Prolegomena to an Aesthetic

TERENCE W. BARRETT
Neuropsychological Laboratories, Stanford University
Stanford, California

ABSTRACT

The subject of concern is the basic informational "givens" or constraints in perceptual processing. The means of study is by perceptual illusions such as the figural aftereffect and the Gibson adaptation phenomenon. Interpretations are given in terms of neural holography using factual data as logical bounds.

In the transcendental aesthetic we shall, therefore, first isolate sensibility, by taking away from it everything which the understanding thinks through its concepts, so that nothing may be left save empirical intuition. Secondly, we shall also separate off from everything which belongs to sensation, so that nothing may remain save pure intuition and the mere form of appearance, which is all that sensibility can supply a priori.

— Immanuel Kant
Critique of Pure Reason
(1787), pages 66–67

INTRODUCTION

There is an undefined area of the study of perception that deals with the basic information used by the nervous system to initiate perceptions. This basic information cannot really be considered "sensation," as this would imply a certain interpretation of that which is the means of interpretation. The writer takes the view that sensations are only interpretable within a perceptual context and not vice versa. Perceptions, therefore, should be interpreted within another context and it is with this neglected

area that this article concerns itself. Kant used the term "aesthetic" to mean the doctrine of sensibility—not to be confused with the empirical study of taste. Whatever the suitability of the term, the concern is with the "physiological a priori." Gibson [16, 17] has concerned himself with aspects of this study; this article, however, attempts to deal with the neurophysiological aspects of the problem, and the theoretical results will, perhaps, differ considerably.

Within this field, it would appear, there are a number of phenomena or problems worthy of study. This article reviews the figural aftereffect (FAE) and the simultaneous contrast effect. In examining these two phenomena, explanations are given in terms that advocate a judgmental view of perceptual activity. The descriptions follow the lines of Piaget [57], while the explanations follow the holographic theory of Pribram [61]. Data supporting the holographic view of the central nervous system are referred to [71].

Finally, the importance of the basic information of proprioception is emphasized and a general scheme of the connection between the proprioceptive and perceptive functions in the organism outlined.

THE FIGURAL AFTEREFFECT AND THE GIBSON SIMULTANEOUS CONTRAST EFFECT

The figural aftereffect consists of color, depth, and displacement effects. After fixation on a spot in a perceptual display (inspection figure or I-figure), the display is exchanged for another, differing in certain respects (test figure or T-figure), and the effects of fixation are noted.

The Gibson simultaneous contrast effect consists of comparison simultaneously of a standard and test figure after prior inspection of the standard figure.

Since McEwen's review [52] of the literature on the figural aftereffect and the Gibson adaptation phenomenon [14–16], a number of studies have appeared that throw more light on this problem area (cf. *Quarterly Journal of Experimental Psychology* 13, 1961).

The Gibson effect has an interocular transfer (the effect is, however, reduced), and occurs without eye fixation. Peculiar to the figural aftereffect is the "distance paradox," namely, that although depth and color effects are most marked in regions of intense satiation, the size displacement effect is greatest not where the T-figure contours coincide with those of the I-figure but at some distance from this.

Koehler [29–34] proclaimed the cortex as a volume conductor but could not account for the fact that when the I-figure coincides with the T-figure, the T-figure appears smaller. According to the volume conduction theory of the figural aftereffect, satiation should be greater and proceed more rapidly inside the I-figure than in the environment. Consequently, the coincident test-figure current should be turned away and more current should flow in the environment than in the interior of the figure. The T-figure should thus appear larger. This discrepancy of fact and theory was mentioned by Hebb ([19], pages 54–58), who noted that with Koehler's theory it is not possible to predict when the test figure will grow and when it will shrink.

In 1954 Sutherland published the controversial paper [74] that intended to show that it is apparent size rather than the retinal size of the I-figure that determines the effect. This conclusion was arrived at after a confrontation of a retinal and apparent sizes on a specific T-figure. Not always, however, has this result held up upon replication.

Sagara and Oyama [66] report that Nozawa [54] studied the Gibson effect using the apparatus shown in Fig. 1. It was found that the extended
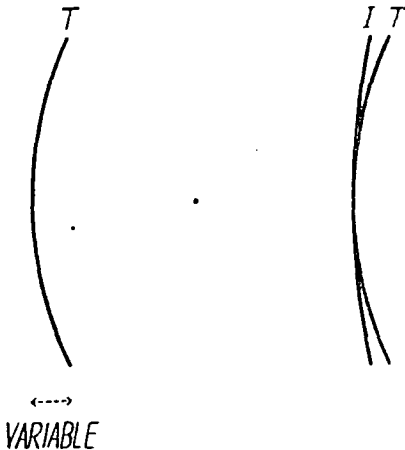

Fig. 1. Inspection and test figures used by Nozawa (from [66]).

"curved line" effect revealed that the T-figure always decreased its apparent curvature, even when it was curved more than the I curve. According to the Koehler theory of volume conduction, the T-figure should have been expected to increase its apparent curvature.

Using circular figures and investigating the figural aftereffect, the authors report that maximal growth occurs when the I-figure is one half the T-circle in diameter and the maximum shrinkage occurs when the I-circle is twice as large as the T-circle. It means that the optimum
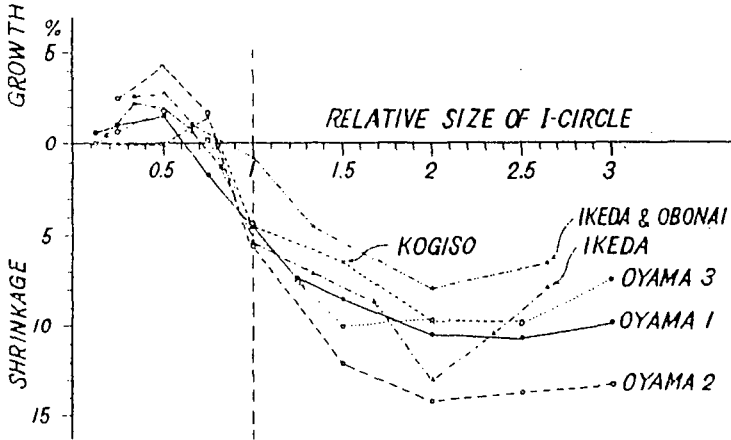

Fig. 2. Aftereffect as a function of the size ratio of the inspection circle to the test circle (from [66]).

condition for displacement, or the limit of the "distance paradox" phenomenon, is not determined by the absolute distance between the outlines of the I- and T-circles, but by the relative size of the I-circle and T-circle (cf. Fig. 2).

The close relationship between the figural aftereffect and the assimilation-contrast illusion was experimentally ascertained by Ikeda and Obanai [24]; they discovered continuous transition of results from one to the other of these two phenomena as soon as the temporal conditions of the two circles were varied from simultaneity to succession by means of a tachistoscope (cf. Fig. 3).

A temporal delay is indeed needed. George [13] showed a contrast effect when the figures were superimposed but an assimilation effect when a temporal delay was introduced.

A significant study was published by Pollack [60], who showed that the proportion of the aftereffect varies in a certain fashion with age. Figure 4 shows the relationship, which will be mentioned again in connection with Piaget's [57] notions on the derivation of certain illusions peculiar to childhood and those peculiar to adulthood.
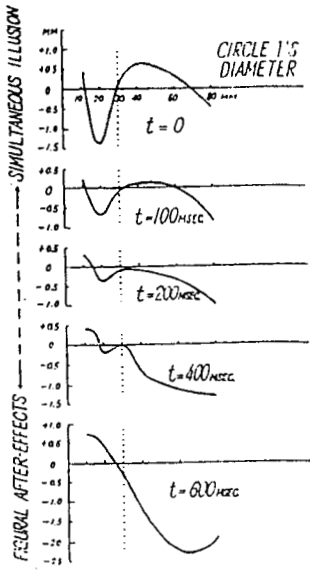
FIG. 3. Aftereffect as a function of the size of inspection circle at each stage of asynchronism of presentation of I-figure and T-figure. Exposure time of both figures is 500 msec, and the start of exposure of the T-figure is delayed 0–1000 msec from that of I-figure (delay indicated by t). From [66].
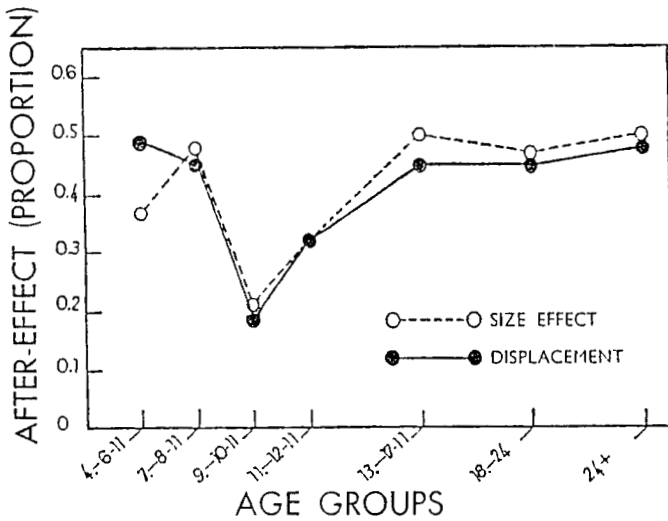

FIG. 4. Graph of proportions of frequencies of normal displacements at each age level for the two stimulus figures. From [60].

Wohlwill [90] found that the effect of assimilation decreases with age, whereas contrast effects, at least of the temporal variety, increase.

THE SIGNIFICANCE OF PIAGET'S THEORY OF PERCEPTION FOR THE FIGURAL AFTEREFFECT

Piaget's mathematical theory of perception summarized in *Les Mécanismes Perceptifs* [57] was developed and presented gradually over a period of thirty years in *Archives de Psychologie*. Vurpillot [85] has provided a short but excellent digest of the theory.

The theory proposes a nonadditive system of perceptual equilibrium, and is derived within the context of the idea that discrimination occurs prior to the application of schemas of space, and so forth, to the input. As it is considered that perception never attains the utmost economy of equilibrium, the theory is concerned with the *constitution* of the input prior to processing.

In the terminology of the theory, a "transport" is an integration of sensations and is derived from the heterogeneity of the spatial-temporal field. A fundamental hypothesis is that not only is a fixated element overestimated relative to that which is not, but the element fixated longest is overestimated in relation to the other one. Elements from one part of a field are progressively "encountered," the model following a logarithmic law whereby to the arithmetic progression $n, 2n, 3n, \ldots,$ which may express the progressive duration of perception, corresponds the geometric progression $(1 - an)$, $(1 - an)^2$, $(1 - an)^3$ of the probabilities of encounter.

The model is used in the comparison of line lengths. As an example, consider two lines L_1 and L_2. In the case of L_2, the probability of complete coupling with the n points of L_1 is P''. For the m points of L_2 the probability of complete couplings with the n points of L_1 will be P''''. For $L_1 = L_2$, the probability of complete couplings becomes $[(p'')p'']'' = p^{m \cdot 2n}$; for $L_1 = 3L_2$ it will be $p^{m \cdot 3n}$. Specifically, to the *arithmetic* progression of the length of L_1 corresponds a *geometric* progression, by a factor of p'' of the probability of complete couplings.

FIG. 5. Graphs of strength of Delboeuf's concentric circle illusion. A's radius is 9, 12, 15, 18, and 36 mm; dotted line represents 5–6 year olds; broken line, 11–12 year olds; solid line, adults. Abscissa: difference between A and A' expressed as percentage with respect to the radius of A (from [58]).

$A = 9$

$A = 12$

$A = 15$

$A = 18$

$A = 36$
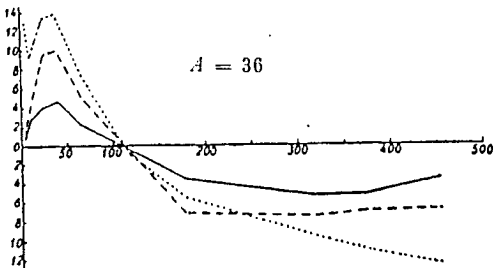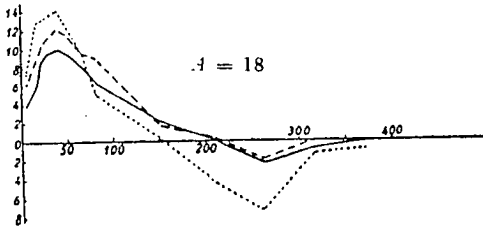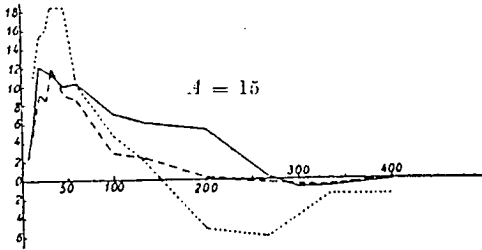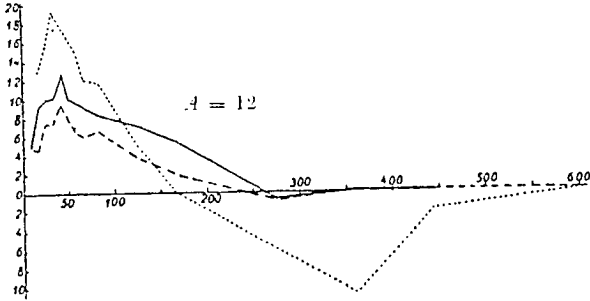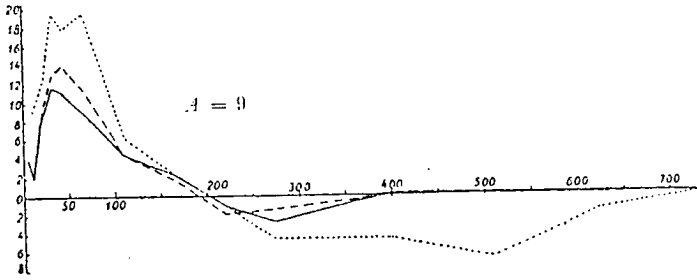
Thus the law of relative centrations represents a twofold probabilistic relationship. The first expresses the probability of difference couplings in relation to the aggregate of possible couplings. The second expresses the probability of couplings over the line that is being measured relative to those applying the largest dimension of the figure.

Not so far removed is the information-gathering model of Binder [2], who also considers entropy differences as determining misperception.

Piaget [56] has pointed out that perception bears the hallmark of irreversibility of infraclasses in his system of logic. This irreversibility is apparent in that perceptually a resemblance (R) is not the exact inverse of a difference (D), but sometimes the one and sometimes the other predominates. The label "deforming" is given to those cases in which a smaller figure is overestimated with respect to a bigger figure. The relationship is thus $R > - D$ when $A > A'$; or, $R = - D + P(RD)$ is the uncompensated transformation relative to the reciprocal inversion. When a small figure is underestimated with respect to a big figure, the
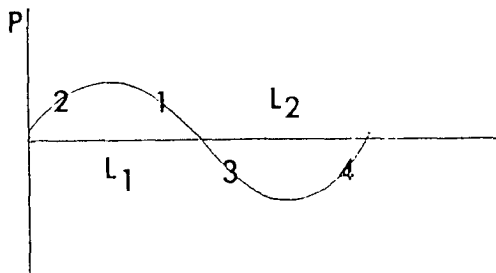
Fig. 6. Probability of perceptual deformations with respect to line fixated (from [56]).

difference between them predominates. Thus, $D > - R$ when $A < A'$; or, $D = - R + P(DR)$. There is a relationship, therefore, between the lengths of L_1 and L_2 and P. Referring to Fig. 6, (1) depicts the magnitude of P between no illusion and the maximum positive illusion; (2) between the maximum positive illusion and the point of origin (where $L_1 = L_2$ and $L_1 = 0$); (3) between the median nulle illusion and the maximum negative illusion; and (4) between this maximum and the nulle terminal illusion (for L_2 so large that there is no effect on L_1). Then,

$$r > - d \quad \text{or} \quad r = - d + P(RD) \quad \text{for} \quad (1),$$

$$r < - d \quad \text{or} \quad r = - d - P(RD) \quad \text{for} \quad (2),$$

$$d > -r \quad \text{or} \quad d = -r + P(RD) \quad \text{for} \quad (3),$$

$$d < -r \quad \text{or} \quad d = -r - P(RD) \quad \text{for} \quad (4).$$

Piaget, Vinh-Bang, and Matalon [59] define the law of relative centration as $P = (L_1 - L_2)L_2 \cdot nL/S \cdot L_{max}$ where L_1 is the longer of the two compared lines (straight) and L_2 is the shorter; L is the straight line upon which the measurement is performed; n is the number of times that $(L_1 - L_2)L_2$ intervenes in the figure generally; L_{max} is the maximum length of the figure; and S is the surface. If each point of the encounter counts but a single time, then the increase in the number of encounters and therefore the increase in the apparent length of the line will not be linear. It will present itself in the form of a logarithmic function or of an exponential that can be written:

$$P = 1 - (1 - P_r)^{nt}$$

where P_r is the probability that n encounters occur and n the number of encounters in t units of time. If the probability of encounters on the
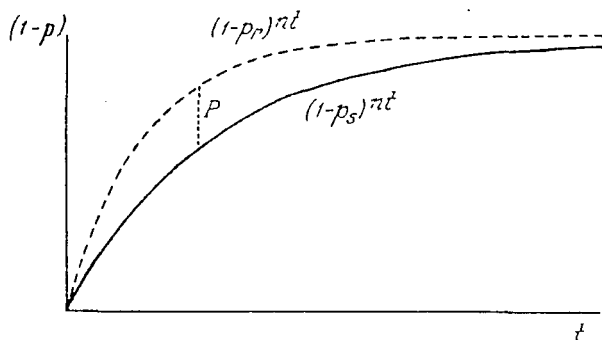
Fig. 7. Graphic representation of the temporal maximum (from [57]).

second of two lines is designated by P_s and the probability of encounters on the first as P_r, then the probability P of incomplete coupling is

$$P = (1 - P_r)^{nt} - (1 - P_s)^{nt}.$$

It is then possible to explain the presence of a temporal maximum of illusion by the aid of the three preceding notions (cf. Fig. 7).

By his topic-neutral probabilistic theory, Piaget [57] is able to explain the Gestalt phenomenon without recourse to mythical neurophysiology. A "good form" for Piaget is one in which the deformations $B(A) > B$ and $B(A) < B$ compensate each other exactly.

Thus, given satiation somewhere in the central nervous system, the figural aftereffect appears as an illusion because, I am suggesting, the interpretation of the satiated input in comparison with the test figure proceeds according to the description of Piaget's law of relative centrations. The relationship between the lengths of L_1 and L_2 depicting the maximum possible illusion explains the distance paradox. The law of temporal maximum explains equally the progression of the illusion from assimilation to contrast as the delay between presentations is reduced [13].

It remains, therefore, to show that there exists higher-order processing of a visual input susceptible to satiation. The data of MacKay and Sutherland indicate this.

EVIDENCE FOR THE EXISTENCE OF HIGHER-ORDER SCHEMAS PROCESSING VISUAL INPUT

Before using the Piagetian notions to explain the data, further studies will be mentioned. An important paper is that by Sutherland [75], who, first, opts for an explanation on the lines that some analysis of the stimulus
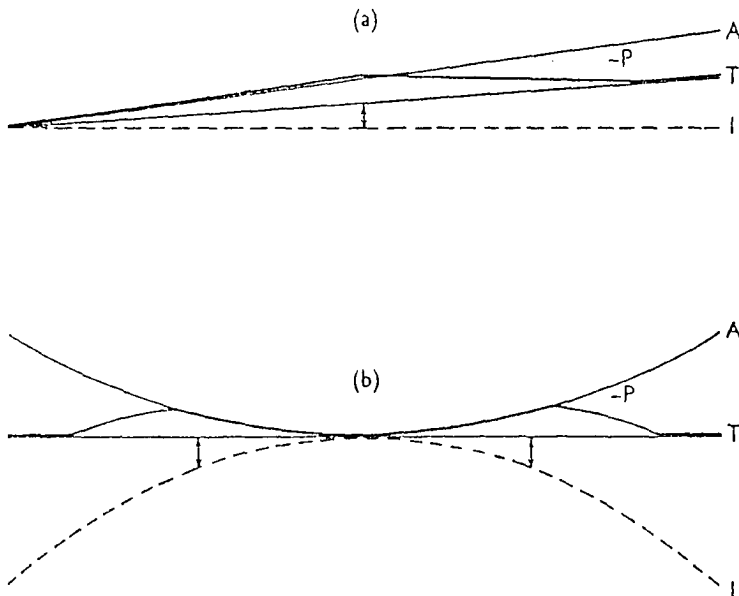

FIG. 8. From [75].

is being performed before the stage of the nervous system at which the process underlying the FAE occurs. Two interesting examples are given, throwing some light upon the distance paradox. In the first figure if the I-line is fixated, the T-line should appear as (P); displacement should be small where I and T lie near together, gradually increasing to a maximum and then decreasing. In fact, T is seen occupying the position of line A. When a curved line is shown (Fig. 8), and a straight line is used as I-figure, the straight line should appear like line P but in fact appears like line A. Thus, Sutherland's data support the notion that the figural aftereffect occurs after analysis of the stimulus is undertaken.

Story [73], using binocular vision, obtained results similar to Sutherland in the apparent size versus retinal size controversy. With one eye fixating the I-figure and the other eye the T-figure, results are negative, which would seem to implicate accomodatory processes in the illusion. Negative evidence for apparent size as a determinant is provided by Terwillinger [78]; it must be borne in mind, however, that Sutherland's figures were in the ratio 1 to 2.5.

Interestingly, for the later conclusion, Duncan [11] has verified that differing inspection times affect only the rate of decay and not the initial amount of the figural aftereffect.

If the figural aftereffect occurs after stimulus analysis, then the work of MacKay [50] is important in showing that there is schemalike activity upon lower centers. When, after watching a rotating neutral pattern, a target figure is observed, a radial complementary afterimage (CAI) has the appearance of rotating. "This suggests that, whatever may be the transformation responsible for the after-impression of rotation, it occurs after the stage at which the CAI is generated, since it operates on the CAI and could have no effect on the circular symmetrical stimulus" ([50], page 347).

Using a stabilized image, it was found that both a streaming effect reported and the CAI are unaffected by the stabilization. The stabilized image fades irregularly and spasmodically and on each fade-out is replaced by a moving complementary afterimage (CI). The CAI transfers from eye to eye and, while viewing a regular pattern with one eye, one can use traces of its CI in a random noise source viewed in the other eye. A retinal locus for the phenomenon has been ruled out on the grounds that blurring of the edges of large-scale patterns may be tolerated over an area that would be covered by 100 lines of the smallest patterns. Furthermore, although the phenomena reported occur with either mono-

cular or binocular viewing, the binocular CAI is twice as lasting, which would hardly be expected if the oscillatory aftereffect were in the retina, unless complex mutual reinforcement is postulated by centrifugal fibers. The effect, therefore, appears to be occurring after the stage of binocular fusion; and has been interpreted as a standing wave phenomenon in the neural network. Let us note, however, that here is evidence that the input is being acted upon and not "categorized" in any passive manner; this mechanism, whatever it is, will be evoked in the final discussion.

MacKay also mentioned patterns that have an interest in that they supply evidence on the order of priorities in perceptual organization. Contradicting the empiricists' belief in a stable "external world," MacKay writes that

> one might have supposed on grounds of "parsimony" that the form of the perceived figure should be preserved invariant under involuntary as much as under voluntary movements of its retinal image. In fact, however, the parsimony is exercised at a lower level. Each local area of the perceptual field appears to have metrical autonomy, constrained only by the topological necessities of linking up with its neighbors. Each area responds to a change by making the minimal alteration justified by the evidence — irrespective of the conceptual improbability of the perceptual result ([50], pages 352 – 353).

In the face of the evidence above that the "rubber sheet phenomenon" generated by gently rotating the eye to and fro is eliminated in the neighborhood of a thread placed across the pattern on one side of the center perpendicular to the direction of the motion, although on the opposite side it continues unaltered, an S-S association theory of perception finds little support. Remember that Piaget's theory requires a stable L_1 against which comparisons are made. Belief in a "given" input just will not do.

MacKay believes that parsimony is exercised at a lower level. Each local area of the perceptual field appears to have metrical autonomy

> ...constrained only by the topological necessities of linking up with its neighbors. Each area responds to a change by making the minimal alteration justified by the evidence — irrespective of the conceptual improbability of the perceptual result.
>
> The (phenomena) are, in fact what one would expect, if, as I have argued elsewhere [49], the perceptual mechanism functions on the principle of Fisher's null hypothesis — taking stability as the norm, demanding adequate evidence before making any change in the world-as-perceived, and in every case making in minimal change (however surprising) that will match such new evidence as may arise ([50], page 353).

Prichard [63] has also investigated visual illusions as stabilized retinal images. They are unaffected by eye movements and, therefore, are not peripheral.

Story [72] investigated the figural aftereffect with an ambiguous I-figure that could be taken for either a B or a 13. Greater effects were obtained when B was suggested to the subject, indicating the central origin of the effect. Set alone, however, is insufficient, as there are no differences between groups who perceived no I-figure.

Let us consider further this "minimum principle" of perception. In a significant study, Rock and Ebenholtz [64] have shown that stroboscopic movement is based upon a change of phenomenal rather than retinal location. Wallach, Moore, and Davidson [89], Wallach and Karsh [86], Wallach and Zuckerman [88], and Wallach and McKenna [87], in a series of studies using a stereoscopic apparatus, have shown conclusively that depth perception is very much a function of accommodation and convergence and definitely not a function of image size. We may conclude, therefore, that the response system is primary in dictating what will be interpreted and discriminated and that afferent control is monitored by the dictates of the efferent system.

Other examples of the minimum principle can be found in Hochberg's article [21], which coined the term, and in the perceptual elaborations of stroboscopic presentations by Toch [79].

In apposition to this view MacKay [45–48], using a stroboscopically lit room, has indicated that change rather than stability is in question when perception is examined:

> Briefly, the argument is that if perception is the adaptive "keeping up to date" of an organism's state of organization for activity in its world, then what requires justification is not the maintenance of stability but the perception of change. The internal state of organization, which implicitly represents the perceived world, should remain unaltered unless sufficient information (in the technical sense) arrives to justify a change, by indicating that the current state of organization is significantly mismatched to the state of affairs sampled by the receptor system. ...the change perceived, however surprising to the observer, is always the most parsimonious which will match the discrepant information, perception would appear to be organized on the conservative principle of the null hypothesis ([48], pages 507—508).

The stroboscopic phenomenon has also been investigated by Piaget, whose idea it is that if the flashing input is at a rate exactly corresponding to the brain's "coupling" activity of comparing one image with the other,

only one image moving from one place to the other will be seen. This, perhaps, is a little at variance with the MacKay notion of parsimony at all costs and would be more akin to doing one's best with the input in the light of inadequate machinery for handling unusual input. Given one extra-experiential reference point, such as pressing the eyeball, the illusion (as MacKay shows) falls to heel. This is the equivalent of giving an L_1 to the organism or, in another sense, giving it proprioception, which never deceives. Rather than the sluggish organism depicted by the MacKay null hypothesis idea, I would prefer the Piagetian notion of an organism with limited information capacity doing its best with the input handled by its own machinery. As MacKay's evidence is based on the stroboscopic phenomenon, which is itself explained and subsumed under Piaget's more comprehensive theory, there seems little reason to believe MacKay's interpretations in this matter.

DISCUSSION

A judgmental theory of perception will not work unless two inputs are specified. For a single input would have to "know" beforehand its own memory address (i.e., provide its own reception). A content-addressable memory does "know" the conditions for its own reception. It is, however, of limited specificity for categorization purposes.

comparator
and locus of
gain control

A

B

A

B

indirect addressable
memory providing
implications (addresses)
for the next input
from A

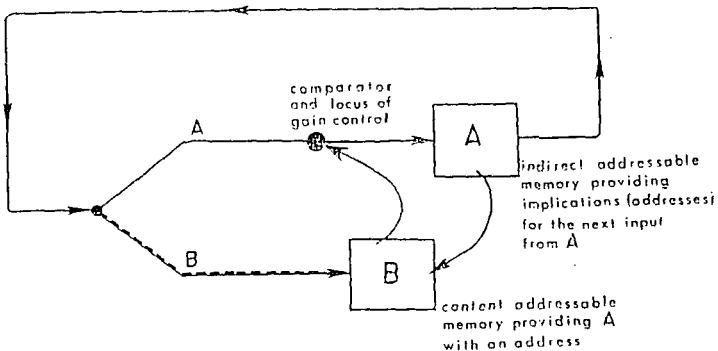content addressable
memory providing A
with an address

FIG. 9.

The input to the central nervous system will be considered as dually represented (Fig. 9). The specificity of representation A warrants an indirect addressable memory system. The generality of representation B warrants a content-adressable memory system (cf. [37]). B's representa-

tion is modifiable over time and provides the criterion for amplification of A's representation. This modification is considered to be adaptation. Habituation is considered to be zero-level amplification. The transmission rate of the B system is considered faster than that of the A system.

Standard   Variable

concentric
circles
(Delboeuf)
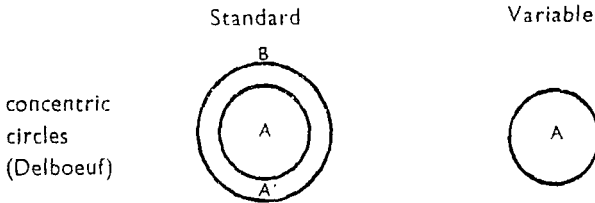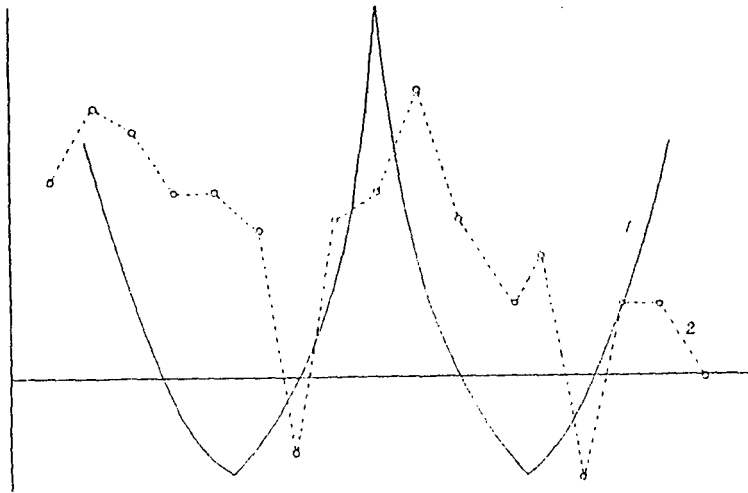
Fig. 10. From [57].

Suppose that both inputs are presented simultaneously and compared. Then under certain conditions the activity of B preceding according to the law of the temporal maximum will effect an assimilation illusion.

Suppose that there exist: (1) a decrease in amplification by B after use; (2) a comparison by B of parts of the input by the law of relative centrations; (3) a coupling over time of parts of the input by the law of temporal maximum. An I-figure presented before a T-figure would result in (1) and (2) and hence contrast. An I-figure presented with a T-figure would result in (2) and (3) and hence assimilation. If (1) and (2) occur, then we will have a distance paradox by the relative sizes of the I-figure and T-figure by the law of relative centration (cf. [66]).

Piaget has classified illusions into two classes: (i) primary, which are experienced by children and hence are illusions of assimilation; and (ii) secondary, which are experienced by adults due to an overcompensation of their schematic activity and hence are contrast illusions.

Consider the following. The Delboeuf illusion shows a maximum positive and two maximum negatives where $2A' = 0.25, 0.5, 0.75$ against the total figure (cf. Fig. 10). Certain illusions have two temporal maximums of illusions, and Pollack's results are again produced in comparison (Fig. 11). All this means is that if the *learned* acquisition of perceptual schemas follows in accordance with the probabilistic analysis of perception over *time*, then children should first be subject to the FAE, then show a decline, then again be subject to its effect. This Pollack has shown.

From Piaget (1961)
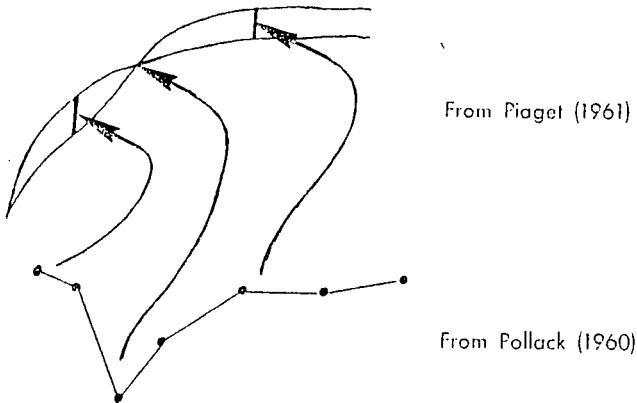
From Pollack (1960)

FIG. 11. Top, from Piaget [57]; bottom, from Pollack [60].

The Gibson normalizing effect may be considered a modification of B on repeated stimulation and disparate from the FAE, which appears to follow the child's growing ability to perceptually accomplish couplings and encounters. It is essentially an adaptation phenomenon.

A MATHEMATICAL DEDUCTION THAT PROPRIOCEPTION IS REQUIRED FOR AN ORGANISM'S ORDERING OF ITS PERCEPTUAL INPUT

Consider the theory of perceptual constancy by Taylor and Papert [76]. It is suggested by these authors that constancy can be established by conditioning each element of an "equivalence class" of states of

stimulation to the same group of responses. The property of giving rise to the same perception defines an equivalence among stimulus states that is referred to as a perceptual equivalence relation. This relation structures the set of stimulus states into equivalence classes (cf. Fig. 12).

FIG. 12. The retinal field with inverting spectacles when the head is (a) erect; (b) rotated through an angle ϕ. The broken line OL' shows where the image of $L(\theta)$ would lie without spectacles (from [76]).
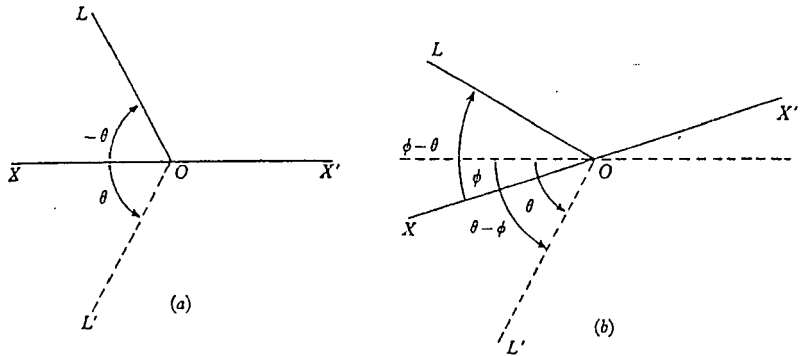
The authors turn to adaptation to inverted prisms. The diagrams show the retinal field with inverted spectacles when the L' head is (a) erect (b) rotated through the angle ϕ. The broken line OL' shows where the image of $L(\theta)$ would lie without spectacles. When the head is tilted through the angle ϕ, the image of $L(\theta)$ makes an angle $\phi - \theta$ with OX, thus giving rise to the stimulus state $(\phi - \theta, \phi)$ that belongs to the equivalence class $E_1(\phi - \theta + \phi) = E_1(-\theta + 2\phi)$. Thus a rotation of the head through ϕ causes an apparent rotation of the external world through 2ϕ. The description of the direction in which this apparent movement takes place needs care, state the authors, as the following statements are not always equivalent.

(P) The world appears to rotate in the same direction as the head but through twice the angle.

(Q) When the head moves through an angle ϕ, the subject sees the same movement as he would were his head kept stationary and the line $L(\theta)$ rotated through an angle -2ϕ to the position $L(\theta - 2\phi)$.

The statement (P) or (Q) may be applied to the subject's phenomenology when the subject removes his spectacles. We are not concerned here with the niceties of adaptation to prisms but only with one important fact. The Taylor–Papert explanation rests upon a purely descriptive realignment

of equivalence classes. In their terms, E_1 equivalence classes are replaced
by E_2 equivalence classes. It appears to me, however, that the whole
description swings upon one assumption that is never made apparent.
The angle ϕ must remain of constant sign for the proposal to work;
hence some ground reference is needed for the realignment of equivalence
classes to take place and this must be provided by proprioceptive align-
ment to the ground axis.

The suggestion is that for adaptation to occur there must be some
basic information that is immutable. By this is meant that experimental
manipulation of the mechanism providing the basic information results
in constant maladaptive behavior. Such behavior does occur [69]. If
this is the case, then the phenomenon of adaptation cannot be considered
the outcome of any particular sensory system acting alone but must be
the result of multisensory (and by this 1 include motor systems) activity.
The reason why there should be a realignment to the dictates of this
primary information is provided in the following section.

A WORKING MODEL FOR ADAPTATION

This general scheme of the connection between the proprioceptive
and perceptive functions in the organism breaks down to three players
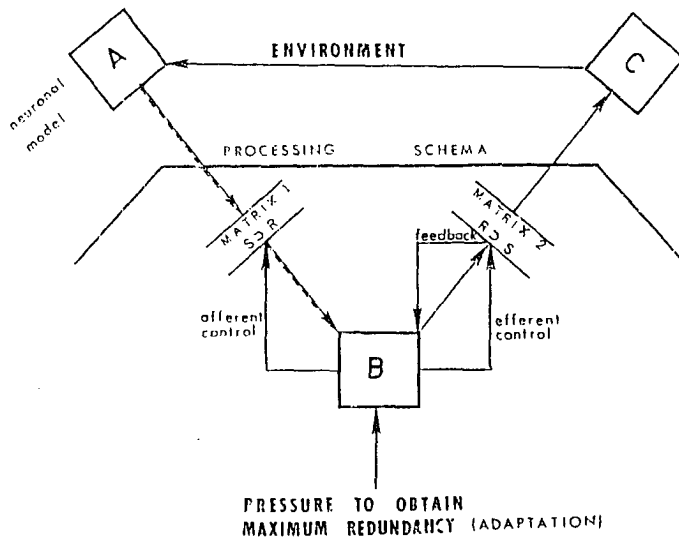

Fig. 13.

in a game in which two matrices of transitional probabilities are provided (Fig. 13). The game is able to take place and is not reduced to chaos only while the output to C and A remains constant. This proprioceptive rule of play cannot be tampered with but the transitional probabilities can be, on unfamiliar input from A. This B accomplishes by the rule that maximum redundancy between the two matrices must be aimed for at all times (adaptation). The three players entail a moving active organism. If the organism is passive, only two players are in session and adaptation has no reason to occur. The Kantian schema takes on cybernetic form.

It should be noted that there are *two* feedback loops involved on the efferent side. There exists one that never leaves the organism. This was the concern of Holst and Mittelstaedt in their epoch-making paper [22]. Another loop leaves the organism and provides further information of a different kind. The first loop is concerned with matrix B and the second with matrix A. The first is also concerned with quantitative information and the second with qualitative information. It is important to realize this distinction, as recent theoretical writings have confounded these two features (cf. [20, 77]).

NEURAL MECHANISMS

From the work of Sokolov [68] it has become apparent that somewhere the sensory input is matched against a comparator before being relayed further in the central nervous system. This does not mean that the central nervous system needs to store an infinite number of sensory "models" for recognition to take place. Vallecalle and Svaetichin [82], using the retina as a model for the functional organization of the nervous system, have postulated a glial setting of the excitability levels of neuronal events. They propose:

1. a feedforward input, which supplies in part a tangential glial controller, which makes available an added duplicated signal;

2. a negative feedback, which is assured through the radial Mueller fiber glial, which is in parallel with the conductors;

3. a time-integral process, which implies the existence of a structure for storing the information and which adds the accumulated information to the instantaneous one. Thus there is a progressive activation resulting, once the balance of the system has been reached, in a feeding into the input of a signal of opposite sign.

What is thus required is a differential amplification of the input so that there is a gradation from large amplification to zero amplification in the case of the habituated response. Habituation, then, could be defined as the degree of similarity of the different inputs and arousal as a correlate of the difference of the different inputs of the same stimulus. Thus Sokolov's data do not require the storage of a model of the environment. All that is required for arousal to occur is a change in the *ratio* of the two inputs. Ratios, not inputs, are recorded. The neuronal model becomes a function of parallel as well as serial processing of input as two inputs from the same stimulus are envisaged as necessary. Furthermore, differential amplification would appear to be a process utilized throughout the nervous system. The following study illustrates this.

Dowling [10] has proposed that the site of the mechanism that decreases sensitivity or gain in the visual system is in the receptor cells. It was established that loss of sensitivity during adaptation to light is unrelated to the amount of bleaching of visual pigment. Level of adaptation depends on the intensity of the background light and not on the amount of visual pigment bleached. This neural adaptation is composed of two parts. The b wave of the electroretinogram arising from the bipolar cells follow a different adaptation course than that of the a wave, which probably arises from the outer plexiform layer. The decrease in the logarithm of the sensitivity of the b wave is linearly related to increase in the logarithm of the background luminances. The a wave, showing little adaptation to dim background luminances, sharply saturates with brighter background luminances. Dowling shows that the a wave behaves very much like certain intracellular responses recorded from cells in the outer plexiform layer in retinas of certain vertebrates [51]. The b wave follows psychophysical adaptation.

John ([25], page 206) has also seen the need for two representational systems, a specific and a general. His reasons for the two systems are, however, different from those presented here and arise from electrophysiological data. John and Killam [26] proposed an exogenous temporal rhythm produced and conducted centrally via the specific sensory pathways. The nonspecific regions of the brain produced an endogenous mode of activity released by the action of the stimulus.

Pribram [61] has proposed that recognition may proceed by arrival patterns in the brain constituting wave fronts. Interference effects are seen as instantaneous analog cross-correlators. Thus memory is viewed as an example of holography or an encoded record of the wave patterns

emitted by or reflected from an object. Kline and Kay [28] report the mathematics and physics to reduce geometrical optics to electromagnetic theory in isotropic and anisotropic media.   Spinelli and Barrett [71] show that the three-dimensional oscilloscope display of computerized collection of spike discharges from single cells in the visual cortex of cat mapping with single spots consists of areas of maximum sensitivity. As the flaxedilized subject's head remains stationary, the oscilloscope display may be viewed as the digital readout from that cell after the analog transformations of the dendritic arborizations have taken place.   The dendritic influences may be likened to the diffractions of a lens, thinking in geometric optical terms, or of wave modulation, thinking in electromagnetic terms. Either way, the cellular discharge represents the result of these processes and may be described in the more general terms of holography.   It is usual to represent the result of wave diffractions as either a Fourier or a Fresnel transform. Lens diffraction is represented by the former. Cooley and Tukey [9] have introduced an efficient method for the machine calculation of complex Fourier series utilized in the reduction of two-dimensional data collection displays to equation form.   The difference between the displays at the cortical level and those at, for example, the lateral geniculate level (cf. [70]) is paralleled by an increasingly complex Fourier transform, or increased wave modulation.   If, as has been suggested [62], adaptation proceeds according to a process of collateral inhibition, this will naturally affect the dendritic diffraction process.   Thus, the so-called "satiation" from the inspection of the I-figure in the figural aftereffect experiment reduces to more general adaptation processes. These may, or may not, occur at the cortical level. They do, however, occur before the final stages of visual processing.

The work of Chang [8] showed that the cortex receives a thalamic pacemaker input.   There are two inputs to the cortex, therefore, one coherent from the thalamus and the other incoherent from sensory receptors. Interferometry (holography) is therefore possible in the dog's auditory cortex, at least, from the work of Tunturi [81]. Tunturi noticed that the standard deviation of spontaneous electrical activity increased during an evoked potential. He then showed that although cocaine applied locally caused a reduction in the mean evoked potential and standard deviation of both spontaneous activity and evoked potential, the onset and peak of the first positive component indicated no change in their latencies; on the other hand, application of cocaine to all the cortex except for a 2- to 3-mm dorsoventral strip resulted in very little

change in the mean evoked potential curve but the standard deviation of spontaneous activity was reduced considerably. This finding suggests the existence of cells converging on cortical pyramidal cells from afar, causing facilitation, inhibition, or other effects.

If interferometry is possible in the cortex, then the Bragg relation holds for the cortex provided that cortical connectivity is not random. If this is true, then the critical *phase* dimension can be stored within a cortical structure, and the cortex may be considered a hologram in the sense prescribed by Gabor ([12], page 456):

> As the photograph of a diffraction pattern taken in divergent, coherent illumination will be often used in this paper, it will be useful to introduce a special name for it to distinguish it from the diffraction pattern itself, which will be considered a complex function. The name "hologram" is not unjustified, as the photograph contains the total information required for reconstructing the object, which can be two-dimensional or three-dimensional.

Van Heerden [84] has described the advantages of storage by interference patterns, which allows simultaneous search for a specific piece of information through the whole memory. The interference patterns considered must satisfy the condition that amplitudes of waves diffracted from different parallel planes add up in phase (Bragg relation). Thus, reflected waves from different planes will not add up in phase, permitting the storage without confusion of many pictures of different frequencies. Van Heerden discusses the possibility of storing time-dependent signals in a three-dimensional medium. This, he speculates, can be accomplished by focusing waves of different frequencies at the focal point of an imaging lens. It is considered that three-dimensional storage of information holds for any wave phenomenon that obeys Huygens' principle, namely, that every point of a wave front may be considered as a center of a secondary disturbance that gives rise to spherical wavelets, and the wave front at any later instant may be regarded as the envelope of these wavelets, plus the condition that a permanent change in the propagation is brought about by the energy of the waves.

Trabka and Roetling [80] have shown how objects of known shape may be detected in a slowly varying background by thresholding the cross-correlation of the object seen with an aperture mask consisting of two narrow bands, one of positive transmittance and the other of negative transmittance, close to and on opposite sides of the object outline.

Possibly relevant to this finding is the work of Burns [5], who showed that in the isolated cerebral cortex in the unanesthetized cat there exist both positive and negative reactions. Suction tubes hollowed out the left hemisphere in such a way that a shell of cortex 7–10 mm thick was left on the left side. Cats were anesthetized with ethyl ether. The weakest stimulus that would elicit a detectable response produced a short-lasting local negativity beneath the electrodes. It spread outward from the point of stimulation in all directions, at a velocity of 2 m/sec, attenuating rapidly as it traveled, so that no response was recorded at distances greater than 1 cm from the center. The negative response was followed by a wave of surface positivity and spread without attenuation to the edges of the isolated area. The magnitude of the positive wave showed an all-or-nothing relation to stimulus strength, while its velocity of spread was 10–20 cm/sec. The surface-positive response, which renders the cortical surface electrically positive to surrounding and inactive tissue, presumably implies activity in a relatively deep-lying cell layer. When a single sharp electrode (insulated to the tip) is used to record the positive response at a variety of depths beneath the surface, the recorded potential changes polarity at a depth of about 0.4 mm. Burns showed that a certain minimum area of the cell network that causes the positive response must remain outside the range of excitation by the surface-negative response before a prolonged after-discharge can arise. The average frequency of repetitive discharge of the cells that produce the surface-positive response appears to be about 65/sec, so that 1/65 sec probably represents the average time for excitation to travel once around the fundamental neuron circuit. Assuming that the velocity of the transmission around this ring of neurons is of the same order as the velocity with which the surface-positive wave front spreads across the cortex, say, 15 cm/sec, then the circumference of the circuit must be of the order of 15/65 cm or about 2 mm. In this way excitation is passed from cell to cell and a wave front of almost synchronous cellular activity spreads indefinitely from the periphery of the primarily excited area at about 15 cm/sec. Behind this wave front the cells of the deep network continue to discharge at some 65/sec as excitation continues to circuit the neuron rings. Fundamentally, anesthetics seem to reduce the excitability and probably increase the refractory period of cells in the deep network responsible for the surface-positive response. The surface-negative response is completely unaffected by the anesthetic. The suggestion is that the mechanism of all anesthetics in the cortex is interference with oxidative metabolism.

Burns [4] used a layer of cortical grey matter with some of the underlying corticocortical fiber's blood supply as the only connection with the rest of the animal. Under chloralose anesthesia, neurological isolation of the parietal cortex results in complete electrical silence of the nerve cells, and no spontaneous activity of the secells, synchronous or asynchronous, could be demonstrated. A single stimulus applied through surface electrodes produced a local response in which the tissue beneath these electrodes became negative to the rest of the brain (superficial local response of Adrian [1]). Repeated stimulation caused discharges consisting, in their simplest form, of a series of potential waves spreading out from the point that had been stimulated. The local response is short-lived and has decayed to half of its peak value in about 30 msec, as the strength of the stimulus was increased so that the peak value of the surface-negative response increased. Ultimately, increase of stimulus beyond some five times threshold strength produced no further increase in the response. When single stimuli of gradually increasing strength were used, it was found that as soon as the negative response exceeded 60%–70% of its maximal value, a second type of response appeared in which the surface of the brain in the region of the stimulating electrode became subsequently positive to surrounding tissue. Two types of wave can be recognized when the spontaneous rhythm of undamaged brain is allowed to excite the "isolated" cells through a gateway of normal cortex. The first is complex in form and attenuates rapidly with increasing distance from the gateway. The second type consists of large waves of surface positivity that travel across the isolated area without attenuation at a velocity of about 15 cm/sec.

Burns and Grafstein [6] remark that perhaps the most surprising property of pieces of isolated cerebral cortex is that a preparation whose minute structure is so complex should give rise only to two types of responses to a single stimulus. Peak negativity was always reached at a depth lying between 0.8 and 1.3 mm, while the absolute value of the maximal negativity was about 2 mV. These experiments have led to the provisional picture of two neuron types. Cells of one of the two types are supposed to give the surface-negative response, while neurons of type B represent those giving the surface-positive response. The distribution of excitability, tested with a deep electrode, always showed two peaks of excitability, at 0.4 and 2.0 mm depth. As a result of rather similar experiments, Chang [7] suggested that the surface-negative response was due to excitation of the superficial dendrites of pyramidal cells; moreover,

in contrast to the results of Burns and Grafstein, he found that the spread
of the response could not be entirely prevented by superficial cuts. That
a stimulating electrode placed with its tip 2 mm below the surface can
cause a surface-negative response to appear at superficial electrodes
placed 2 and 4 mm distant must imply, as pointed out by Burns and
Grafstein, that excitation has traveled up to the surface radially and
then run along superficial branches of the excited neurons toward the
recording electrodes.

The matched filter (Vander Lugt [83]) has been used for character
recognition. This is none other than a spatial filter. Brown and Lohmann
[3] have investigated the type of diffraction object that will yield a
Fraunhofer diffraction pattern. The effect of Fraunhofer diffraction on
the complex light amplitudes is describable by a Fourier transformation,
the filter F from the diffraction pattern u being

$$F(v_x, v_y) = \int u(x, y) \exp[-2\pi i(xv_x + yv_y)]\, dx\, dy$$

where $F(v_x, v_y)$ is the diffraction object and $u(x, y)$ is the Fraunhofer
diffraction pattern. The authors explain that the complex amplitude
$F(v_x, v_y) = A(v_x, v_y) \exp[i\alpha(v_x, v_y)]$ can be realized by a photographic plate
of proper transmittance in order to gain the amplitude factor $A(v_x, v_y)$.
For the phase $\alpha(v_x, v_y)$ there are three methods: (1) retardation while
traveling through a dielectric; (2) phase jump at reflection; (3) detour
phase. In their example, the authors illustrate the third. I am suggesting
that the first is more appropriate when looking at the brain.

Mertz and Young [53, 91] made use of Rogers' [65] way to explain
holography. They realized that coherence is not essential. It is only
essential that each object point somehow generate its own Fresnel zone-
plate (FZP) pattern on the hologram. Lohmann [44] has developed a
method of splitting the spherical wave coming from each object into two
portions. Later, these two portions are recombined to generate interference
fringes. The two portions are mutually coherent because they are originated
by the same object point. If both portions are still spherical waves but
with different curvatures, the interference pattern has an FZP shape.
The center point of the FZP pattern is collinear with the centers of the
two spherical waves. It would be interesting to know whether this is
possible in the brain.

The work of Lilly [38, 39] and Lilly and Cherry [40, 41] has shown
how recordings from 25 electrodes have picked up wave front propagation

that is neither a mere local primary response nor the single traveling wave described by Adrian [1]. This would seem to indicate that the cortex does have properties of functioning that would permit diffraction processes.

Rather than the connectivity of the cerebral cortex forcing a theory of neural holography, it would appear that holographic storage is warranted by the data of Lashley [36] and supported by the probabilistic rather than deterministic approach to the theory of neural nets (Shimbel and Rapoport [67]).

Lilly and Cherry's [43] electrical figures were defined as a pattern of variation of electrical potential that at a given instant has a closed set of equipotential surfaces in three dimensions in the brain and its immediate surroundings, and that may change with time in size or location, or both. The authors speculate that, assuming the cortex contains 40,000 cells per cubic millimeter, at a given instant, a given electrical figure of the type analyzed (whose maximum area may be between about 800,000 to about 1,280,000 cells) has a peak potential difference across the figure and its surroundings of about 500 mV in the surface-positive direction. Presumably, all of these cells are not necessarily synchronously active at this instant; if they were so active, the peak potential difference would be 100 times the 500-mV peak found, as is found for the spike elicited by placing strychnine on the cortex. The slow speeds of growth, travel, and die-away; the long durations of activity at each point; the large size of the active area at each instant; and the evasive directions of new growth are all consistent with the view that the electrical figures are generated by a system that has short, multisynaptic, and numerous interconnections in each small area. The velocities found by Adrian [1] in intact cortex electrically stimulated (0.1–0.4 msec) and by Burns [4] in isolated cortex similarly stimulated are of the same order as Lilly and Cherry's extreme range (0.05–0.36 msec) for both leading and trailing edges of their figures. Lilly and Cherry suggest two possibilities for the subcortical origination of these figures. They propose that possibly the anterior origin is a focus of important connections with the reticular activating system, and the posterior one has important connections with the recruiting response system. Lilly and Cherry [42] note that, except in a region showing relatively surface-negative activity, the trailing edge tends to move over the cortex in directions that approach angles close to 90 deg to the directions taken previously by the leading edge. In the light of the known connections for acoustic areas I and II, the high-velocity leading edge, they postulate, is probably due to a preformed afferent

figure moving up to the cortex from below, firing the cortical cells first anteriorly and later posteriorly. Thus the leading edge reflects sequential firing of the cortex by impulses coming into the cortex at different times at different places: the "velocity" of the leading edge reflects these differences.

The work of Lilly shows, therefore, that there exist enough electrical activity and divergence of electrical activity in the cerebral cortex for diffraction to take place.

CONCLUSION

In this article I have attempted to show that: (a) there are basic informational "givens" to the visual system that constitute the confines of sensation and cannot be derived therefrom; (b) there is a basic informational given to the sensory systems in terms of which they are interpreted. This information is never changed by adaptational processes; indeed, the stability of the information provides the means for the adaptation process. This information is a proprioceptive "link" to a ground or body reference. Finally, certain perceptual phenomena that are constituted at the presensory level are explained with reference to mathematical description (Piaget) and are given a neurophysiological context (neural holography).

The figural aftereffect appears as a phenomenon of different amplification effects in the visual field. The Gibson effect appears as a normal adaptation procedure. The neural mechanisms underlying these two phenomena are presensory.

REFERENCES

1 E. D. Adrian, The spread of activity in the cerebral cortex, *J. Physiol. (London)* 88(1936), 127–161.
2 A. Binder, A statistical model for the process of visual recognition, *Psychol. Rev.* 62(1955), 119–129.
3 B. R. Brown and A. W. Lohmann, Complex spatial filtering with binary masks, *Appl. Optics* 5(1966), 967–969.
4 B. D. Burns, Some properties of the cat's isolated cerebral cortex, *J. Physiol. (London)* 111(1950), 50–68.
5 B. D. Burns, Some properties of isolated cerebral cortex in the unanaesthetized cat, *J. Physiol. (London)* 112(1951), 156–175.
6 B. D. Burns and B. Grafstein, The function and structure of some neurones in the cat's cerebral cortex, *J. Physiol. (London)*, 118(1952), 412–433.

7 H. Chang, Dendritic potential of cortical neurones produced by direct electrical stimulation of the cerebral cortex, *J. Neurophysiol.* 14(1950), 1–21.

8 H. Chang, The repetitive discharge of cortico-thalamic reverberating circuit, *J. Neurophysiol.* 13(1950), 235–237.

9 J. W. Cooley and J. W. Tukey, An algorithm for the machine calculation of complex Fourier series, *Math. Comp.* 19(1965), 297–301.

10 J. E. Dowling, The site of visual adaptation, *Science* 155(1967), 273–279.

11 C. P. Duncan, Amount and rate of decay of visual figural after-effect as functions of type of inspection stimulus and inspection time, *Amer. J. Psychol.* 75(1962), 242–250.

12 D. Gabar, Microscopy by reconstructed wave-fronts, *Proc. Roy. Soc.* A197(1949).

13 F. H. George, On the figural after-effect, *Quart. J. Exptl. Psychol.* 5(1953), 128–135.

14 J. J. Gibson, Adaptation, after-effect and contrast in the perception of curved lines, *J. Exptl. Psychol.* 16(1933), 1–31.

15 J. J. Gibson, Adaptation with negative after-effect, *Psychol. Rev.* 44(1937), 222–243.

16 J. J. Gibson, *The perception of the visual world*. Houghton, Boston, Massachusetts, 1950.

17 J. J. Gibson, *The senses considered as perceptual systems*. Houghton, Boston, Massachusetts, 1966.

18 J. J. Gibson and M. Radner, Adaptation and after-effect in the perception of tilted lines, I: Quantitative studies, *J. Exptl. Psychol.* 20(1937), 453–467.

19 D. O. Hebb, *The organization of behavior*. Wiley, New York, 1949.

20 R. Held, Exposure history as a factor in maintaining stability of perception and coordination, *J. Nerv. Ment. Dis.* 132(1961), 26–32.

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

22 E. von Holst and H. Mittelstaedt, Das Reafferenzprinzip, *Naturwiss.* 37(1950), 464–476.

23 H. Ikeda, Studies in figural after-effects, Unpublished Ph. D. dissertation, Tokyo Bunrika University, 1951.

24 H. Ikeda and T. Obanai, The studies in figural after-effects, IV: The contrast-confluence illusion of concentric circles and the figural after-effect, *Jap. Psychol. Res.* 2(1955), 17–23.

25 E. R. John, *Mechanisms of memory*. Academic Press, New York, 1967.

26 E. R. John and K. F. Killam, Electrophysiological correlates of differential approach-avoidance conditioning in the cat, *J. Nerv. Ment. Dis.* 131(1960), 183.

27 I. Kant, *Critique of pure reason* (N. Kemp Smith, trans.). Macmillan, New York, 1963.

28 M. Kline and I. W. Kay, *Electromagnetic theory and geometrical optics*. Wiley, New York, 1965.

29 W. Koehler, Relational determination in perception, in (L. A. Jeffress, ed.) *Cerebral mechanisms in behavior* (the Hixon Symposium), pp. 200–230. Wiley, New York, 1951.

30 W. Koehler and D. Emery, Figural after-effects in the third dimension of visual space, *Amer. J. Psychol.* 60(1947), 159–202.

31 W. Koehler and H. Wallach, Figural after-effects: An investigation of visual processes, *Proc. Amer. Phil. Soc.* 88(1944), 269–357.

32 W. Koehler and R. Held, The cortical correlate of pattern vision, *Science* 110(1949), 414–419.

33 W. Koehler, R. Held, and D. N. O'Connell, An investigation of cortical currents, *Proc. Amer. Phil. Soc.* 96(1952), 209–330.

34 W. Koehler and J. Fishback, The destruction of the Mueller-Lyer illusion in repeated trials, 1: An examination of two theories, *J. Exptl. Psychol.* 40(1950), 267–281; 2: Satiation patterns and memory traces, 40(1950), 398–410.

35 I. Kogiso, Unpublished data.

36 K. S. Lashley, Studies of cerebral function in learning, VII: The relation between cerebral mass, learning and retention, *J. Comp. Neurol.* 41(1926), 1–58.

37 C. Y. Lee and M. C. Paull, A content addressable distributed logic memory and applications to information retrieval, *Proc. IEEE* A111, 924–932.

38 J. C. Lilly, Moving relief maps of the electrical activity of small areas of the pial surface of the cerebral cortex. *EEG Clin. Neurophysiol.* 2(1950), 358.

39 J. C. Lilly, Equipotential maps of the posterior ectosylvian area and acoustic 1 and 11 of the cat during responses and spontaneous activity, *Fed. Proc.* 10(1951), 1.

40 J. C. Lilly and R. Cherry, Travelling waves of action and of recovery during responses and spontaneous activity in the cerebral cortex, *Amer. J. Physiol.* 167(1951), 806.

41 J. C. Lilly and R. Cherry, New criteria for the division of the acoustic cortex into functional areas, *Fed. Proc.* 11(1952), 1.

42 J. C. Lilly and R. Cherry, Surface movements of click responses from acoustic cerebral cortex of cat: leading and trailing edges of a response figure, *J. Neurophysiol.* 17(1954), 521–532.

43 J. C. Lilly and R. Cherry, Surface movements of figures in spontaneous activity of anaesthetized cerebral cortex: Leading and trailing edges, *J. Neurophysiol.* 18(1955), 18–32.

44 A. W. Lohmann, Wavefront reconstruction for incoherent objects, *J. Opt. Soc. Amer.* 55(1965), 1555–1556.

45 D. M. MacKay, Moving visual images produced by regular stationary patterns, *Nature* 180(1957), 849–850.

46 D. M. MacKay, Some further visual phenomena associated with regular patterned stimulation, *Nature* 180(1957), 1145–1146.

47 D. M. MacKay, Moving visual images produced by regular stationary patterns, *Nature* 181(1958), 362–363.

48 D. M. MacKay, Perceptual stability of a stroboscopically lit visual field containing self-luminous objects, *Nature* 181(1958), 507–508.

49 D. M. MacKay, *Proc. 15th Intern. Congr. Psychol.* (1959).

50 D. M. MacKay, Interactive processes in visual perception, in *Sensory communication* (W. A. Rosenblith, ed.), pp. 339–355. M.I.T. Press, Cambridge, Massachusetts, 1961.

51 E. J. MacNichol and G. Svaetichin, Electric responses from isolated retinas of fishes, *Amer. J. Ophthalmol.* 46(1958), 26–46.

52 P. McEwen, Figural after-effects, *Brit. J. Psychol. Monogr. Suppl.* 31(1958), 1–106.

53 L. Mertz and N. O. Young, *Proc. ICO Conf. Opt. Instr. (London)* (1961), p. 305.

54 S. Nozawa, Prolonged inspection of a figure and the after-effect thereof, *Jap. J. Psychol.* 23(1953), 217–234; 24, 47–58.

55 T. Oyama, Experimental studies of figural after-effects, 11: Spatial forms, *Jap. J. Psychol.* 25(1954), 195–206.

56 J. Piaget, *Les études d'epistémologie génétique 6.* Presses Universitaires de France, 1957.

57 J. Piaget, *Les mécanismes perceptifs.* Presses Universitaires de France, 1961.

58 J. Piaget, M. Lambercier, E. Boesch, and B. von Albertini, Recherche sur le développement des perceptions, I: Introduction à l'étude des perceptions chez l'enfant et analyse d'une illusion relative à la perception visuelle de cercles concentrique (Delboeuf), *Arch. Psychologie (Genève)* 29(1943), 1–111.

59 J. Piaget, Vinh-Bang, and B. Matalon, Note on the law of the temporal maximum of some optico-geometric illusions, *Amer. J. Psychol.* 71(1958), 277–332.

60 R. H. Pollack, Figural after-effects as a function of age, *Acta Psychol.* 17(1960), 417–423.

61 K. H. Pribram, Some dimensions of remembering: Steps toward a neuropsychological model of memory, in *Macromolecules and behavior* (J. Gaito, ed.), pp. 165–187. Academic Press, New York, 1966.

62 K. H. Pribram, Unpublished manuscript, 1967.

63 J. M. Prichard, Visual illusions viewed as stabilized retinal images, *Quart. J. Exptl. Psychol.* 10(1958), 77–81.

64 I. Rock and S. Ebenholtz, Stroboscopic movement based on change of phenomenal rather than retinal location, *Amer. J. Psychol.* 75(1962), 193–207.

65 G. L. Rogers, *Proc. Roy. Soc. (Edinburgh)* A63(1952), 193.

66 M. Sagara and T. Oyama, Experimental studies on figural after-effects in Japan, *Psychol. Bull.* 54(1957), 327–338.

67 A. Shimbel and A. Rapoport, A statistical approach to the theory of the central nervous system, *Bull. Math. Biophys.* 10(1948), 41–55.

68 E. N. Sokolov, Neuronal models and the orienting reflex, in *The central nervous system and behavior* (M. A. B. Brazier, ed.), pp. 187–276. Josiah Macy, Jr., Found., New York, 1960.

69 R. W. Sperry, Neural basis of the spontaneous optokinetic response produced by visual inversion, *J. Comp. Physiol. Psychol.* 43(1950), 482–489.

70 D. N. Spinelli, Receptive field organization of ganglion cells in the cat's retina, submitted to *Exptl. Neurol.* (1967).

71 D. N. Spinelli and T. W. Barrett, Unpublished manuscript, 1967.

72 A. W. Story, Figural after-effects as a function of the perceived characteristics of the inspection figure, *Amer. J. Psychol.* 72(1959), 46–56.

73 A. W. Story, Has apparent size been tested as a factor in figural after-effect? *Quart. J. Exptl. Psychol.* 13(1961), 204–208.

74 N. S. Sutherland, Figural after-effects, retinal size and apparent size, *Quart. J. Exptl. Psychol.* 6(1954), 35–44.

75 N. S. Sutherland, Figural after-effects and apparent size, *Quart. J. Exptl. Psychol.* 13(1961), 222–228.

76 J. G. Taylor and S. Papert, A theory of perceptual constancy, *Brit. J. Psychol.* 47(1956), 216–224.

77 H. L. Teuber, Sensory deprivation, sensory suppression and agnosia: Notes for a neurologic theory, *J. Nerv. Ment. Dis.* 132(1961), 32–40.

78 R. T. Terwillinger, Retinal size as a determinant of the direction of size distortion in figural after-effects, *Quart. J. Exptl. Psychol.* 13(1961), 209–217.

79 H. H. Toch, The perceptual elaboration of stroboscopic presentations, *Amer. J. Psychol.* 69(1956), 345–358.

80 E. A. Trabka and P. G. Roetling, Image transformations for pattern recognition using incoherent illumination and bipolar aperture masks, *J. Opt. Soc. Amer.* 54(1964), 1242–1252.

81 A. R. Tunturi, Anatomy and physiology of the auditory cortex, in *Neural mechanisms of the auditory and vestibular systems* (G. L. Rasmussen and W. F. Windle, eds.), Chapter 13. Thomas, Springfield, Illinois, 1960.

82 E. Vallecalle and G. Svaetichin, The retina as model for the functional organization of the nervous system, in *The visual system: Neurophysiology and psychophysics* (The Freiburg Symposium) (R. Jung and H. Kornhuber, eds.), pp. 489–492. Springer, Berlin, 1961.

83 A. Vander Lugt, Signal detection by complex spatial filtering, *IEEE Trans. Information Theory* IT-10(1964), 139–145.

84 P. J. van Heerden, Theory of optical information storage in solids, *Appl. Optics* 2(1963), 393–400.

85 E. Vurpillot, Piaget's law of relative centrations, *Acta Psychol.* 16(1959), 403–430.

86 H. Wallach and E. B. Karsh, The modification of stereoscopic depth perception and the kinetic depth effect, *Amer. J. Psychol.* 76(1963), 429–435.

87 H. Wallach and V. V. McKenna, On size perception in the absence of cues for distance, *Amer. J. Psychol.* 73(1960), 458–466.

88 H. Wallach and C. Zuckerman, The constancy of stereoscopic depth, *Amer. J. Psychol.* 76(1963), 404–412.

89 H. Wallach, M. E. Moore, and L. Davidson, Modification of stereoscopic depth perception, *Amer. J. Psychol.* 76(1963), 191–204.

90 J. F. Wohlwill, Developmental studies of perception, *Psychol. Bull.* 57(1960), 249–288.

91 N. O. Young, *Sky & telescope* January, 1963, pp. 8–9.