note that having a difference of sound sensation in the two ears is by no means the same as to hear the direction of a sound. The last case is instructive, for we do not in fact have such binaural differences in sensory experience but we do localize sounds.

Having sensations is not perceiving, and this fact cannot be glossed over. Nevertheless, perceiving unquestionably depends on sensing *in some meaning of that term*. That is, it depends on sensitivity or the use of the sense organs. To observe, one must sense. The question I wish to raise is whether or not it is true that to observe one must have sensations.

I realize that any inquiry into the relation of sensing to perceiving raises the ghosts of formidable men. It is disconcerting to feel that Locke, Berkeley, and Hume are looking over one's

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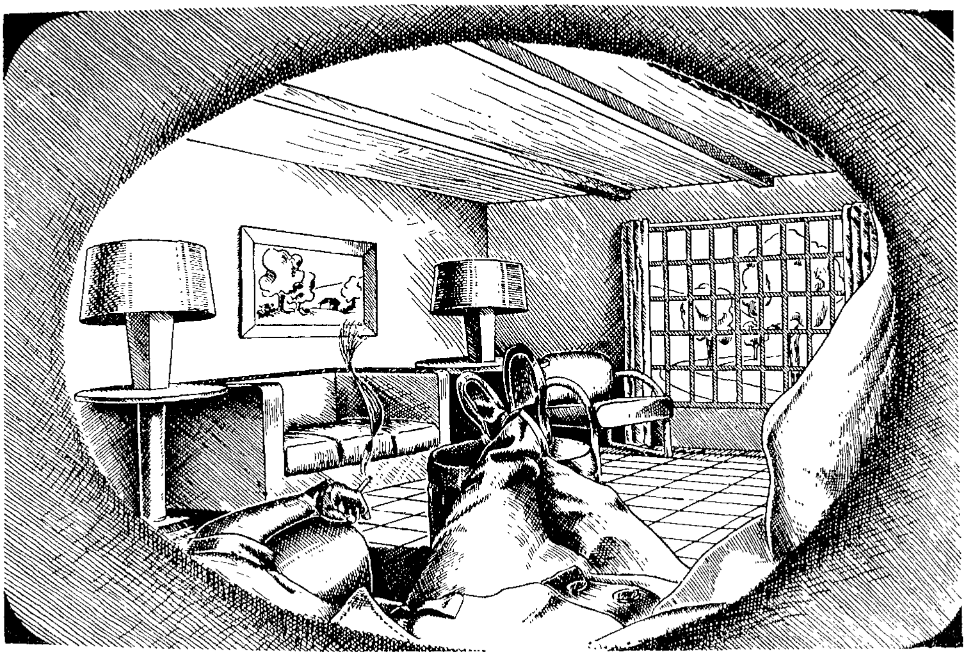

FIG. 1. Momentary cross section of the light entering a human eye.

shoulder, or that Kant and two generations of Mills are raising their eyebrows. A perceptual theorist can get into staggering muddles, and he does well to be cautious. Nevertheless, I have a set of hypotheses to propose and you may judge it both for internal contradictions and for conformity with the facts. My first suggestion, the general thesis, is that the useful dimensions of sensitivity are those that specify the environment and the observer's relation to the environment. There are other dimensions of sensitivity which do not specify such facts and relations, but they are not useful in this way, being only incidental to the activity of perception.

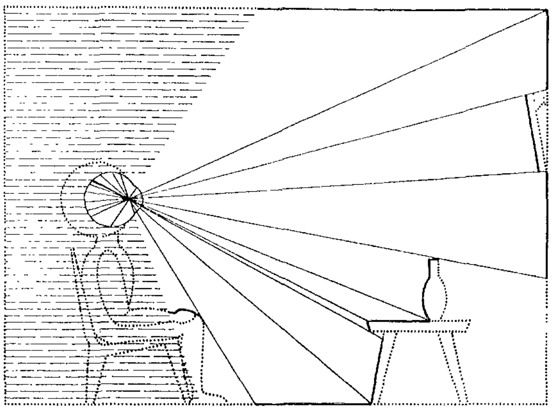

FIG. 2. Longitudinal section of the effective sector of an optic array.

A whole set of correlative hypotheses go along with this radical thesis. They need to be understood before it begins to have plausibility, and the theory should be considered as a whole. The facts of sensory psychology and sense physiology are so varied and voluminous that it is not easy to stand back and take a fresh look at the evidence. Moreover, each of us is apt to have his own private opinion about the data of his senses. But if you will suspend belief in the standard doctrine of sensation and question your favorite introspections, I hope to convince you that the explanation of sense perception is not as difficult and roundabout as it has always appeared to be.

Consider first the puzzle of perceptual constancy. I will not attempt to review the experiments measuring the tendency toward constancy which are limited to vision and which, in any case, are indecisive. Instead I will point to the general evidence for an invariance of perception with varying sensations. This invariance appears not only in vision but also in other senses, notably those excited by mechanical energy, hearing, and touch. The paradox of constancy—the "distal focusing of perception" as Egon Brunswik (1956) put it, is more than a matter of color, size, and shape constancy; it is the heart of the problem of useful sensitivity.

Figure 1 is a picture of a patchwork of visual sensations. Note that it is a cross section of a wide-angle cone of light rays which might enter a human eye, the left eye in this case. Figure 2 is a longitudinal section of such a wide-range cone. It is stationary and momentary as represented in the picture, but whenever the eye moves to a new fixation point it will take in a new cone of rays. At that station point in the room there exists a complete optic array of available stimulation, the array being sampled and explored by new fixations. Figure 3 shows that if the *man* moves, instead of his eye moving, the pattern of the entering array is *transformed,* that is, every patch of color in the array changes form, and the patchwork as a whole is altered.

All this is simply the outcome of the laws of ambient light, or what may be called optical perspective (Gibson, 1961). The laws of *pictorial* perspective with which we are more familiar are a special case involving the sheaf of rays at a picture plane (Gibson, 1960b). Figure 4 is an illustration of so-called linear perspective on a picture.

The sensations of the visual field shift with every movement of the eye, and transform with every movement of the head. But, the perception of the room remains constant throughout. There is invariance of perception with varying sensations.

There are two kinds of seeing, I argue, one resulting in the experience of a visual field and the other in the experience of a visual world (Gibson, 1950). The field is bounded; the world is unbounded. The field is unstable; the world is stable. The field is composed of adjacent areas, or figures; the world is composed of surfaces, edges, and depths, or solid objects and interspaces. The field is fluid in size and shape; the world is rigid in size and shape. As pure cases, they are distinct, although in many experimental situations the observer gets a compromise experience between the two extremes. However, these experimental situations are seldom ones in which the observer is free to explore a complete optic array with his eyes, and are never ones in which he is allowed to move about so as to obtain a series or family of perspectives.

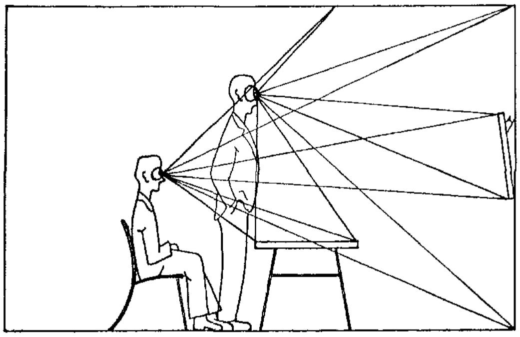

FIG. 3. Perspective transformation of the patchwork of an optic array due to change of viewpoint.

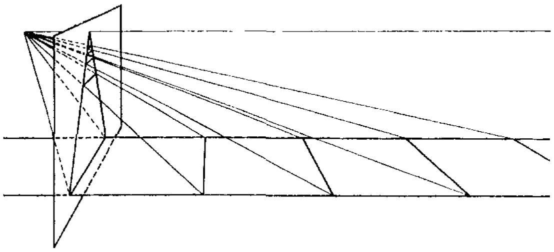

FIG. 4. The special case of a ray sheaf at a hypothetical picture plane.

The visual *field* ahead of the observer during locomotion expands in a sort of centrifugal flow governed by the laws of motion perspective. The visual *world* during locomotion is phenomenally quite rigid. Sensation varies but perception is invariant. To be sure, the observer sees his locomotion. The expansion of the field ahead *specifies* locomotion. This suggests a strange and radical hypothesis—that the visual sensation in this case is a symptom of kinesthesis, having reference to the self instead of the world, and that it has nothing to do with the visual perception of the world (Gibson, 1958).

Another case is that of the perception aroused by the perspective transformation of a silhouette in an otherwise empty field of view. As an experiment, this does not require a panoramic motion picture screen, and it can be carried out in a laboratory. There results a perception named stereokinesis, or the kinetic depth effect, or simply rigid motion in depth (Gibson & Gibson, 1957). Behind the translucent screen in such experiments, at an indefinite distance, there appears a virtual object moving in space. The form of the silhouette changes; the form of the phenomenal object remains invariant. The observer can see a change of form if he attends to the flat screen, but what he spontaneously reports is a rigid object. Ordinarily the transformation is seen as motion of the object, not as a sensation.

Another example is the familiar one that the color of the surfaces of the environment, including the white to black series, do not change as the illumination goes from brilliant to dim. The corresponding sensations, however, the film colors obtained by seeing a surface through an aperture, vary widely with illumination. The perception of whiteness is quite a different matter from the sensation of brightness. With the available stimulus of a complete optic array, the ambient light reflected from a whole layout of surfaces, one can detect the actual physical reflectance of each surface. The absolute luminous intensity of a color patch determines the sensation of brightness, but only if it is taken in isolation.

Finally, I remind you of the difference between the binocular sensations of objects in depth and the binocular perception of the depth of objects. When one attends to his visual sensations one can notice the doubling or diplopia of images in the field of view; crossed diplopia from here to the fixated object, and uncrossed diplopia beyond that point. This doubling changes with every change in convergence, especially as we look to or away from what our hands are doing. We ought to see nothing as single except what lies on the momentary horopter. But of course we see everything as single, that is, we perceive it so. There is a phenomenal unity of each object despite an ever-varying doubleness of its sensation.

Auditory perception, we say, is based on a different mode or department of sense from visual perception. But the paradox of invariant perception with varying sensations holds nevertheless. Consider those very peculiar and special sounds, the phonemes of speech. They are acoustically analysable, it is true, in terms of intensity, frequency, and the frequency spectrum, but their distinctive nature consists of higher-order variables which are now beginning to be specified. Phonemes are the same at quite different levels of pitch and loudness, and hence are phenomenally constant for the voices of men, or women, or children. Speech cannot only be voiced; it can also be murmured, shouted, whispered, or sung. It can be emitted in falsetto, or even by a sort of whistling, without completely destroying the distinctive features which define the phonemic units of speech. They are invariant with changes of auditory sensation.

Consider also the hypothetical sensations that a hearer would get during auditory localization—the different sense impressions or sense data from the two ears. The main stimulus differences are ones of intensity and time of onset. As we know from the experiments of Wallach (1940) and others, the hearer turns and tilts his head from side to side, as if exploring, when he hears an unseen event. For a repeating sound, this means that the relative loudnesses and onsets of sensation are continually changing during the head turning. But the perception is that of a fixed or constant direction of the sound in space. As a matter of fact there is no evidence to show that any man or animal ever heard the changes of binaural sensations when turning his head. There is no awareness of such a flux. Binaural disparity never becomes conscious as binocular disparity can (Rosenzweig, 1961). I prefer to believe that the binaural mechanism is an active system which responds to disparity and tends to react by nullifying it, that is, by pointing the head toward the source of sound. The system responds to the sound field in the air, and we are misled when we consider only the wave train entering each ear separately.

So much for hearing. It is the sense of touch, so-called, that provides the clearest examples of the invariance of perception with varying sensations. In the last two or three years I have been running a series of experiments to test the limits of what an observer can do by touching or feeling without vision, that is, to discover what he can detect or discriminate about surfaces, edges, interspaces, objects, and motions in the neighborhood of his body. In these experiments we can compare the classical results obtained with passive punctate stimulation of the skin (intensity, locus, duality, and motion of a cutaneous impression or a pattern of such impressions) and the results obtained with the self-produced stimulation of touching. In general, an observer can perceive the properties of an object by active touch with quite surprising success. So also, of course, can a blind person. The following results come from a long series of observations (Gibson, 1962).

Rigidity. For example, when pressing on a rigid object with a finger, or squeezing it with the hand, there is an increase of sensation and then a decrease, or usually a flow of changing intensities. The perception, however, is of a constant rigidity of the surface. One simply feels the object. The impression on the skin as such is hard to detect. When one is touched *by* the same object instead of touching it, however, the variation of intensity is easy to detect. An observer can distinguish correctly between two protuberant surfaces, one rigid and the other yielding, when he presses them, but not when they are pressed on his passive skin.

Unity. When feeling one object between two fingers, only one object is felt, although two separated cutaneous sensations occur. This is a surprising fact when you consider it. The different local signs of these impressions have seemingly dropped out of the experience. The result is the same whether the object is held with two, three, four, or five fingers; the multiplicity of impressions on the skin has no effect on the perception of spatial unity of the object. It can be held by two hands and still be one object. It can be felt by many combinations of all 10 fingers, in rapidly changing combinations, and the perception of the object is all the better for it.

Stability. Active touch is exploratory and the observer tends to slide his finger over a corner or protuberance of a hidden object. The impression is then displaced over the skin and a feeling of tactile motion would be expected to occur. But the object is perceived to be stationary in space, and the tactile motion is not noticed. The perception is stable although the sensation is moving.

Weight. When one holds or lifts an object, the judgment of its weight is easier than when it is allowed simply to press downward against the skin of the supported resting hand. In active lifting, a whole set of additional inputs is involved. Besides the end organs of the skin and the deeper tissue, the receptors of the finger joints, wrist joints, and arm joints are excited, and the whole neuromuscular feedback system of the arm is activated. The flux and array of pressure sensations and articular sensations from a dozen or so joints ought to be of bewildering complexity. It

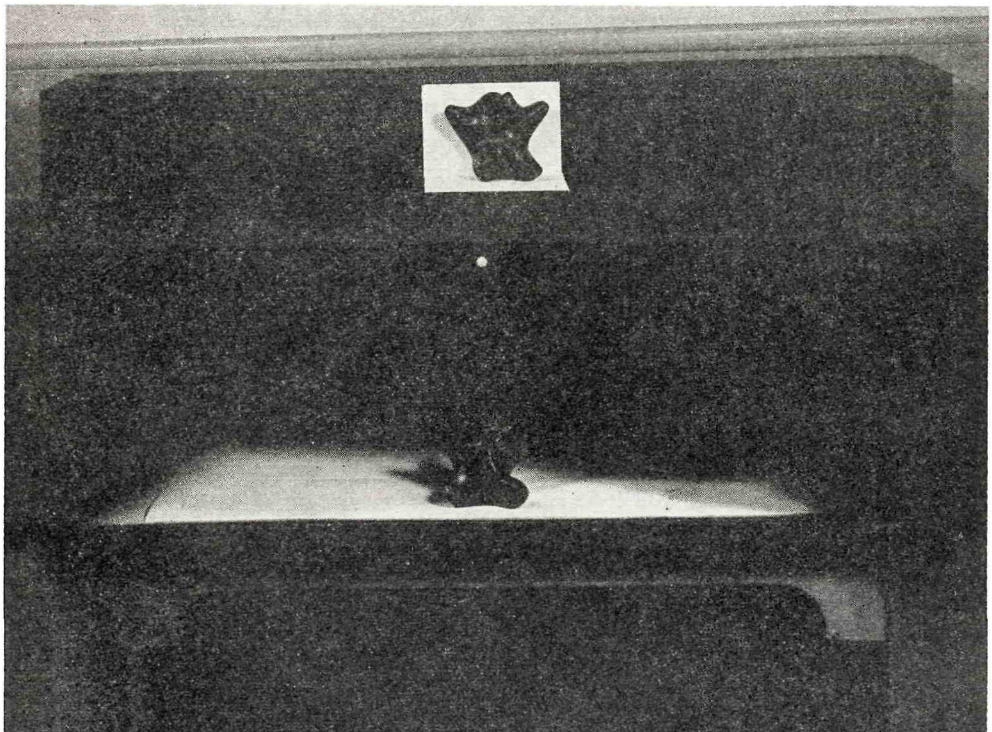

FIG. 5. The visible object and the tangible object.

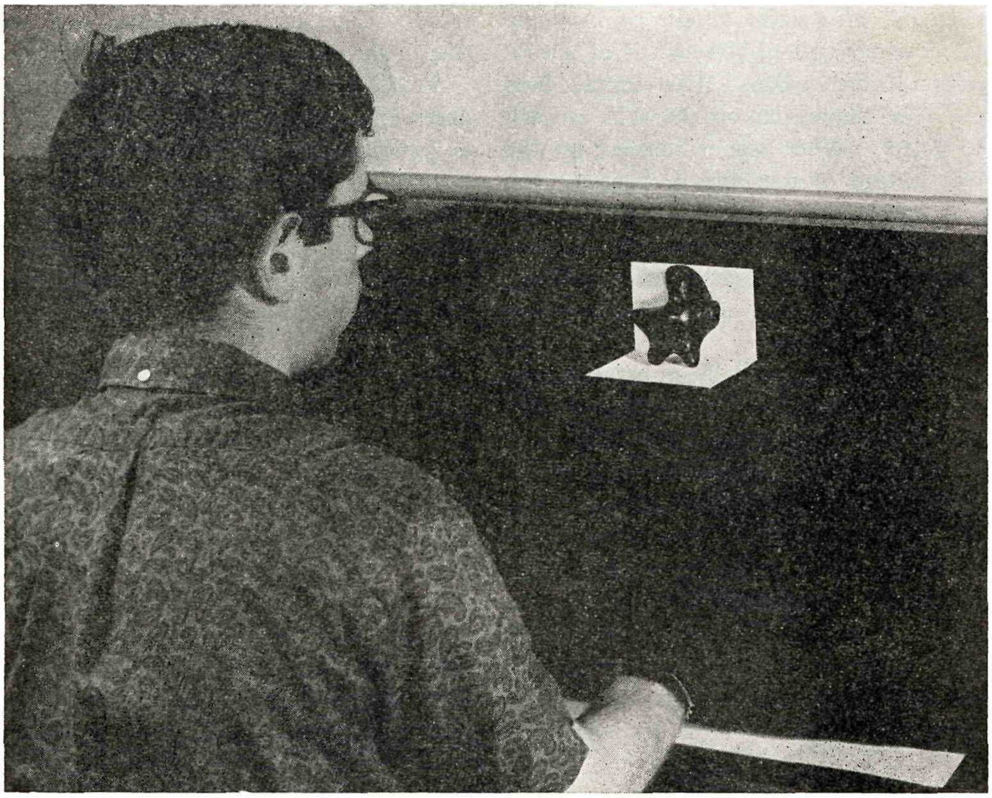

FIG. 6. An observer looking at one object and feeling another.

probably would be if introspection could detect all that goes on in hefting a weight. But what the observer perceives is the mass of the object, unchanging despite the changing sensations. A weight comes to be as well or better perceived, in fact, when the object is shifted back and forth from one hand to the other. Something invariant emerges from this seeming mishmash of excitation. The perception is equivalent to that which accompanies the controlled and isolated sensory impressions of the standardized weight-lifting experiment.

Shape. A method of investigating the perception of unfamiliar shape by active touch is illustrated. Figure 5 shows an object behind a curtain with another identical (or different) object visible on a turntable. Figure 6 shows an observer feeling the object with both hands and judging whether the visible one is the same or different. Alternatively he might be required to match it with one of 10 visible objects, as shown in Figure 7. The degree to which these sculptured free forms differ among themselves is illustrated in Figure 8, where two are identical and the third different, and also in Figure 9, a view from the side. All these objects have six protuberances in front, and a rounded back. The ordinary observer, after very little practice, can distinguish among the tangible objects and match them to their visible replicas with little error (Caviness & Gibson, 1962).

The haptic system of the exploring hand is sensitive to the variables of solid geometry, not those of plane geometry. It gets nothing of a flat picture, but it gets a great deal of the shape of a solid object. The hand can detect all of the following properties: the slant of a surface, the convexity or concavity of a surface, the edge or corner at the junction of two or more surfaces, and the separation of two edges, as our experiments demonstrate. Now it has always been assumed that the skin must be analogous to the retina—that it is a sensory mosaic which registers the form or pattern of the receptors excited. The skin and the retina can, in fact, do so when they are passively stimulated, and this has been taken to be their basic or sensory function.

If the cutaneous form sense is the basis for the feeling of objective shape, however, an impossible

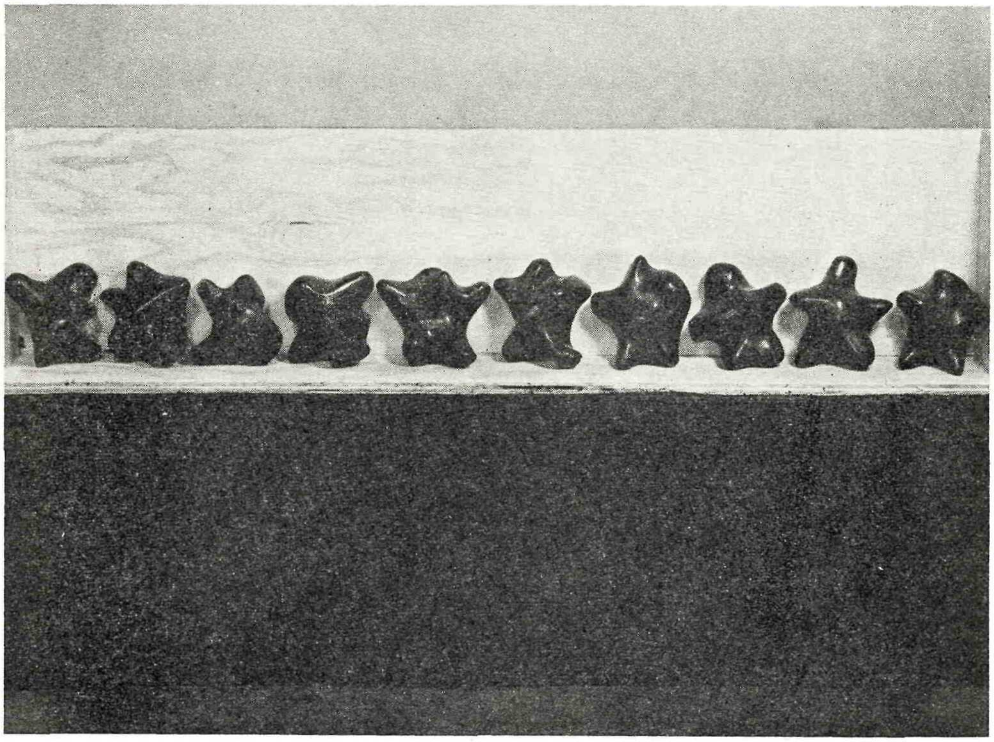

FIG. 7. The 10 sculptured objects used.

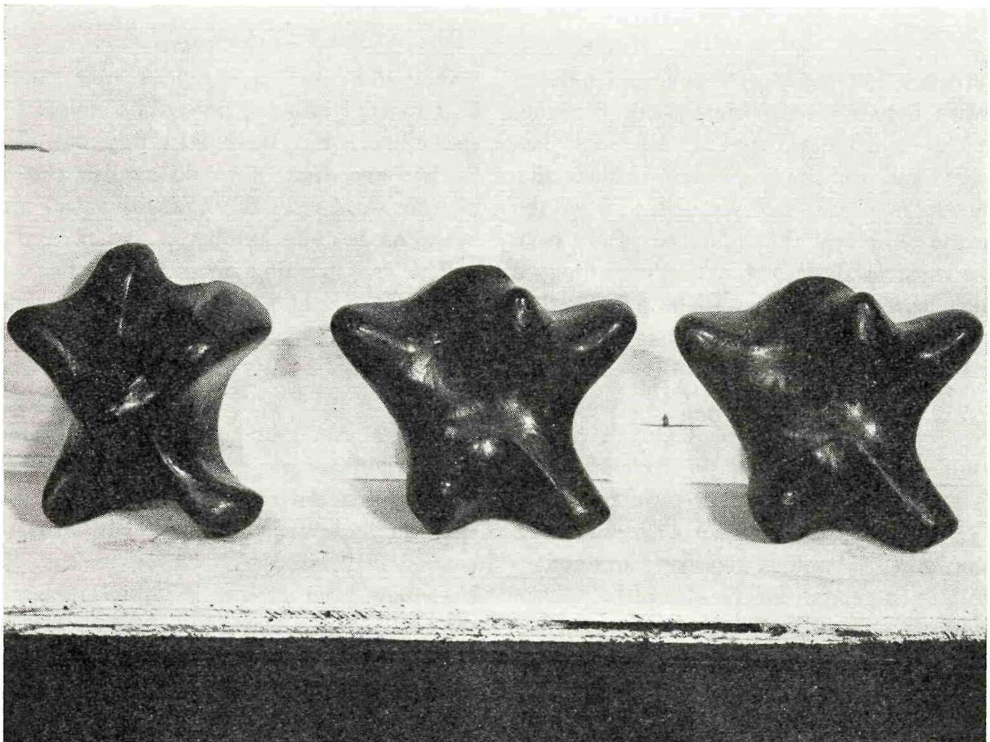

FIG. 8. Close-up of two identical and one different object.

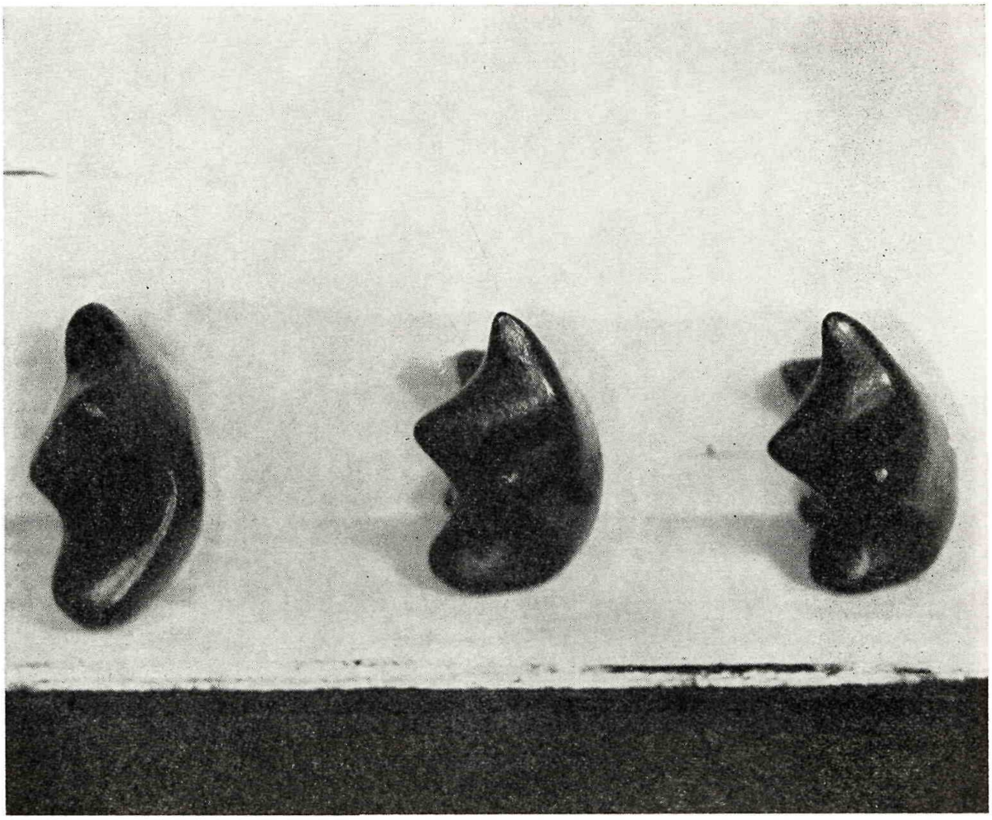

FIG. 9. Side view of three objects.

paradox arises. The series of cutaneous pressure patterns with a pair of exploring hands is something like that of a kaleidoscope; it seemingly has no rationale, and no single pattern is ever like the shape of the object. Nevertheless, from the inputs of the skin and the joints together, from the sensory system if not from the sensations, a remarkably clear perception of shape arises. The phenomenal shape of the object is invariant although the phenomenal patterns of sense data fluctuate and vary from moment to moment.

Conclusion. From all these facts of vision, hearing, and touch we ought to conclude that sensations are not the cause of perceptions. This is a strange statement. But I am willing to draw this conclusion. Conscious sensory impressions and sense data in general are incidental to perception, not essential to it. They are occasionally symptomatic of perception. But they are not even necessary symptoms inasmuch as perception may be "sensationless" (as for example in auditory localization). Having a perception does not entail the having of sensations.

The difficulty in accepting this conclusion is how to explain sense perception *unless* by way of sensations. But there is a way out of this difficulty, and that is to distinguish two meanings of the word "sense." Sensitivity is one thing, sensation is quite another.

The first meaning refers to the effects of stimulation in general. The second refers to conscious impressions induced by certain selected variables of stimulation. We can now assert that in the first meaning sensory *inputs* are prerequisite to perception, but that in the second meaning sensory *impressions* are *not* prerequisite to perception. In other words the *senses* are necessary for perception but *sensations* are not. In order to avoid confusion it might be better to call the senses by a new term such as *esthesic system.* We can then distinguish between sensory perception and sensory experience, between perception as a result of stimulation and sensation as a result of stimulation. The variables of stimulation that cause the first must be different from those that cause the second. Likewise the dimensions of sensitivity to informative stimuli must be different from those to uninformative stimuli.

How is the invariance of perception with varying sensations to be explained? By higher-order variables of stimulation which are themselves invariant, and by the sensitivity of esthesic systems to such invariant information. This kind of sensitivity is useful to animals. It may be innate, or acquired, or a little of both—that is a question for experiment. We can study it directly. We do not have to solve the puzzle of how there can be invariance of perception despite varying sensations. We do not have to inquire how sensations might be converted into perceptions, or corrected, or compensated for, or how one set of sensations might reciprocally interact with another set. If the sensations are disposed of, the paradox of perceptual constancy evaporates. Clearly the hypothesis of stimulus invariants is crucial for this explanation, and I will have to return to it later. Note that with this approach, a seemingly useful tool of experimenters, the index of constancy, loses its meaning. It ceases to be a measure of perceptual achievement. The supposed baseline of this ratio, the "retinal" size, shape, or brightness, cannot be used in a computation of the achievement if it is not the basis of the perception. It falls in a different realm of discourse, and it simply is not commensurable with perceptual size, shape, or brightness.

What are sensations? We might well pause at this stage to consider what is being discarded. Just what are these experiences that the perceptual theorist should no longer appeal to? I suggested at the beginning that our understanding of sensations has always been obscure. The reason for this, I think, is that the term sensation has been applied to quite different things. Let us examine the various meanings of the word to be found in philosophy, psychology, and physiology.

1. The theoretical concept. Theories of perception, as already noted, have always assumed that sensations were the necessary occasions of perception; that they were entailed in perceiving. This is precisely the assuption that is being challenged by my distinction between sensation and sensitivity. Its plausibility comes only from the evidence that *stimuli* are the necessary occasions of perception. I shall argue that none of the kinds of experience which have been called sensory *requires* this theoretical assumption.

2. The experimentalist's concept. In psychophysical experiments the variables of sensation have been taken to be correlates of the variables of physical energy which the experimenter could apply to his observer. In the past, the latter have tended to be those which were fundamental for physics proper, and which were controllable by borrowing the instruments of optics, acoustics, and mechanics. The favorite physical variables were intensity and frequency for wave energy, along with simple location or extension, and time or duration. But these dimensions of stimulation have little to do with the environment. They are fundamental for physics but not necessarily so for sense organs. The dimensions of available stimulation in a natural physical environment are of higher order than these, being variables of pattern and change. We are beginning to be able to control these natural stimulus variables. Note also that the stimuli of classical psychophysics are *applied* to a passive observer by an experimenter whereas the stimuli in perceptual psychophysics are *obtained* by an active observer (although the opportunities for obtainable stimulation are provided by the experimenter). The experiences resulting from these two situations are apt to be different, as the experiments on active touch demonstrate.

3. The physiological concept. The early physiologists discovered the receptor elements of the sense organs and assumed that these cells (rods, cones, hair cells, etc.) were the units of a receptor mosaic. Hence a sensation was taken to be a correlate of a single receptor, that is, the end organ of a nerve fiber. But we are now fairly sure, after recording from single fibers with microelectrodes, that the functional units of a sense organ are not the anatomical cells, but groupings of cells. It was also assumed, after Johannes Müller, that a specific mode or quality of sensation corresponded to any given nerve or fiber. But this generalization too, can no longer be supported since, for one thing, the same fiber can participate in different groupings and have thereby different receptive functions. When Müller insisted that the mind had no direct contact with the environment but only with the "qualities of the sensory nerves," he was con-

fusing sensitivity with sensation. He assumed that the function of the senses was to provide sensations. He was right, surely, to maintain that perception depends on stimulation but wrong to maintain that it depends on the conscious qualities of sense. A sense *organ* has to be defined as a hierarchy of functional groupings of cells, and they are not always adjacent anatomically.

4. The analytic concept. The attempt to reduce consciousness to its lowest terms by introspection culminated in Titchener. A sensation was taken to be an irreducible experience not analysable into components—a simple datum. It is fair to say that the attempt failed. Sensations as combining elements are no longer advocated, although the elegance and force of the structuralist program was such that traces of it are still influential in psychology. Conscious perceptions *cannot* always be reduced to conscious sensations, as the Gestalt theorists have shown. It is clear that sensation in this meaning of the term is not prerequisite to perception.

5. The empiricist's concept. According to Locke and all the thinkers influenced by him, sense impressions are the original beginnings of perceptual experience prior to learning. They are innate, and pure sensations are had only by the new-born infant. They are without meaning and probably without reference to external objects. They are data for thought (or inference, or interpretation, or association, or other kinds of learning, either automatic or rational). What they are like has been the subject of endless inquiry, and this explains our strong curiosity about the first visual experiences of the congenitally blind after the operation for cataract. The theory that original experience was composed of sensations has always appealed to psychologists because the available alternatives, nativism and rationalism, implied either a faculty of perception or a faculty of reason. But we can reject sensation as the original beginning of perception and accept useful sensitivity as something present from the start of life without being driven into the arms of faculty psychology. We can also avoid the nagging difficulty that infants and young animals (and the cataract patients, in my opinion) do not, on the evidence, seem to have the bare and meaningless sensations that classical empiricism says they should have.

6. The concept of an experience with subjective reference. There is still another possible meaning of the term sensation. It is the meaning used in saying that a stomach-ache is sensory rather than perceptual. The same could be said of an after-image as compared with an object, for it seems to refer more to the observer than it does to the outer world. In cases of passive tactual experience, the observer can feel either the impression on the skin as such or the object as such, depending on how he directs his attention. It is as if the phenomenal experience had both a subjective pole and an objective pole. Pain is ordinarily subjective (although there may be some objective reference, e.g., a pin) and vision is ordinarily objective (although there can be a subjective aspect, e.g., dazzle), but all senses, in this view of the matter, carry both subjective and objective information. The observer's body, as well as his environment, can always be noted, together with the relation between them. The body and the world are different sources of stimulation; there is propriosensitivity as well as exterosensitivity. Sherrington was wrong only in supposing that there are separate proprioceptors and exteroceptors. All organs of sensitivity, I suggest, have this dual function.

Note that sensation considered as the subjective pole of experience is quite different from the other meanings of sensation. This is not the provider of data for perception or of messages or elements, nor is it the innate beginning of perception. This is a legitimate and useful meaning, but not the classical one—the basis of the experience of the external world.

Conclusion. Having examined the various kinds of experience that have been called sensory, I conclude that no one of them is required as the necessary occasion of perception. Several of them do undoubtedly occur in a man who introspects, or who serves as subject in an experiment, but the explanation of perception can dispense with all of them.

Reconstruction of a Theory of Perception

If sensitivity is distinguished from sensation, and if perception depends on the former but not the latter, we will have to make a fresh start on the explanation of perception. We will have to discard many cherished doctrines and formulas (like separate and distinct modalities of sense), to clarify and find words for new things (like stimulus patterns and transformations), and to devise new experimental methods (such as how to control stimulus information instead of traditional stimuli). What are the requirements of a theory of perception not mediated by sense data?

Obviously it will have to show that sensitivity, with or without accompanying sensations, is adequate for all the manifold properties of perception (Gibson, 1959). It will have to show that the afferent inputs to the nervous system of a child or a man are rich enough to explain the degree to which he is aware of the world (but the inputs are taken to be those of active systems, not passive receptors or even sense organs). It will have to show that there is information in available stimulation (but the potential stimuli are taken to be limitless in variables of higher order). It will have to show that there are constants in the flow of available stimulation in order to explain constancy. It will have to show that these invariants in the ambient light, sound, and mechanical contact, do in fact specify the objects which are their sources—that something in the proximal stimulus is specific to the distal stimulus (Gibson, 1960a). It will have to suggest how these invariants can be discovered by the activity of selective attention (but there are hints of such a mechanism in what we already know about sense-organ adjustments, so-called, and about the selective filtering of higher nerve centers). It will have to explain propriosensitivity (self-perception) along with exterosensitivity (object perception), but without appealing to the oversimplified doctrine of a special sense of kinesthesis.

Moreover, the theory will have to explain all the observations and experiments of past generations which seem to make it perfectly evident that the observer *contributes* meaning to his experience, that he *supplements* the data, and that significance *accrues* to sensation. I have assumed limitless information in available stimulation from the natural environment. Therefore, the explanation must be that the *experimenter* has limited the available information in all such experiments, or else that, in a natural situation, the available stimulus information is impoverished, as by darkness or a disadvantageous point of view. Psychologists are accustomed to use stimulus situations with impoverished, ambiguous, or conflicting information. These have been devised in the hope of revealing the constructive process taken to characterize *all* perception. In these special situations there must indeed occur a special process. It could appropriately be called *guessing*. But I would distinguish perceiving from guessing, and suggest that we investigate the first and try to understand the second by means of corollaries about deficient information.

The theory will have to provide an explanation of illusions, not only the optical ones but those of all the other channels of sensitivity. The postulates of stimulus information and stimulus ecology, however, suggest ways in which the various illusions can be, for the first time, classified into types and subtypes of misperception, with the reasons therefore. A proper description of the information in an optic array will necessarily include a description of the information in a picture, and the ambiguous, conflicting, equivocal, or misleading information that can be incorporated in a picture. Note that illusions will be treated as special cases of perception, not as phenomena which might reveal the laws of the subjective process of perception.

Finally, the theory will have to be consistent with the known facts about social perception and all the information that has accumulated about the perception and learning of symbols and words. Here, you may think, a sensitivity theory of perception must surely fail. Even allowing that physiognomic and expressive character may have some basis in complex stimulation, words can have no meaning except that supplied by the perceiver. But this objection, cogent as it may sound, entirely misses the point. Once it is granted that stimuli may carry information, or have meaning, the whole theory of meaning is revolutionized, and we have to make a new start on it. Once it is granted that a child or a man can develop sensitivity to the invariants of the ecological stimulus environment it is no great step to admit that he can also learn to respond to the invariants of the social and the symbolic environments. The laws by which stimuli specify events and objects are not, of course, the rules or conventions by which chosen events or objects stand for others, but both are lawful. If animals and children can register perceptual meanings it is not surprising that children and adults can go on to register verbal meanings. However, just as the

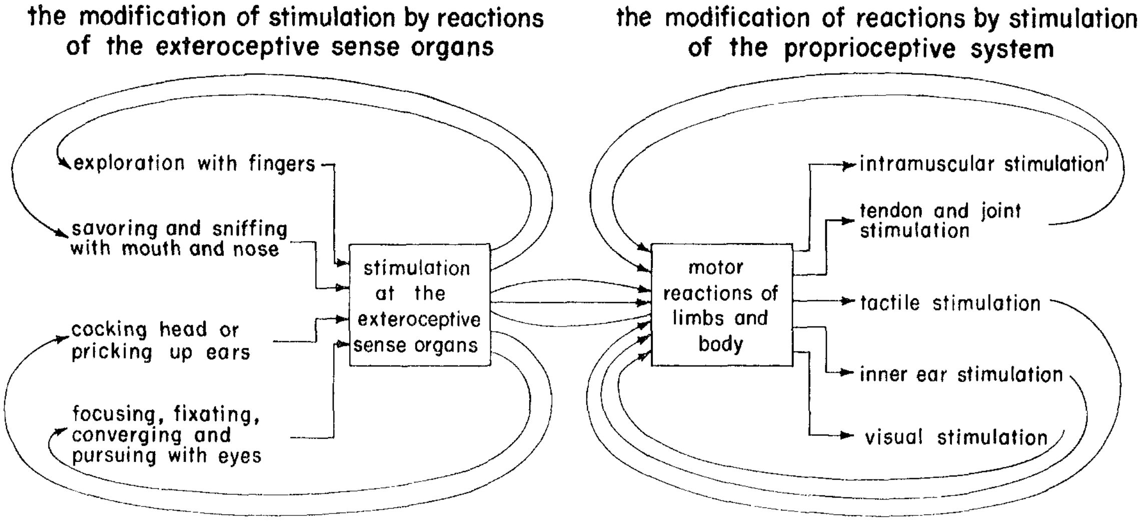

FIG. 10. The feedback loops for exploring stimulation and those for controlling behavior. (The angular lines represent physical action; the curved lines represent neural action.)

child does not first have a repertory of sensations and then attach meanings, so also he does not first hear a vocabulary of words and then attach meanings.

Role of Attention in Perception

An entirely different picture of the senses has emerged. For this to happen, we had to suppose that their sole function was not to yield sensations. Instead of mere receptors, that is receivers and transducers of energy, they appear to be systems for exploring, searching, and selecting ambient energy. The sense organs are all capable of motor adjustment. Figure 10 is a diagram which supplements and alters the usual stimulus-response diagram. It shows on the left the modification of stimulation by reactions of the exteroceptive system, and on the right the modification of reactions by stimulation of the proprioceptive system. The latter is familiar nowadays under the name of feedback, that is, the neural loops essential for the control of behavior. But the loops on the left are just as essential as those on the right. The organism has two kinds of feedback, not one. There are two kinds of action, in fact, one being *exploratory* action and the other *performatory* action. Muscles can enhance perception as well as do work and some, like the eye muscles, have this function exclusively. The hands, mouth and nose, ears, and eyes are all in their own way active systems, as the body is. The primary reaction to pressure on the skin is exploration with the fingers. Chemicals at the nose and mouth first elicit sniffing and savoring. Sound at the ears causes head turning. Light at the eyes brings about focusing, fixating, converging, and exploring of the light. Note that the outcome of all these adjustments is to obtain stimulation or, rather, to obtain the maximum information from the available stimulation.

This new picture of the senses includes attention as part of sensitivity, not as an act of the mind upon the deliverances of the senses. Every esthesic system is an attentional system. Attention is not an intervening process, therefore, but one that starts at the periphery. It also continues to select and filter the already selected inputs at nerve centers, as we know both from introspection and from the evidence obtained by microelectrode recording.

Pattern and Change of Stimulation

Consider the sense organs in the old way, each as a population of receptive units. We have thought of the retina, the skin, the tongue, and perhaps the olfactory epithelium as examples of a sensory surface, a mosaic. Even the Organ of Corti and the lining of the statocysts may be conceived in this way. But note, parenthetically, that the flat surface analogy does not hold at all for the articular sense, that is, the set of receptors for all the joints of the skeleton. The point is that any population of receptive units is capable of delivering a *simultaneous array of neural inputs* (although it is gratuitous or false to call this a two-dimensional pattern or picture, as we do for the retina and are tempted to do for the skin). Apart from this muddle, every sense, then, is a pattern sense. Equally, they are all capable of delivering *a sequence or stream of neural inputs or changes in the simultaneous pattern.* Every sense is therefore a transformation sense as well as a pattern sense.

Consider next the stimulation for these senses, the *proximal* stimulation. In every case it also is a simultaneous array and a successive flux. There are two kinds of order in stimulation, as I once put it, adjacent order and sequential order (Gibson, 1950). Pattern and change are characteristic of stimulation in general, unless it has been sterilized by an experimenter, and here is where the information lies. For example, pattern and change occur at the retina and the skin—even more at the dual retina and the two-handed skin, as the experiments reported have shown. They occur at the basilar membrane of the cochlea as, respectively, the momentary sound spectrum and the transients of sound; moreover the binaural disparity patterns change with head movement. The simultaneous pattern of input from all joints of the skeleton taken together is a highly intricate and interlocked configuration, yet its slightest transformation seems to be registered when the individual moves. Pattern and change occur at the gustatory and olfactory surfaces, and even for the statocysts and the semicircular canals. Pattern and change are universal.

Now, sensory physiologists have always recognized the importance of patterns of stimulation and tried to relate them to the sensory projection areas of the brain. What they have not understood is transformations of pattern. They have tried to imagine a cortical correlate of form, which is difficult enough (as witness Hebb's recent attempt to explain visual form perception, 1949), but not the changes of form which I have described. A tabulation may help to clarify the problem (Table 1).

The motionless frozen observer with his eyes fixed on a motionless frozen world gets a pattern of stimulation from each of his senses (Type I stimulation) but the situation is hardly typical. The array at the eyes is comparable to a panoramic still picture. If he moves, or if something moves, the arrays change (at the eyes, the skin, and the joints, for instance) in specific ways or dimensions (Type II stimulation). I have worked out the dimensions of transformation for the eyes, and it ought to be possible to do this for the other systems. Subjective movement and objective motion (A and B) normally yield different stimuli even at the eyes. The observer can see himself moving, as one does in automobile driving, and even see his own eye movements, as in observing the shifting of an afterimage, but these are perceptions with subjective reference. They are "proprioceptive." We might say that the stimuli are propriospecific, since they carry information about the self.

The third type of stimulus variable is crucial since it is taken to explain the invariance of object perception. Change of an array usually involves nonchange. Some order is preserved in every transformation. Neither at the eye nor the skin nor at any other organ does the energy scintillate, as it were, like the random flashing of

TABLE 1

A CLASSIFICATION OF STIMULUS VARIABLES FOR PERCEPTION

I. The unchanging stimulus array. *Unvarying variables*
   Dimensions of pattern, form, and structure as such

II. The changing stimulus array. *Varying variables*
   A. Self-produced transformation—specifies *motion of self*
      1. With sense-organ exploration—control of *attention* (e.g., eye movement)
      2. With gross motor reactions—control of *performance* (e.g., locomotion)
   B. Other-produced transformation—specifies *motion of object*

III. The *invariants* in a changing stimulus array. *Invariant variables*
   Unchanging dimensions under transformation—specify *rigid surfaces and objects*

the fireflies in a field. There are always invariant variables alongside the varying variables. They are specific to (but not copies of) the permanent properties of external things. It is not a paradox that perception should correspond to the distal object, although it depends on the proximal stimulus, if the object is in fact specified in the stimulus. The Ames demonstrations purporting to show that optical stimulation can *never* specify objects depend on a frozen array from which the invariants cannot emerge.

Consider the difference between *unvarying* and *invariant* variables of stimulation (Type I and Type III). In the former case the stimuli that would be invariant do not get separated off from those that would vary if the array underwent transformation. The frozen array, the case of continuous nontransformation, carries less information. The case is one that never occurs in life. A prolonged freezing of the pattern of stimulation on the retina or the skin, in fact, yields an input which soon fades away to nothing.

The normal world is sufficiently full of motions and events to make a stream of stimulation. But even without external motions a flow is produced. The normal activity of perception is to explore the world. We thus alter its perspectives, if events do not alter them for us. What exploration does is to isolate the invariants. The sensory system can separate the permanence from the change only if there is change.

In vision, we strive to get new perspectives on an object in order to perceive it properly. I believe that something analogous to this is what happens in the active exploratory touching of an object. The momentary visual perspectives, of course, are pictures or forms in the geometrical sense of that term whereas the momentary tactual perspectives are not. Nevertheless they are similar since, for an object of a given solid shape, any change of cutaneous pattern like any change of retinal pattern is *reversible*. The impression of the object on the skin, like its impression on the retina, can recur by a reversal of the act that transformed it. The successive patterns thus fall into a family of patterns which is specific to the object. I submit to Hebb the suggestion that the first problem in perceptual physiology is not how the brain responds to form as such, unvarying form, but instead how it responds to the invariant variables of changing form. I think we should attempt a direct physiological theory of object perception without waiting for a successful theory of picture perception.

Invariant Properties of a Changing Stimulus Array

The crux of the theory of stimulation here proposed is the existence of certain types of permanence underlying change. These invariants are not, I think, produced by the acquiring of invariant responses to varying stimuli—they are *in* the stimuli at least potentially. They are facts of stimulus ecology, independent of the observer although dependent upon his exploratory isolation of them. This kind of order in stimulation is not created by the observer, either out of his past experience or by innate preknowledge. Just as the invariant properties of the physical world of objects are not constructed by the perceiver, so the invariant properties in available stimulation are not constructed by him. They are discoverable by the attentive adjustments of his sense organs and by the education of his attention.

Some of these stimulus invariants are extremely subtle. The ultimate subtleties of the information in stimulation may well be unlimited. But other invariants are quite simple and easily detected. The optical texture that specifies a physical surface (in contrast with the textureless patch that specifies an empty space) is invariant with illumination and under all transformations of perspective. Introspectively we say that one yields a surface color and the other a film color, but the spatial meaning is what counts, not the introspection. The textures of earth, air, and water are different, and the differences are constant. So are the differences that specify to the young of any species the fur, feathers, or face of the mother. The intensity and wave length of the light are irrelevant. The infant seems to be sensitive from the beginning, more or less, to such external stimuli as these. The tablet of his consciousness may be nearly blank at birth, as Locke believed, but the impressions that do appear are vague perceptions, not bare sensations. The earliest dimensions of sensitivity are useful ones.

Classical sense impressions, I think, are something of which only a human adult is aware. They tend to arise when he introspects, or when he tries to describe the content of experience, or the punctate momentary elements of perception, or when simple variables of physical energy are experimentally isolated for him by a psychologist, or when stimuli are applied to his receptors instead of his being allowed to obtain them for himself. Far from being original experiences, they are sophisticated ones; they depend on having had a great deal of past experience.

This is not to deny that perception alters with learning or depends upon learning. Instead it points to a different kind of learning from that we have previously conceived. Unquestionably the infant has to learn to perceive. That is why he explores with eyes, hands, mouth, and all of his organs, extending and refining his dimensions of sensitivity. He has to separate what comes from the world and what comes from himself. But he does not, I think, have to learn to convert sensations into perceptions.

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