## *An experimental study of the effects of long fixation of visual stimuli*

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# AN EXPERIMENTAL STUDY OF THE EFFECTS OF LONG FIXATION OF VISUAL STIMULI

by

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CONTENTS


| Chapter | | Page |
|---|---|---|
| I | Introduction | 1 |
| II | Adaptation to a Norm | 4 |
| III | Figural after-effects | 10 |
| IV | Satiation | 26 |
| V | After-effects: Figural and Negative | 39 |
| VI | Experiment I: The Indirect Effect | 53 |
| VII | After-effects in Depth | 63 |
| VIII | Experiment II: Third-dimensional figural after-effects | 75 |
| IX | Experiment III(a): After-effects in the Perception of Relative Depth: Adjustment Method | 81 |
| X | Experiment III(b): After-effects in the Perception of Relative Depth: Constant Stimulus Method | 95 |
| XI | Conclusion | 104 |
| | References | 111 |

# I INTRODUCTION

Two main approaches have been made to the rather neglected problem of the effects of long fixation of particular stimuli on the perception of other stimuli. Helson has greatly extended the scope of psychophysics which, though of great methodological importance, had actually contributed little to the content of perceptual theory. The judgement of a point on a dimensional scale, whether of size, distance, colour, beauty or pleasure, is not simply a matter of establishing an invariant one-to-one relationship between the point on the stimulus scale and a corresponding point on a parallel subjective scale. Rather it is a matter of setting up an indifference point or "adaptation level" for the scale and judging individual stimuli according to their relationship to this point. This "true zero of functioning" is dependent on (a) organic and constitutional factors within the organism and the residual effects of his past experience with similar stimuli, (b) the stimuli actually being responded to, and (c) all other stimuli immediately present and forming a background or context for focal stimuli. This last category corresponds closely to the use of inspection figures in the work discussed in the present study.

Helson's formula, which has been shown to be a fair fit for a wide range of experimental data, provides a means of predicting the effect of a background, "anchoring" stimulus at a particular point on the scale. In a strictly visual context but with similar theoretical assumptions Gibson showed the effect on the judgement of certain dimensional qualities of prolonged inspection of stimuli which deviated from the "norm" or neutral point of the dimension.

The other major approach to the problem is the study of "figural after-effects", and particularly the theories of Köhler and Osgood & Heyer. In contrast to the judgemental, phenomenological theories discussed above these are "lower-level" theories employing neurological constructs and concerned with local events in receptors and on the primary projection areas of the cortex. The figural after-effects predicted by these latter theories consist of distortions induced in perceived figures as a result of prior stimulation. They are dependent on the spatial relationships rather than the dimensional qualities of the stimuli.

It has been widely supposed that the dimensional effects described by Gibson can be subsumed under the theories of figural after-effects. It is the purpose of this paper to test certain predictions from both sets of theories and to obtain some indication of the theoretical relationship and the relative importance of the two types of effect in situations where they can both be expected to occur. It will first be necessary to examine in some detail the various positions and the data that they attempt to encompass.

## II ADAPTATION TO A NORM

Gibson (1933) reported that a curved or bent line-segment changes during continuous perception in the direction of becoming straight and thereafter an objectively straight line appears curved or bent in the opposite direction. These phenomena were named "adaptation" and "negative after-effect" respectively. Gibson avoided the term "successive contrast" because it might imply an after-effect without the correlative adaptation which he regards as the basic process involved. These findings were confirmed by Bales & Follansbee (1935). Later it was demonstrated that similar effects can be obtained using tilted lines, i.e., inspection of a line tilted somewhat from the vertical or horizontal leads to a progressive lessening of the apparent tilt and to subsequent perception of an objectively vertical or horizontal line as tilted in the opposite direction (Vernon, 1934; Gibson & Radner, 1937).

It must be noted that these adaptation effects are only partial: the discrepancy (tilt, curvature, etc.) decreases but does not disappear, reaching a plateau after about two minutes. The shift of apparent tilt may be two or three degrees. After inspection a ten degree line looks like eight degrees, two degrees looks vertical and vertical looks like minus two degrees. The effect does not apply to the visual field as a whole but is roughly limited to the region previously occupied by the stimulus-line. This localization shows that the effects, though analogous to judgement-contrast, are not illusions of judgement. They are also subject to interocular transfer but again only between corresponding areas of the two retinae and in this case the magnitude of the effects is reduced.

Gibson looks upon shape (curvature) and direction (tilt) as the immediate sensory qualities of a line and the phenomena under discussion he regards as analogous to sensory adaptation. He seeks an explanation in the nature of the perceptual process itself. In support of Koffka (1922) Gibson argues that every sense quality falls on a dimension of some type and it is possible to speak of a stimulus and a sensation only so long as one means a point on a scale. A sensory dimension is functionally "all of a piece"; the series is "a discriminatory unit."

But there are different types of series. Adaptation applies only to "opposition series", i.e., sensory dimensions with centrally placed "norms" or indifference regions from which deviations in either direction mean increased intensity of one of the two opposed qualities represented on the dimension. Linear shape and direction are two such dimensions, independent of one another. The effects are well known in the case of skin temperature. "Chromatic adaptation operates so as to shift the hue which is evoked by any stimulus in the direction of the complementary of the adapting stimulus" (Troland, 1930). The facts of light and dark adaptation also fit into this framework. In the case of movement the negative after-effect is well known and has been given detailed study by Wohlgemuth (1911), but Gibson (1937b) shows that adaptation also occurs: a moving stimulus tends to slow down during prolonged fixation, i.e., there is an apparent shift towards the norm of motionlessness. Several of these effects have been demonstrated in the tactile-kinaesthetic modality, by Gibson (1933) for curvature and by Thalman (1922) for movement. Specifically excluded are distance, duration, pressure, visual size and olfactory intensity; all examples of "intensive series", i.e., ones which vary from zero to an extreme in one direction only.

The norms of the opposition series are defined statistically as the most frequent and prolonged condition in the organism's environment. Horizontal and vertical lines are norms in this sense. Usually such norms correspond with the norms of the appropriate psychological dimensions, e.g., objective and apparent vertical correspond closely for most subjects. Hence, since these norms are anchoring points for the whole of their respective dimensions, the stimulus dimension and the sensory dimension coincide. With perception of an abnormal quality, however, a gradual shift in the correspondence between the two dimensions occurs, tending to the point where the subjective norm corresponds to the present stimulus. The objective norm must now correspond to a point on the sensory scale somewhat displaced away from the original stimulus, e.g., an objectively vertical line is reported as tilted away from the line to which the subject has previously adapted. This constitutes the negative after-effect, a mere by-product of the adaptation or normalization process.

For some qualities, e.g., colour, brightness and temperature, this shift can be of appreciably greater extent than for others (e.g., tilt and curvature). Gibson suggests that this distinction may serve as a partial substitute for the ancient concept of primary and secondary qualities.

An additional effect is found in the special case of tilt. When one of the visual axes, either vertical or horizontal has been altered by the inspection of a tilted line the other axis is found to be altered in the same way, though to a lesser extent. In other words, the rotary shift in the apparent direction of a stimulus-line tends to be the same throughout the whole gamut of visual directions in the affected area. A tilt of 45°, midway between the norms does not show any adaptation toward either norm.

Gibson does not put forward a physiological explanation though he suspects that the process is characteristic of the whole projection system from end-organ to cortex. More often (e.g., 1937b) he sees the adaptation as a striving towards equilibrium in a field which includes both organism and environment, a process designed to keep the experiental norm coincident with the norm of external conditions - the state which involves the least output of energy.

One final point is worthy of note. Unlike simultaneous contrast or the mechanisms generally supposed to account for figural after-effects, the adaptation process does not enhance the difference between stimuli; rather it moves both stimuli towards the opposite end of the continuum leaving the difference between them unchanged. This certainly follows from the model outlined above and Gibson clearly assumes it to be true since in his later experiments he does not measure the size of the adaptation, inferring it instead from the size of the negative after-effect. That this may not be a valid assumption is suggested by his own quantitative results which reveal that, though on the average the two effects were equal they were in fact equal for only six of his thirty subjects.

Helson has demonstrated similar effects in several other dimensions, including weight and brightness. When the subject is asked to categorize a series of stimuli he adopts a norm or indifference point which is usually approximated by the geometric mean of the series. But when he is frequently exposed during the series to a background stimulus to which he does not have to respond and which deviates from this norm, the norm itself tends to be shifted in the direction of the anchoring stimulus.

## III FIGURAL AFTER-EFFECTS

The scope of Gibson's work has been greatly extended by Köhler & Wallach (1944). Working with reversible figures Köhler (1940) discovered that the rate of reversal tends to increase with prolonged inspection. This finding suggested that the specific cortical figure process which occurs whenever a figure appears in the visual field tends, during prolonged fixation "to block its own way." It soon became clear that this hypothesis was not specific to reversible figures but could be extended to the general proposition that the continued presence of <u>any</u> figure in a given location with reference to the visual system must change conditions for subsequent figure processes in the same region of the field.

During a detailed analysis by Köhler & Wallach (1944) of the perceptual changes, or "figural after-effects," which occur as a result of these changes in conditions in the visual system, it seemed to the authors that the principles they arrived at could adequately subsume most of Gibson's data. For example, they formulated a rule to the effect that when one arm of a small angle is inspected for a time and then the other arm presented, the angle appears larger than it otherwise would. This occurs irrespective of the absolute direction of the two arms and is not as Gibson thought contingent upon a particular relationship to the vertical or horizontal. A similar widening of the scope of Gibson's law about the effect of inspection of a curved or bent line upon the perception of a straight line reinforced the suggestion that the Gibson effects were merely examples of a much wider set of phenomena.

Köhler & Wallach introduced the procedure which has become the standard technique in this field. The subject is presented with a card bearing a centrally placed fixation point and two figures identical in size, shape and brightness and placed symmetrically on either side of the fixation point. The subject is asked to report any perceived differences between the figures. This test card is replaced by an inspection card bearing fixation point with a single inspection figure placed to one side of it. The subject fixates the point steadily for a measured period, often several minutes, and then looks at the test card and again reports any perceived differences between the two figures. Typically the figure on the same side as the inspection figure has undergone alterations in apparent size, brightness and position. Such changes constitute the operational definition of figural after-effects.

Fixation of the point enables the test figures to be presented in widely separate areas of the field, typically on opposite sides of the vertical meridian, and hence ensures that any changes in the affected test figure are due to the period of inspection. It also enables the experimenter to control the relative positions on the retina, of the test figure and the inspection figure and thus to some extent at least to control the resulting perception.

The basic law formulated by Köhler & Wallach states that a test contour appears displaced away from the position of an inspection contour. It may also appear less bright and perhaps farther away in depth. A test figure will undergo apparent size changes appropriate to the displacement of its contours, for examples, a test square wholly enclosed by an inspection square will appear to shrink; if the relationship were reversed it would appear to expand. The magnitude of the effects varies as a function of time, reaching a plateau after an inspection period of the order of one minute, and as a function of distance, rapidly rising from zero when the two contours coincide to a maximum and then gradually falling to zero again. This characteristic dependence on distance is known as the "distance paradox."

In the first independent test of the satiation position Walthall (1946) found that an outline square lying entirely within the boundary of a previously inspected outline circle appeared smaller than an identical square in a neutral position. He concluded that "the Köhler effect is real and is stable enough to submit to measurement."

The results of Weitz & Post (1948) on the other hand suggested that subjects' reports were determined more by the arrangement of the figures than by the inspection period. Marks (1949a) failed to find support for this latter suggestion but found a significant incidence of figural after-effects in control situations. Figural after-effects were not a universal phenomenon and satiation theory could not fully account for his results. Only about half the subjects in Weitz & Compton's study (1950) showed figural after-effects and the same effects occurred with(out) or without fixation.

Brown (1953) demonstrated half meridianal differences in control situations and the large individual differences they show. Though he was satisfied that figural after-effects had been adequately established in other experiments he warned that several experimental arrangements in use could be contaminated by H.M.D.'s.

George (1953) used a variant of Köhler & Wallach's Fig. 5, in which two identical squares arranged horizontally are the test figures and one of them is surrounded by a circle which is the inspection figure. The finding that only four out of 22 subjects on the pre-inspection trial saw the identical squares as equal is an important methodological caution. George's results do not show convincing evidence for figural after-effects unless the direction of size change is wholly neglected, contrary to satiation theory. However, all subjects reported the expected effect when judgements were required "as quickly as possible" and a second inspection figure, a small circle within the contours of the previously unaffected square, was added. McEwen (1958) suggests that the unconvincing results of the first experiment may have been due to George's short inspection period (25 sec.) so it may not be correct to list this study among the opposition to satiation theory.

Marquart's study (1954) on the other hand poses a definite problem for Köhler's point of view. The Gestaltists hold that perception of a pragnant figure is characterized by the presence of less kinetic energy than the perception of a complex figure; hence the hypothesized currents associated with a pragnant cortical figure should be less intense; hence, on satiation theory the after-effects resulting from inspection of a pragnant figure should be of lesser magnitude. Marquart found on the contrary that after-effects are greater from a more pragnant than from a less pragnant figure on the side of the non-dominant eye. Her reasonable conclusion is that either satiation theory is wrong or else that a pragnant figure has more intense currents associated with it, in which case such a radical revision of Gestalt theory would be necessary that satiation theory would inevitably be modified in any case.

Parallel after-effects have been domestrated in kinaesthesis by Köhler & Dinnerstein (1947) and Nachmias (1953). Charles & Duncan (1959) found close qualitative similarities with the visual effects but considerable quantitative differences. They demonstrated the distance paradox for the kinaesthetic effects. Wertheimer (1955) found a positive correlation between the two sets of effects though this has been challenged in more recent work (McEwen & Rodger, 1960; and Spitz & Lipman, 1960).

Jaffe's (1956) cross modal study in which visual inspection produced kinaesthetic after-effects appears to oppose the isomorphic assumptions of satiation theory; Köhler & Dinnerstein admit that their findings are "almost inaccessible to the theorist"; and Smith (1948) regards this as an important criticism of satiation theory. But Krauskopf & Engen (1960) reporting a further confirmation of the distance paradox argue that this strongly suggests some sort of place-localization in the processes related to kinaesthesis, a hypothesis with some neurophysiological support (Mountcastle, 1957).

Auditory figural after-effects have been demonstrated by Deutsch (1951) and Christman (1954) for pitch and by Jones

& Bressler (1959) and Krauskopf (1954) for localization. The two latter studies suggest the existence of a distance paradox.

Following on from the initial observations of Köhler (1940) which provided the starting point for satiation theory, several studies of reversible figures have appeared. Hochberg (1950) showed that prior inspection of one aspect of a reversible figure-ground decreased the probability of a subject's perceiving that aspect when the total figure was reconstructed in the test period. Carlson (1953) reported a similar result with reversible perspective figures - the aspect not previously inspected tended to appear first in the test period - and he controlled for suggestion by using Boring's "wife-and-mother-in-law" figure in which the alternative interpretations differ in meaning, not in perspective. Here the opposite result was obtained, prior inspection of an alternative favoured rather than depressed that alternative in the test period. Carlson's results suggested also that the depressed perspective appeared for shorter periods during the first few cycles in the test period. Brown (1955) used the projection of a three dimensional rotating circle of pins as a reversible figure. His results show a strong resemblance to the characteristic curves for figural after-effects and

Brown argues that assuming the two processes to be the same the rate of apparent change is a more convenient measure than contour displacement. Mull, Locke & Ord (1954) failed to find any effect of illumination or contrast on the rate of fluctuation of a Neckar cube. They take this as evidence against satiation theory, and certainly the rate of satiation should vary with contrast at least. Cohen (1959), using flat drawings and the increase of reversal rate with time as indicator of satiation, concluded that there is a large measure of similarity between reversible figures and figural after-effects. He showed that (a) there is transfer of satiation from a black-on-white figure to a white-on-black figure; (b) there is no transfer spatially on the retina; and (c) there is no transfer from one type of figure to another. The first two properties are shared by figural after-effects, the last one is not.

Howard (1961) used a skeletal cube rotating at one revolution per second about its vertical axis. This is a situation of biassed ambiguity. The true perspective is always seen first and the first reversal takes a relatively long time, the "satiation period," thereafter reversals are frequent and regular. Howard claims that this measure is quicker and more direct than conventional measures of figural after-effects; no estimates of extent are necessary on the part of the subject; attitude and suggestion are shown to have a negligible effect; the effect is present in all subjects provided they have stereoscopic vision; changes of stimulus are eliminated; central factors are predominant. This last point is supported by evidence that peripheral factors such as eye movements, focussing, movement after-effect and fixation fatigue do not influence the satiation period; and even more decisively by the finding that the elimination of stereoscopic cues by using monocular fixation significantly reduces the satiation period. There is as yet no convincing proof that figural after-effects are central in origin. McEwen (1958) and Day (1958) have pointed out that interocular transfer, often regarded as proof of central origin, is not in fact conclusive. A further interesting finding is that if the direction of rotation of the cube is reversed immediately the first apparent reversal occurs the next apparent reversal takes almost twice as long as the first. In general, it is difficult to see how any of the theories put forward to explain figural after-effects can cover effects generated by stimuli repeatedly moving across the retina since none of them postulate a satisfactory direction-sensitive mechanism. The pattern used by Howard does not generate a homogeneous area or volume of satiation but "a specific movement-in-depth-cubic-pattern of satiation" which does not transfer to other types of figure in the same location. Howard concludes that his results support the formal aspects of Köhler's theory but not the non-neural model of cortical conduction.

Taken together, the work of Crutchfield & Edwards (1949) using autokinetic movement, Christman (1953), using apparent movement, and Livson (1953), using both phenomena, seems to establish the following conclusions. A stationary inspection figure produces after-effects of the usual kind on a stationary test figure and also on an apparently moving, actually stationary point of light. An inspection figure composed of alternating lights produces after-effects in the form of a reduction of autokinetic movement or a displacement of a stationary test figure. Finally, alternating stimuli giving phenomenal movement are more effective than alternating stimuli not doing so, or than stationary inspection figures. Train & Walthall (1958) further found that the magnitude of the after-effect of inspecting real and apparent movement is the same.

Weizkrantz (1950) showed that a stationary inspection figure can alter the distance of an apparent movement in the direction expected on satiation theory. Deatherage & Bitterman (1952) induced a distortion in the shape of the pathway of an apparent movement, and sometimes its total destruction, by interposing a stationary inspection figure between the two stimuli giving rise to the apparent movement. These results were confirmed by Shapiro (1954).

Deatherage (1954) showed that the optimal time interval for stroboscopic movement was affected in the same way by a real change in the distance between the stimuli and by a functional change induced by long inspection of the apparent movement. Real and satiation-induced changes in the size of the stimuli also produced similar changes in the optimal time interval. These results were in line with Köhler's predictions. But Brenner (1953) reported evidence against a simple isomorphism between perception and cortical events. She found that the range of interval between stimuli giving rise of apparent movement decreased significantly following four different types of continuous stimulation: (i) fixating a circle of light (ii) listening to a buzzer (iii) voluntary movement and (iv) simple mental arithmetic.

Satiaton theory implies that when a cortical contour falls on a region of homogeneous satiation it will suffer no apparent displacement. Hence there should be no displacement when test and inspection figures are exactly superimposed; as the test figure is progressively separated from the inspection figure displacement should build up to an asymptote and then fall away to zero when the test figure reaches a region beyond the range of the residual effects of the inspection figure's currents. This "distance paradox" was confirmed in a rather sketchy experiment of Köhler & Wallach in which they measured displacement as a function of degree of separation between test and inspection figures. They found a maximal displacement when the two figures were about $\frac{1}{4}$ inch apart. However, the distance paradox can by no means be considered to have been established. Sagara & Oyama (1957) report an experiment using concentric circles as test and inspection figures, in which the point of maximal displacement appeared to be determined by the relative sizes of the figures rather than the absolute distance between them.

Köhler & Wallach themselves report that sometimes when test and inspection figures coincide the test figure appears smaller as well as paler and farther away. McEwen (1958) points out that the brightness effect is easily explained: it is quite plausible that satiation reduces the intensity of the figure currents producing it. The third-dimensional effect would probably be an inference from the brightness effect. However, the size change does appear to be contrary to expectations. Hebb (1949) argues that on the satiation principle it would appear that two contours look farther apart when the tissue separating their cortical representations increases in resistance, i.e., becomes satiated. Hence, when the test figure is enclosed by or coincident with the inspection figure it should appear larger since the tissue within the cortical figure has undergone an increase in resistance. But Köhler & Wallach (1944) and Walthall (1946) report apparent shrinkage of circles under these conditions and in a more recent study involving 540 subjects Duncan (1960) confirms this result. However, if the problem is seen in terms of where the figure currents can flow rather than of absolute changes in resistance it becomes clear that test figures enclosed by inspection figures should shrink; but Hebb's argument still seems valid in the case where the figures coincide since the area within an inspection figure should certainly be more densely satiated than the area outside.

Köhler & Wallach in a brief discussion of the problem seem to imply that the outline circle may be a special case, as regards its own self-satiation. Although, they say, satiation is greater inside than outside a circle, the satiated area is greater on the outside. But shrinkage due to self-satiation is not limited to outline circles. Ikeda & Obonai (1953) found that inspection of a pair of parallel vertical lines on one side of a fixation point made them appear closer together and shorter, in relation to an identical pair on the other side. Nozawa (1955) similarly reported shrinkage of a horizontal line, which under optimal conditions was of the order of 10 per cent of its total length. These findings seem to present even more difficulties for satiation theory than those involving circles. Duncan (1960) recommends a close analysis of these reults to determine whether they might not be artefacts of the brightness and depth effects or of foveal-to-peripheral inhomogeneities of satiation.

Yoshida (1953) found that test figures consisting of dots were apparently attracted towards the contours of inspection figures. Smith (1948) claims that several of Köhler & Wallach's demonstrations show attraction between test and inspection figures and he has published three original sets of figures which produce the same result (Smith, 1954). Hebb (1949) and McEwen (1958) cite further figural arrangements of Köhler & Wallach which lead to findings opposed to the theory. Oyama (1953) questions the dependence of satiation processes on time. He found that a one second inspection period was sufficient to produce almost maximal displacement and that longer inspections merely increased the duration of the effects.

Several of Smith's criticisms have already been referred to; several others from his highly critical paper (1948) are worthy of mention. His chief general point is that satiation theory is not readily testable since it leads to no specific predictions beyond the obvious empirical generalizations and not even all of these are to be taken seriously. He argues that it is likely that a similar mechanism underlies both figural after-effects and visual after-sensations such as the waterfall illusion and the Plateau spiral illusion. Yet in these cases there can be little possibility of configurational satiation: a moving area of stimulation crosses the retina uniformly and the visual system must presumably remain homogeneously sensitive. Similarly, in Gibson's original discoveries after-effects occurred after subjects had been wearing distorting spectacles for a relatively long period and had inspected many curves: hence there is no reason to suppose that a particular cortical area was satiated; yet the after-effects are similar to those obtained under conditions of constant fixation. Gibson's later demonstrations included inspection by looking at a curved line and fixating, regularly or at will, various points along it, providing at most a diffuse sort of satiation.

Malhotra (1958) stresses the importance of central factors of a judgemental kind. When the genuine effects are perceived and similar presentations are repeated the subject expects that the effect will still be present and so perceives it. In Wertheimer & Leventhal's (1958) demonstration of the persistence of the effects over periods of months the identical test procedure was repeated several times with the same subjects. Spitz & Blackman's (1959) finding that mentally retarded subjects show poorer satiation and Köhler & Adams' (1958) discovery of a relationship between figural after-effects and attentiveness further underline the importance of controlling for cognitive factors.

The plausibility of the neurophysiological assumptions of a psychological theory are of less importance than its ability to generate true propositions concerning behavioural events throughout the field covered by its assumptions. It seems clear that satiation theory as it stands cannot reliably predict the changes in apparent size or position of a figure, which result from prior inspection of another figure. In the next chapter we shall consider the physiological processes which have been postulated to account for these changes.

# IV SATIATION

Köhler sees figural after-effects in a wide context of phenomena characteristic of basic visual processes, and perhaps of perceptual processes in general; and the main function of research in this field is to provide evidence for the general brain-field theory. This is an electro-chemical theory based on the assumption that it is the tissue fluid surrounding the cortical cells rather than the cells themselves which is the physiological medium of perception. Stroboscopic movement and the grouping of adjacent figures provides evidence that percept processes are physiologically represented beyond their own limits. Stimulation by a contour, it is claimed, induces a flow of direct current in the tissue fluid. This flow is subject to a density gradient whose peak represents the contour itself. Just as in electrolytic conduction local resistances may be heightened and the permeability of the interfaces themselves altered so these "figure currents" polarize the cell membranes through which they pass, lowering the polarizability and conductivity of the region as a function of the duration of stimulation.

This satiation alters the medium for the flow of current produced by any other visual pattern in a similar location.

Specifically, when a new cortical pattern is imposed upon a configuration of residual satiation either it coincides with the location of the previous pattern in which case, since it occupies the peak of the gradient and has areas of equal satiation on either side, no displacement is expected, or it has areas of unequal satiation to either side and the currents it produces can be expected to flow more into the less affected region and away from the region of relatively high impedance; in this case the peak of the gradient of the new figure currents is shifted away from the place it would have occupied had it been imposed on an area of homogeneous satiation. The new figure is correspondingly perceived as being displaced away from the locus of the previously inspected figure and changes in apparent size are readily accounted for in terms of contour displacement.

A direct confirmation of the development of direct currents associated with the cortical representations of objects would greatly strengthen Köhler's position. This has been attempted by Köhler & Held (1949), Köhler (1951), and Köhler, Held & O'Connell (1952), using E.E.G. recordings from scalp electrodes, mainly on human subjects. A narrow bar was moved across the field while the subject fixated a stationary point. Deflections were obtained in the form of a wave trough extending in a continuous line with maximal displacement corresponding with the fixation point. This previously unreported occipital activity suggests prima facie evidence for isomorphism and for figure currents of the required type. But Lindsley and Gerard, replying to Köhler in the Hixon Symposium (1951), suggested that the recordings could be artefacts of G.S.R. from the scalp or polarity potentials from the eye-balls or artefacts of vascular reactions. Again, as McEwen (1958) points out, even should the records prove to be of genuine brain potentials their connection with figural after-effects remains to be established. Lashley, Chow & Semmes (1951), using two rhesus monkeys, placed strips of gold foil and gold pins in contact with, or through, the visual cortex in the macular area. The monkeys showed no deterioration in learned discriminations or any other visual function, even though the metallic conductors should have interfered with the hypothesized figure currents. This is one of the strongest pieces of evidence against satiation theory.

Both Hebb (1949) and Lashley et al (1951) point out that the site of these processes must be in Brodmann's area 17 since beyond this the point-to-point retino-cortical correspondence is lost. Köhler must account for the anatomical fact that objects equally spaced on the retina are not equally spaced on the visual cortex and this he tries to do in terms of a greater permanent satiation of the cortical area representing the periphery. But the evidence suggests that satiation would have to be uniform in area 17 and so this explanation is untenable.

Another important problem for satiation theory is raised in various forms by Smith (1948), Lashley et al. (1951) and Osgood & Heyer (1952). How do currents, so selective as not to affect functionally unrelated though structurally close areas nevertheless manage to affect the contralateral hemisphere? - for figural after-effects have been demonstrated when test and inspection figure were on opposite sides of the vertical meridian - and, even if the corpus callosum were a highly conductive connection, as Köhler & Wallach suggest, how could the currents remain so selective when they reached the other hemisphere? In any case, the corpus callosum is probably irrelevant as Lashley reports cases where it was congenitally absent and yet sensory integration appeared quite normal.

Lashley et al. (1951) also point to the lack of evidence for functional changes correlated with known changes in cerebral fluid content whereas Köhler requires cerebral activity to be extremely sensitive to such changes. Their final criticism concerns pathological studies. Lesions and tumours should, but apparently do not, disrupt figure currents. Similarly Spitz (1958) reviewing the literature on the perceptual behaviour of organics concludes that it "brings out many inconsistencies in satiation theory."

Wertheimer & Wertheimer (1954) and Klein & Krech (1952) have put forward rather similar suggestions concerning a relationship between metabolic efficiency, cortical modifiability and figural after-effects but there has been little independent work based on this interpretation and the evidence is indecisive. The most important alternative theory has been that put forward by Osgood & Heyer (1952).

Köhler & Wallach (1944) admit that their theory is incompatible with contemporary views of the nervous system and they feel that these views must eventually be changed. Osgood & Heyer (1952) have tried to resolve this conflict by attempting "to demonstrate that figural after-effects can be accounted for within the bounds set by generally accepted neurophysiological principles."

Osgood & Heyer consider that the transverse differentials of neural activity in the higher centres necessary to account for figural after-effects have been established and described in detail by Marshall & Talbot (1942). Neurons are not as a rule detonated by the firing of a single bouton. A single retinal cone for example has equivalent connections to a group of cortical cells and continuous eye movements further enlarge the neural region excited by a fine line or contour. Osgood & Heyer postulate that the representation of a contour in area 17 is a normal distribution of excitation, symmetrical about its axis transversely and extending as a ridge throughout the longditudinal extent of the contour; that on-off type fibres and their central connections are chiefly responsible for such distributions of excitation; that the rate of excitation of such fibres varies with their nearness to the peak of such a gradient (on-off fibres respond with bursts of impulses to changes in stimulation intensity such as occur during the constant transverse "scanning "of a contour; fibres close to such fluctuating gradients are in a continuous or near-continuous state of activity while those farther away adapt quickly and become inactive under constant stimulation). Additional postulates are that, under constant fixation of a figure, cells in area 17 mediating the on-off activity will become differentially adapted as a negatively accelerated function of the rate and duration of excitation; that such adaptation gradients will become flattened during recovery; and that the apparent localization of contour in visual space corresponds with the localization of maximal excitation in area 17 - we perceive a fine line or point, not a "graduated blur."

After inspection of a contour the gradient of excitation representing a second, nearby (test) contour falls in a region made differentially excitable by the differential adaptation just described. This produces a shift of the whole gradient, including its peak, away from the peak of the established gradient. Since the localization of the peaks on the cortex corresponds with the localization of the contours in visual space, such a contour will appear to be displaced away from the inspected contour.

Smith's strong attack on satiation theory (1948) did not imply that he would be prepared to give unqualified support to any alternative theory. In fact he was the first to take the field against the statistical theory when it appeared (Smith, 1952). He acknowledges its clear superiority over satiation theory in logic, elegance and lucidity but he points out that it is strikingly similar to satiation theory not only in the predictions it generates but also in the criticisms to which it is exposed. For example, selective adaptation is implausible in illusions such as the waterfall and the Plateau spiral, in the effects induced by the wearing of distorting spectacles and in Gibson's type of inspection where there is no constant fixation. Of the latter cases Osgood (1953a) says that he "does not see the point of the comment," since both theories explain how such effects occur. However, it does seem a valid point that both theories require a localization of the effects in a way scarcely possible in these cases. Osgood suggests that the illusions are a different class of phenomena probably involving cortical regions beyond area 17.

Of the median longitudinal fissure in the striate cortex Smith says that "both statistical and field interpretations flounder over this apparent gap in the projection system" - a rather unnecessary criticism when Osgood & Heyer (1952) and Osgood (1953b) fully admit the schism between functional and anatomical knowledge. Smith's most crucial point is that statistical theory does not offer, any more than satiation theory does, an account of figural after-effects in other modalities. Osgood (1953a) replies that these other types of figural after-effect are to be expected if either the statistical or the satiational model applies to sensory projection systems in general. This oversimplifies the matter as Smith's point is particularly effective against Osgood & Heyer in view of their theory's dependence on eye-movements: it is difficult to see what can be substituted for these in other modalities.

Statistical theory, like satiation theory, requires that when test and inspection figures coincide there should be no displacement. Yet, as Smith points out, the data of

Köhler & Wallach and of others are consistently opposed to this prediction. Osgood (1953a) replies, unconvincingly, that displacement never occurs in these conditions and that any reported size change is due to a paling and blurring of contours, which Osgood & Heyer can predict and which Marks (1949b) reported. The statistical theorists present a better account of why displacement and brightness change are maximal at different degrees of separation. The distance paradox in fact follows directly from their assumptions although they make no attempt to reinforce the slender empirical basis on which it stands, preferring to accept it, as they do most of Köhler & Wallach's data, apparently without question. Köhler & Wallach noted that effects were greater when the figures were arranged horizontally than when they were arranged vertically but they offered no explanation. Osgood & Heyer (1952), on the other hand, can easily account for this observation on the basis of the fact that eye-movements are more frequent in the horizontal plane.

The theory would require drastic revision to encompass several of the findings reported by Sagara & Oyama (1957) which also embarass the satiation theorists and effects at the considerable distances reported by Heinemann & Marrill (1954) and by Bevan (1951) in his work on intensity thresholds though the latter writer confirms that the brightness effect is maximal when the two figures coincide. In so far as Smith's contention (1948, 1954) is justified, that under certain conditions test and inspection figures approach one another, this also constitutes a difficulty for statistical theory.

Hochberg & Hay (1956) questioned whether movements of the retinal image of the inspection figure are necessary for the establishment of figural after-effects. Obtaining a kind of "stopped image" by presenting the inspection figure very briefly and letting the subject observe its after-image, they showed that the after-effects were similar to those achieved by conventional methods. Krauskopf (1954b) found a mean after-effect displacement of 12.6 ' of arc when a test figure was presented 1.8 seconds after an inspection figure. The test period lasted 0.3 seconds. Since the mean nystagmic fluctuation is said to be four minutes of arc, he questions the possibility that it could create after-effects of the magnitude he achieved. The same author (1960) reported that stabilizing the retinal image by means of a mirror embedded in a contact lens did not influence the magnitude of figural after-effects, indicating that "the Osgood-Heyer theory is invalid."

Much the most damaging attack on Osgood & Heyer's position has been presented by Deutsch (1956). This criticism rests on a connection between the shifts in peaks of excitation postulated in the theory, and thresholds for separation. It follows from the theory that one contour can displace another only when their distributions of excitation overlap to a considerable extent. But Deutsch shows that if they do overlap to any extent the distance between the peaks must be actually or almost sub-threshold. Further, the amount of displacement possible on this theory must always be a fraction of the distance between the contours. Thus any displacement predicted by Osgood & Heyer should be too small to be detected by the subject. Deutsch also reveals that Marshall & Talbot's theory, on which the statistical approach is based is vague and complicated and open to other interpretations than those of Osgood & Heyer. For example, it is difficult to accept the idea of cortical summation of excitation from adjacent receptors, which would lead to loss of information. In fact, the actual anatomical evidence referred to by Marshall & Talbot (1942) is opposed to such summation and Marshall & Talbot are grossly misleading about this evidence (Glees & Clark, 1941). Deutsch points to the vagueness of Marshall & Talbot about numerical values for the extent of the spread of excitation and the time constants for integration of information on the cortex. He also remarks that the notion of a distribution peak corresponding to the location of a contour in visual space is difficult to assimilate to Marshall & Talbot's position; that they do not reject third dimensional projection while Osgood & Heyer do; and that Marshall & Talbot deal with lines, Osgood & Heyer with contours.

Deutsch cites evidence by Ratliff (1952) and by Riggs, Ratliff, Cornsweet & Cornsweet (1953) to the effect that acuity is hindered rather than helped by eye-movements. Ratliff & Riggs (1950) also claim that under optimal conditions of fixation eye-movements are so small as to be unlikely to exceed the width of one receptor - too small for Osgood & Heyer's purposes; while Hartridge & Thompson (1948) present evidence that the eye is essentially motionless during fixation.

Deutsch concludes that there is little to choose in physiological respectability between satiation theory and statistical theory. Reviewing the literature on visual acuity Falk (1956) finds that "When the Marshall-Talbot conception of overlap and path multiplication .......... is confronted with the known data it fares rather poorly," and Falk makes it clear that this position is not by any means to be treated as orthodox neurophysiology.

It is scarcely surprising that predictions from statistical theory are almost identical throughout with those from satiation theory; Osgood & Heyer constructed their theory to account for precisely the same set of data - the reports of Köhler & Wallach (1944). Osgood & Heyer admit that they present no empirical evidence against satiation theory. They base their claim on their ability to account for all Köhler & Wallach's data as easily as Köhler & Wallach do and on their ability to do it without introducing any novel, speculative neurophysiological assumptions. This claim must be considered extremely doubtful in view of the evidence reviewed above.

## V. AFTER-EFFECTS: FIGURAL AND NEGATIVE

Despite the assertions contained in Köhler & Wallach's (1944) paper there is still considerable doubt about the relationship between figural after-effects and Gibson's adaptation processes. Apparently the first protest from Gibson himself appeared in his review of McEwen's (1958) monograph in the American Psychologist (1959) and at the same time Bergman & Gibson (1959) reported a study designed to demonstrate that negative after-effects occur "for phenomenal objects as well as for sensations." Köhler & Emery (1947) in their work on third-dimensional after-effects had used relatively untextured surfaces and stressed contours as the determinants of their phenomenal depth. But an impression of depth is possible without contours when the surface is strongly textured and the subject observes through a constant aperture. Under these conditions almost all of Bergman & Gibson's subjects reported normalization and negative after-effects. A surface sloping backwards appeared to become more nearly vertical during inspection and a subsequently presented vertical surface appeared to slope forward. In a second experiment they showed that binocular depth cues are not necessary for these effects: the foreshortening of optical texture is sufficient; nor is constant fixation of the type involved in figural after-effects necessary: textural stimulation is as effective when repeatedly transposed over the retina as when motionless. Gibson claims that figural after-effects are contaminated by the after images which inevitably occur as a result of constant fixation. Negative after-effects are localized in the visual world, not in the visual field, and there will be no knowledge of the neural substratum of the visual world until the eye-movement paradox has been resolved. Much or all of the effect produced by stimulating one eye can be observed with the other. Hence there must be a point in the sensory projection system beyond which the eye used is irrelevant; after images of hue and brightness occur before, negative after-effects after this point.

Gibson admits that dimensional adaptation is not appropriate to all perception, that figural after-effects are more relevant to closed contours or forms. Köhler's mistake is to look upon figure-on-ground as the prototype of all perception. Findings such as those of the Innsbruck studies (Ivo Kohler, 1951) are more easily explained by normalization of geometrical qualities. A biassed visual world becomes more normal in colour, curvature, density and stability; when the bias is removed it looks abnormal in these qualities in the opposite direction. Bergman & Gibson conclude that any theory dealing only with contour processes cannot cover all perception, that normalization is not a local alteration in the retinal or cortical field and hence that negative after-effects cannot be subsumed under satiation theory.

It is not altogether clear that their third-dimensional effect cannot be due to figure processes, for the texture itself must have involved a density gradient in a fine pattern and there is no reason why a Kohler-type satiation process should not occur differentially over such a texture gradient. Nor have they satisfactorily demonstrated that the effect is not specific to the locality of the retina stimulated. They showed that steady fixation is not necessary but to establish their point they must show that with steady fixation an inspection figure on one part of the retina affects a test figure subsequently presented to another part.

Gibson's original data suggest two points at which the satiation and adaptation theories diverge. The normalization of a tilted or curved line to the vertical or straight cannot easily be accounted for in terms of satiation theory. Secondly, the reported effect on one axis, either vertical or horizontal, of a line tilted from the other axis - Gibson's "indirect effect" - is in the opposite direction to the displacement which would be predicted from satiation theory. This second point is a special case of the general rule that normalization of an inspection line should produce displacements in the same direction of all stimuli on the scale including those more tilted or curved than the inspection line itself; whereas satiational displacements should cause lines more and less normal than itself to be displaced away from it, i.e., in opposite directions.

The first of these points of divergence was studied by Prentice & Beardslee (1950). They met with an apparent dilemma in trying to demonstrate normalization. On the one hand, vertical and horizontal lines such as the edges of the conventional type of stimulus card are known to cause satiational displacement of a tilted stimulus line towards the vertical or horizontal. On the other hand, absence of such an objective frame of reference may allow tilted lines to give rise to general disorientation effects such as the tilted-mirror effect reported by Wertheimer (1912) and studied in detail by Asch & Witkin (1948).

Prentice & Beardslee held that this latter type of effect cannot be equated with normalization since it is not restricted to the neighbourhood of fixated lines and it can sometimes occur immediately without prior inspection. More recent studies, however, have questioned both the areal restriction of the adaptation effects and their time-dependance. Prentice & Beardslee attempted to escape from this dilemma by using cards so large that their contours were separated from the stimulus lines by distances greater than those over which figural after-effects had been reported, by showing that doubling these distances did not affect their results and finally by cutting the edges of the screen parallel with the stimulus lines. In all cases normalization of a tilted line was reported. In the latter case the possibility of a general disorientation effect was excluded by the fact that the foveal stimulus lines were seen to normalize with reference to the peripheral screen contours. They also failed to find any indirect effect, a result which supported their thesis concerning the areal restriction of the adaptation effects, but in this case they themselves were the only observers. A final finding of interest was that the norm which the tilted line approaches is a psychological rather than a retinal one. Thus the effects are not due to a permanent satiation gradient from top to bottom of the retina.

Fox (1951) provided further confirmation of normalization. While studying the distance paradox in figural after-effects and in general confirming it he obtained certain unexpected results. These he attributed to normalization induced by the asymetrical arrangement of his rectangular inspection figures. When this factor was eliminated by making the figures symetrical the paradoxical results disappeared.

Heinemann & Marill (1954), ironically students of Gibson, question Prentice & Beardslee's confirmation of normalization. They suggest that the distances used were not in fact sufficiently great to exclude the possibility of satiation effects and that even in the control condition in which the vertical edges of the screen were cut parallel with the stimulus line a satiation gradient caused by the more intense satiation in the acute angles of the screen could have produced the obtained displacements. Using apparatus and procedure closely similar to the earlier workers' Heinemann & Marill showed that when the screen was tilted and the line was vertical, thereby excluding normalization there was a significant alignment of the stimulus with the edges of the screen. On the other hand, when figural after-effects were excluded by setting the line parallel with the edges of the screen but tilting the whole array from the vertical there was no significant displacement of the stimulus even though on Prentice & Beardslee's assumptions conditions were such as to produce normalization.

If Heinemann & Marill are right then figural after-effects occur at greater distances than is generally assumed, and most figural after-effect apparatus is too small to eliminate the effects of its own contours. If the Gibson effect does not occur then such unexpected results as those of Fox are difficult to explain. On the other hand, if it is a genuine, independent phenomenon then many of Kohler & Wallach's demonstrations are undoubtedly contaminated by it.

The second point of divergence between the two theories has been investigated by Morant & Mistovitch (1960). Using fields of parallel lines they found that inspection of a figure tilted through ten degrees from one axis induced a shift of somewhat over two degrees in that axis and about one degree in the other axis. The directions of displacement were in agreement with Gibson's direct and indirect effects. The authors agree that the confirmation of the indirect effect disproves Kohler's claim to account for tilt after-effects. They also defend the use of tilted lines without any true frame of reference against the doubts raised by Prentice & Beardslee that it would lead to a general disorientation effect. After inspecting Wertheimer's tilted room it comes to appear normally erect even when tilted through $45^{\circ}$ whereas a rod with a much smaller degree of tilt never completely normalizes. Also, Wertheimer's effect appears to be independent of the degree of tilt whereas the magnitude of tilt after-effects is closely dependent on the degree of tilt of the inspection figure and falls to zero when the latter is between $40^{\circ}$ and $50^{\circ}$. But Morant & Mistovitch also point out that Gibson's claim that the effects are locus specific is scarcely compatible with the existence of the indirect effect and that his assumption that the extent of normalization is the same as the negative after-effect on the grounds that it causes a displacement of the whole scale is not compatible with the difference in magnitude between the direct and the indirect effects.

Further doubt was thrown on the areal restriction of Gibson's effects by Morant & Mikaelian (1960). They showed that when an inspection rod was tilted $13^{\circ}$ from the vertical and followed by a vertical test rod 14 ins. away, the latter was seen by a subject seated five feet from the array as tilted away from the original inspection figure. When the figures were on the same side of the vertical meridian the a apparent displacement was about $1{\cdot}5^{\circ}$, when they were on opposite sides it was about one degree.

The authors proceed to examine the observations which led Gibson to postulate the spatial specificity of the effect. In one case, the inspection figure consisted of a tilted line containing a fixation point and located between two vertical lines and the test figure had three vertical lines in similar positions. Gibson showed that whichever of the test lines was fixated appeared tilted the others remained vertical. Morant & Mikaelian claim that this merely shows that simultaneous stimulation of various parts of the retina with differently oriented lines leads to different after-effects in different parts of the field, not that the after-effect of a tilted line in the absence of any other figures will be restricted to the locus of stimulation. A more reasonable conclusion than either of these appears to be that the effect transfers but only partially, as a function of distance, and that the "unaffected" test lines appear vertical only in relation to the greater tilt of the "affected" line.

Gibson also supported his contention by noting that inspection of a tilted line does not cause the room to appear tilted. Morant & Mikaelian point out that not even that part of the room which corresponds to the locus of the original stimulation appears tilted and therefore the observation does not prove that the effect is local but merely that it does not occur when the test object has a highly stable frame of reference.

Calbert (1954) has added to the confusion over the effect of a stable frame of reference on tilt after-effects. He points out that the conventional techniques in this field involve a distortion of the field with respect to the subject, usually a tilting of the field about the visual axis such as frequently occurs in everyday experience. He asks whether the subject's phenomenal axes will be similarly affected when the field itself is systematically distorted internally in a way which does not occur in any real situation. His subjects adjusted a line to the apparent horizontal after exposure to a rectangular grid composed of 10 vertical and 10 horizontal lines. In different conditions the grid was subjected to geomentric transformations such that while the vertical lines remained constant the horizontal lines assumed various degrees of tilt. He found that the phenomenal horizontal was displaced towards the "horizontal" lines of the inspection pattern and that the degree of displacement was a curvilinear function of the distortion of the inspection pattern reaching a maximum when the latter was ten degrees. The inspection pattern and test pattern were presented to different eyes. It remains to be shown whether in this situation the phenomenal vertical is similarly affected despite the stable vertical frame of reference. If it is not, serious doubt is cast on the contention of Morant &

Mistovitch, that the phenomenal axes are rigidly linked and that Gibson's contrary observations were produced by the interaction between figural and negative after-effects.

A further set of phenomena with which negative after-effects have been compared is the brilliant series of observations by Ivo Kohler (1951). When an observer wears inverting spectacles over long periods of everyday activity he gradually learns to adapt to his new environment and eventually becomes quite proficient in complex skills such as fencing, playing football and riding a bicycle as well as in the more mundane task of merely "getting about" his environment. These effects are closely similar to Wertheimer's tilted-mirror effect and raise the same problem of their relationship to ordinary tilt after-effects. Morant & Mistovitch's points with regard to the tilted mirror effect have already been mentioned and apply equally to the Kohler effects. There would seem to be a wide discrepancy between the acceptance as normal of a complex everyday pattern tilted through any angle including 180° and the incomplete normalization and after-effect of a tilted line, effects which vary as a function of the degree of tilt and reach zero when it is about 45°.

The crucial finding seems to be that at no time do the inverted objects come to appear upright: the criterion of their acceptance as normal is that the subject makes appropriate motor responses to them. On the other hand, the tilted line does come to appear more nearly vertical. And here the motor element has a purely arbitrary connection with stimulus, imposed by the experimenter for the duration of the experiment only, and quite unlike the complex adaptive responses involved in "getting about" one's environment. The closely related factor of meaningfulness is negligible in the case of tilted lines. Hence while the Gibson effects are entirely visual the type of adaptation described by Kohler appears to be a matter of stimulus-response coördination.

Would prolonged passive inspection of an inverted room affect its appearance or give any "saving" in the subsequent learning of appropriate responses to it? Research to date has left these important questions unanswered but the interpretation suggested above receives support from work carried out recently in Brandeis University. Held & Hein (1958) used prisms which displaced the retinal image during the inspection period and found that subsequent hand-eye coordination was disturbed only if the subject had "re-afferent" stimulation during the inspection period, i.e., only if he could see self-produced movements of his hand.

Watching his motionless, or passively moved, hand was ineffective in producing an after-effect. The disturbance of coordination was in the direction which would be expected if the subject had learned to allow for the distorting effects of the prisms and then carried this learning over into the test period when the field was again normal and his new coordination therefore inappropriate.

Held & Bossom (1961) measured errors in egocentric localization following exposure with prisms which caused a lateral deviation of the retinal image. They showed that self-produced movement (walking as opposed to being pushed in a wheelchair) during the exposure period was necessary to produce compensative errors in subsequent localization. The magnitude of the error was a function of the length of exposure; after about 21 hours distributed over four days some subjects achieved total compensation, i.e., their errors were as great as the distortion induced by the prisms. The authors suggest that identical processes underlie this type of adaptation and the early development of coordination. In support they cite evidence that in neonatal chimpanzees (Riesen, 1958) and kittens (Riesen & Aarons, 1959) the visual stimulation resulting from gross bodily movement is necessary for the development of visual-spatial performance.

Mikaelian & Held (abstract, 1961) have succeeded in factoring out experimentally the two types of adaptation. Using prisms which rotate the field through 20° they have shown that stimulation produced under these conditions by active movement causes both tilt adaptation and a more general adaptation of visual direction, whereas passive inspection produces a small but significant degree of tilt adaptation but none of the general adaptation of visual direction.

This recent work appears adequately to distinguish the tilt after-effects from the general disorientation effects, and justifies the omission of a stable frame of reference in work on the former effects, thus resolving the dilemma of Prentice & Beardslee and other previous workers. This policy was therefore adopted in the study of the indirect effect to be reported in the next chapter. The relationship between tilt adaptation and satiation effects has not been made so clear and since the indirect effect is a crucial point in the discussion it was felt that a confirmation of Gibson's original observations would be valuable. After the experiment was undertaken Morant & Mistovitch (1960) reported their own confirmation of the effect, as discussed above.

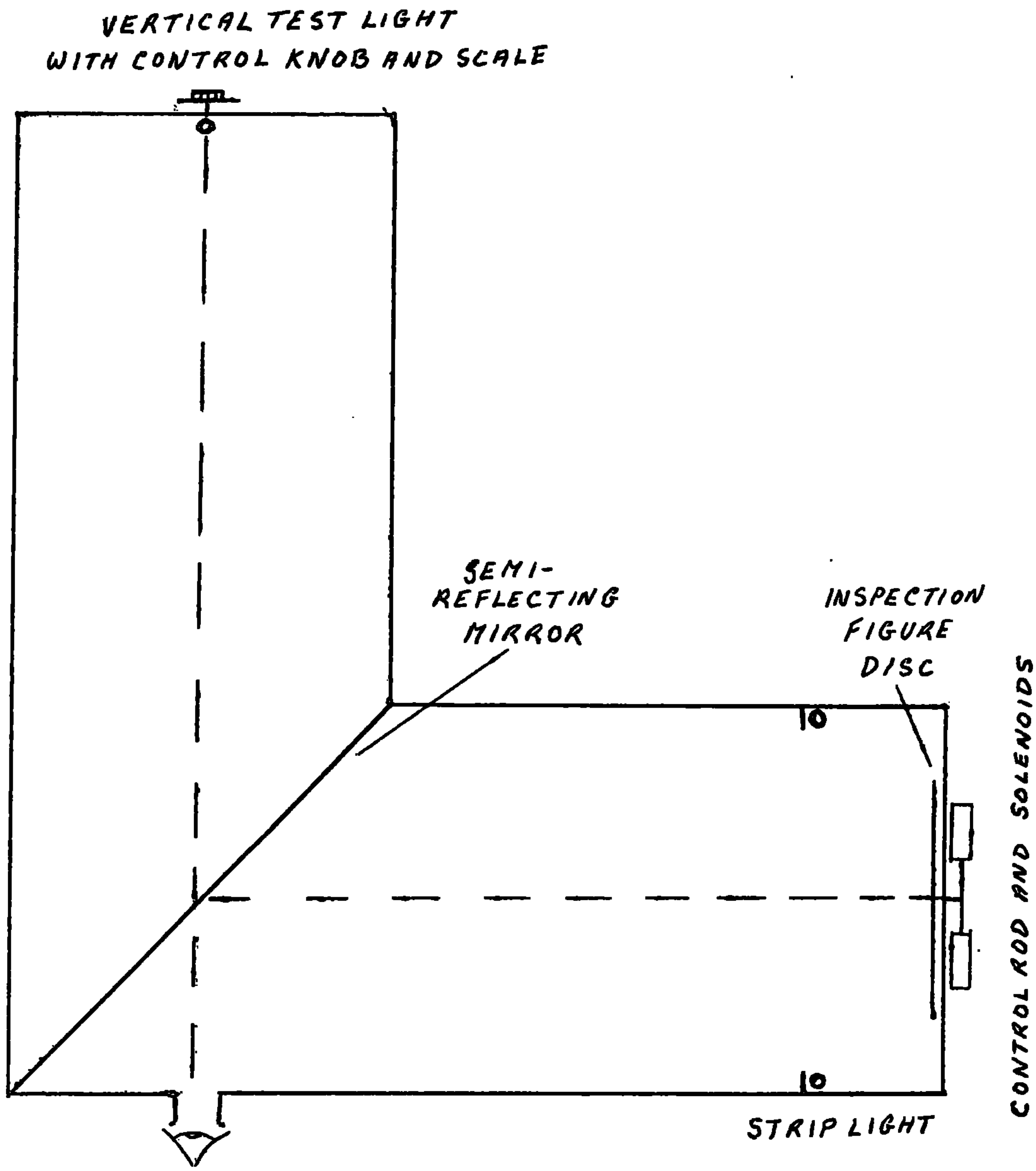
# VI EXPERIMENT I: THE INDIRECT EFFECT

## Apparatus

A tachistoscope was used which had two viewing channels, each 40 in. long and of 16 in. square cross-section, set at right angles to one another, as shown in Fig. I. A front-silvered mirror of approximately equal reflectance and transmission was mounted at 45 degrees between the channels. The inspection pattern appeared in one channel, the test pattern in the other. Their exposure was controlled by two electronic timers.

The inspection pattern consisted of a white cardboard disc, 10 in. in diameter with a black inspection point at its centre. It was filled with a series of black parallel lines one sixteenth of an inch wide and one eighth of an inch apart. It was mounted centrally in the end wall of the viewing channel. Illumination was provided by two 11 in., 60 watt strip-lights mounted vertically on the walls of the channel six inches from the end. Over this six inches the floor and walls of the channel were lined with mirror to diffuse the light. The disc could be rotated about its centre so that the lines were horizontal or tilted 10 degrees clockwise or anti-clockwise from the horizontal. The two latter positions could also be alternated on successive trials by means of solenoids operated

Fig. I: Apparatus for Experiment I.



by the timers. This change-over of the inspection pattern always occurred when the test pattern was exposed, so that the subject never saw the movement.

Mounted in the end wall of the other channel was the test figure, a single strip-light pivoted about its centre. It was completely covered with cardboard except for a single strip ten inches long and one sixteenth wide. When illuminated this strip appeared as a narrow line of light in a dark field. It had a black fixation spot at its midpoint. The setting of the line was by manual control through a reduction mechanism of 80:1. A dial on the control knob was marked with five points. The five points indicated the angular position of the line - vertical and one and two degrees each way from the vertical.

The fixation points on the two patterns were superimposed when illuminated simultaneously. A single flexible rubber eye-piece was mounted externally on the box and centrally to the viewing channels. A cardboard stop, close to the eye, restricted the field of view in each channel to the size and shape of the circular inspection pattern. The tachistoscope was mounted on a rigid table whose surface was set truly horizontal.

The experimenter had five keys corresponding to the five positions of the test figure and these were wired to a recorder which stamped the digits one to six. Another two-way switch was placed convenient to the subject and wired to the first two channels of the recorder. The sixth channel was used as a spacer and was automatically pulsed after each trial by a unit controlled by the timers.

Procedure

The subject was seated on a stool close to the tachistoscope. He pressed his left eye against the flexible rubber eye-piece so that all extraneous light was excluded. He was asked to adjust his position until the black spot in the middle of the array of horizontal lines was centred in the circular field of his eye-piece. He was told that there would always be such a spot in the centre of the field and he must constantly fixate it throughout the experiment. He would be shown the horizontal lines for a period of six seconds; then they would be replaced by a single near-vertical line with a black spot at its mid-point. This would be exposed for only one half second and he must indicate immediately, by means of the switch, which way it appeared to be tilted from the vertical. The sequence would then be repeated.

There were three series of trials in which the inspection lines were orientated as follows:

(i) Horizontal - 50 trials

(ii) Ten degrees clockwise and ten degrees anti-clockwise, from the horizontal, on alternate trials - 100 trials.

(iii) Ten degrees clockwise - 50 trials.

A minute's rest was allowed between the series and also half-way through series (ii).

The order of conditions was standardized for all subjects, as only the inspection figure in series (iv) could be expected to build up a unidirectional satiation which might cause systematic errors in subsequent series.

During each six-second inspection period the experimenter set the test line to one of its five positions: vertical and one degree or two degrees clockwise or anti-clockwise from vertical. In series (i) and (iii) each position was presented ten times in random order. In series (ii) the set of 50 even trials and the set of 50 odd trials each consisted of 10 presentations of each position in random order. The program was arranged in this way so that the 50 readings which had been preceded by the clockwise (or anti-clockwise) inspection figure, could later be extracted and would still form a series in which the figure had been presented 10 times in each of its five positions.

## Results

The conditions used in the analysis were the result of the manipulations described above. The respective inspection figures were:

1 Ten degrees anti-clockwise mixed (i.e. presented in alternation with $10^{o}$ clockwise).

2 Horizontal control

3 Ten degrees clockwise mixed (i.e. presented in alternation with 10° anti-clockwise).

4 Ten degrees clockwise.

Each subject made 50 judgements in each condition and the number of "clockwise" responses was counted for each subject in each condition. These means are plotted in Fig. 2.

For the indirect effect to manifest itself fixation of a line tilted anti-clockwise from the horizontal not only must displace an objectively horizontal line in a clockwise direction (the direct effect) but must also displace in the same direction lines close to the vertical. Hence, there should be more clockwise responses following inspection of an anti-clockwise figure (condition 1) and fewer clockwise responses following inspection of a clockwise figure (conditions 3 and 4) as compared with the number of clockwise responses following inspection of a horizontal figure (condition 2).

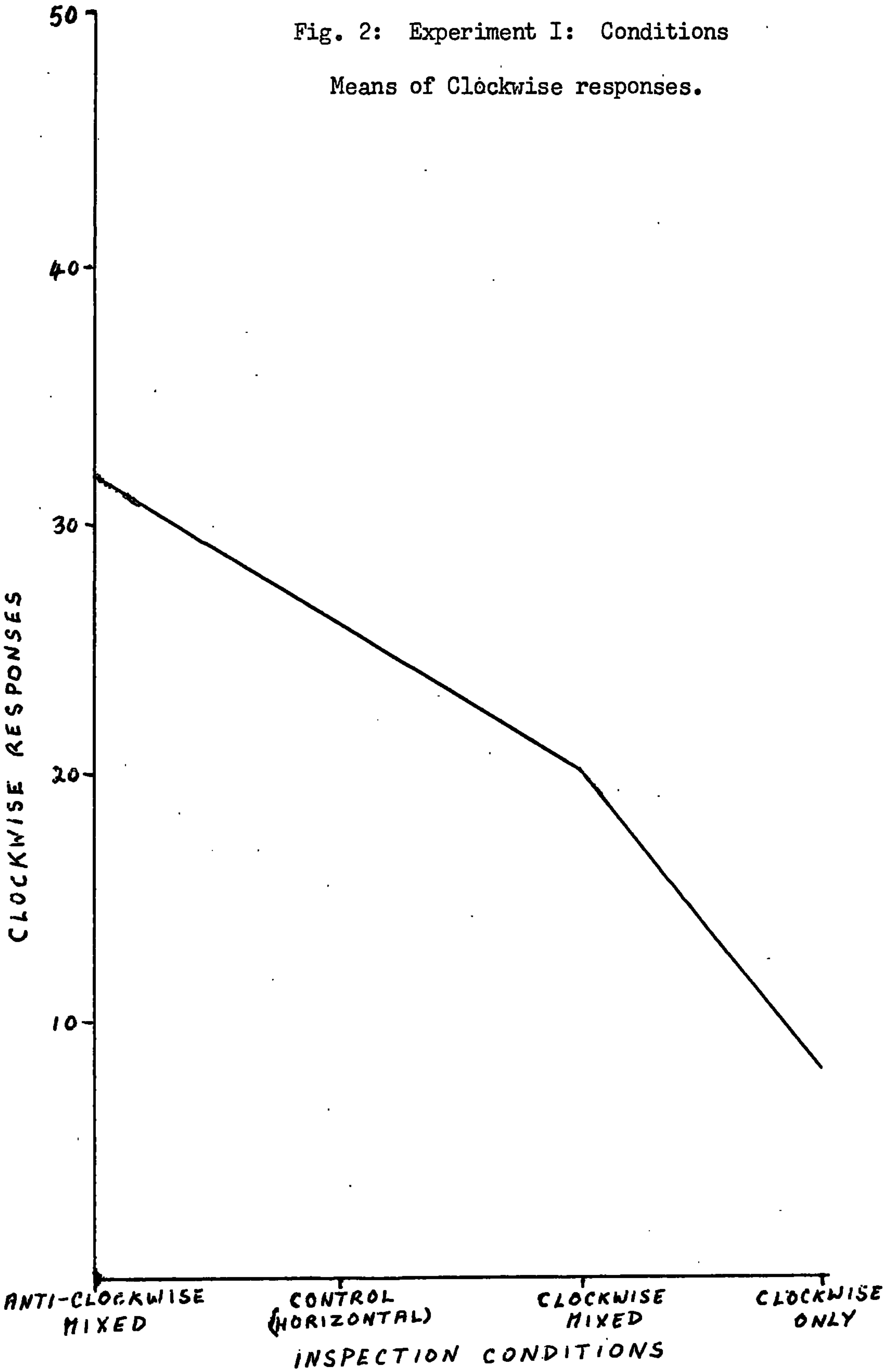
Table 1: Mean number of "clockwise" responses

| Conditions | | | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 10° anti-clockwise mixed | Horizontal control | 10° clockwise mixed | 10° clockwise |
| 31.8 | 26.0 | 20.1 | 8.4 |

Table 1 shows that the means of the "clockwise" responses do vary between conditions in the expected direction. An

Fig. 2: Experiment I: Conditions

Means of Clockwise responses.



analysis of variance was performed on these means:

Table 2: Analysis of variance for clockwise responses

| Source | Degrees of Freedom | Sums of Squares | Estimated Variance | F | |
|---|---|---|---|---|---|
| Conditions | 3 | 2999 | 1000 | 74 | $P < .001$ |
| Subjects | 9 | 883 | 98.1 | 7.25 | $P < .01$ |
| Residual | 27 | 364 | 13.5 | | |
| Total | 39 | 4246 | | | |

Since the conditions contribute a very highly significant portion of the variance, the smallest of the differences between means - that between conditions 1 and 2 - was tested using the residual variance from the F-test. The t-ratio was calculated as 3.52 for 27 degrees of freedom, which is significant at the 0.01 level. Therefore each of the four means differs significantly from all the others since all the other differences are larger.

Thus we have demonstrated Gibson's indirect effect. The mean points of subjective verticality and their P.E.'s were computed using Urban's constant process to derive the median of the best-fitting ogive (Table 3).

Table 3: Mean points of subjective verticality and their probably errors, in degrees from the vertical, positive figures representing anti-clockwise deviations.

| Inspection figure | $10^{\circ}$ anti-clockwise mixed | Horizontal control | $10^{\circ}$ clockwise mixed | $10^{\circ}$ clockwise |
|---|---|---|---|---|
| Mean point of subjective verticality | 0.81 | 0.12 | - 0.54 | - 2.34 |
| Probable error | 0.15 | 0.13 | 0.13 | 0.17 |

The size of the indirect effect is calculated as 2.46 degrees, the differences between the means of the control condition and the condition where the inspection figure was tilted $10^{\circ}$ from the horizontal throughout. The mixed conditions yield smaller but significant indirect effects of $0.69^{\circ}$ (anti-clockwise condition) and $0.66^{\circ}$ (clockwise condition).

The "mixed" conditions were included in the experiment partly as a trial for what was thought to be a promising new technique whereby one might study the effect of short inspection periods without recourse to the long rest intervals between trials which are needed to avoid the effects of a cumulative build-up of satiation over a series of short identical inspections. The technique is not wholly satisfactory since it is not clear how much of the six second inspection period is required to cancel the effects of the previous inspection and how much goes to produce the observed effect. However, it may have value in the comparison of different processes. For example, in the type of arrangement used in this experiment one would not expect two opposed dimensional shifts to occur together - one would have to be broken down before the other was established; but two such inspection figures could presumably build up areas of neural satiation which while possibly interacting would not be mutually exclusive. What the technique does demonstrate of importance in the present experiment is that the observed effect is not simply a successive contrast phenomenon - since the "mixed" condition yields a smaller displacement - but is a genuine time-dependent process; and it provides a basis for a more detailed exploration of this time-dependence in later experiments.

## VII AFTER-EFFECTS IN DEPTH

The only report of an investigation into figural after-effects in depth is one by Köhler & Emery (1947). They first confirmed Gibson's prediction (1937b) that in the third dimension there are strict analogues to the curved-line, tilted-line and bent-line effects. In a typical demonstration a card with a line drawn vertically down its centre was mounted at right angles to the subject's line of view but tilted backwards or forwards by $15^{\circ}$ from the frontal plane. The subject fixated a point at the midpoint of this line for two minutes. A similar line, slightly shorter to equate its length with the projection of the tilted line, was then presented in the frontal plane and appeared tilted the opposite direction to the previously inspected line. Similarly inspection of bent or curved lines either convex or concave to the subject induce in flat, upright lines an apparent bending or curvature in the opposite direction. They further showed that curved or tilted surfaces could also be used to produce the after-effects, presumably because the position of a homogeneously textured surface is determined by the position of its contours and these are subject to satiation processes. It was also demonstrated that when a figure is inspected it displaces away from itself figures placed either in front of or behind it, thus exemplifying the law which is said to govern two-dimensional effect, viz. that test objects are displaced away from the contours of inspection figures.

Several other similarities between the two sets of phenomena were observed: periods of inspection necessary to produce the third-dimensional effects were, on the average, the same, and the range of individual differences among subjects was similar in this respect; if inspection periods were prolonged or, especially, if they were repeated, the effects showed the same marked increase in persistence; they showed the same degree of localization in the frontal plane as frontal plane effects themselves; monocular inspection produced somewhat weaker effects and the effects were transferable from one eye to the other; the effects tended, as in the frontal plane, to be stronger in the lower half of the field; and finally, reversal of brightness relations between inspection and test figures did not diminish the effects.

The crucial experiment which demonstrated that test figures both in front of and behind the position of the inspection figure are displaced in depth away from that position was a qualitative one and the only specifications reported were the distance relations between the subject and the various figures. However, this evidence appeared to the investigators to be sufficient to justify the conclusion that frontal plane and third-dimensional after-effects are merely different manifestations of the same principle. This experiment also convinced them that two factors which are known to operate in such situations did not in fact influence the results to any significant degree. Retinal fatigue is known to cause the affected figure to appear darker at first and hence to stand out less against the background. Also, Köhler & Wallach (1944) showed that quite apart from figural after-effects in depth any object which lies in an affected zone, tends to recede somewhat from the position it would normally occupy. Köhler & Emery point out that it is as easy to produce displacements towards the subject (when these uncontrolled factors would be opposing the displacement) as away from him.

It remained to be demonstrated that the recession of test figures from inspection figures shows the same characteristic dependence on distance in the third dimension as it does in the frontal plane. The experiment in which the distance paradox was demonstrated in the third dimension is one of the few for which this group of investigators provide adequate descriptions of apparatus and procedure, though this advantage is somewhat offset by their use of only four subjects. One of the subjects had previously taken part in similar experiments; the degree of sophistication of the others was not specified. The figures were white cardboard figures against a black ground. Subjects viewed from a distance of 13 ft. The test figure was always in the plane of fixation, i.e., the same distance from the subject as the fixation point. The inspection figure was directly behind the test figure and the distance between them was varied systematically. Before and after the 45 sec. inspection period the test figure was exposed, and an identical comparison figure placed on the other side of the fixation point and therefore presumably unaffected was set at apparent equidistance to the test figure. The difference between the pre- and post-inspection settings constituted the after-effect and was plotted as a function of the distance between the inspection and test figures.

Three of the four subjects showed the distance paradox, displacement being maximal when the figures were 25 cm. apart and falling off on either side of this point. The experimenters suggest that this optimal distance may be partially dependent on the distance of the whole display from the subject. For the fourth subject, displacements were in general more than twice the size of those for any other subject at a given separation of the figures, and they reached a plateau at 35 cm. of separation which they maintained to 55 cm., the largest separation permitted by the apparatus. Despite this anomaly Köhler & Emery were satisfied that the distance paradox applies in depth as in the frontal plane.

In a further series of qualitative demonstrations in which the position of the fixation point is varied in relation to the test and inspection figures the same writers show that a satiated region has a location which is constant with reference to the fixation plane and moves with it through absolute space. This would corroborate the classical theory that depth in binocular vision is given by relations to the horopter. Their observations further suggest that in the third dimension, two-dimensional effects are not localized in absolute space but in the same fashion as third-dimensional effects themselves, viz., in relation to the plane of fixation.

Work which could possibly be cited in support of Köhler & Emery's findings is that of Bergman & Gibson (1959). These authors claimed that by using a texture gradient as the cue to depth and viewing through a constant aperture to eliminate contour changes they had ensured that the after-effect they obtained was not a figural after-effect, though the displacements were in the same direction. But we shall argue elsewhere that this claim is not valid since a texture gradient of the type used could give rise to contour processes. If this argument were accepted the work would be the only independent confirmation of the existence of third-dimensional figural after-effects.

Smith (1948) criticized the satiational interpretation of figural after-effects in the third dimension. These effects can be achieved monocularly (Köhler & Emery, 1947); but there is no known correlate in the monocular visual system for the distance from which a stimulus emanates; how then can a certain distance be satiated? Köhler & Emery hold that visual depth is a sensory fact and that there must be somewhere a direct neurological correlate of it.

Köhler & Emery do not defend any neurological model of the third-dimensional effects since such a model would have to be related to an as yet nonexistent theory of depth perception. Though two-dimensional isomorphism and the relatedness of retinal extension to cortical extension is plausible it is a long step to three-dimensional isomorphism, i.e. to the thesis that objects at different distances from the subject produce processes at different levels of the cortex which can be displaced from one level to another. Though they discarded that picture because of its "neurological strangeness," they suggest that "the actual representation of the third dimension must be functionally isomorphic with the one which would follow from that picture." In so far as this enigmatic statement means that they do in fact hold to this "layered" view of cortical topography the same criticism may be levelled against their attitude as against the general theory of satiation. On the other hand if they have rejected this view and do not hold that the underlying mechanism is the same as that for frontal plane effects, then there is no reason, apart from their own rather scanty evidence, to assume that the depth effects follow the same phenomenological laws.

Kohler & Emery discuss a suggestion by Wallach that figural after-effects in the third dimension may be explained in terms of two-dimensional after-effects. Kleist (1934) and other neurologists have suggested that corresponding points of the two retinae are represented opposite each other in two layers of the visual cortex while disparate points are represented in oblique positions.

Suppose the inspection object (I) and the test object (T) are at different distances in the median plane and the subject fixates on the position of I. Fig. 3 depicts the representation of this arrangement in the cortical layers.

| | | | |
|---|---|---|---|
| | I | T | Layer 1 (left eye) |
| T | I | | Layer 2 (right eye) |

Fig. 3 Cortical representation of objects at different distances in the median plane.

Assuming that the satiation produced by a cortical object is much stronger in its own layer than in the other layer, the effect of the inspection processes would be to displace the test figure representations away from themselves. The test figure inputs from each eye would be displaced in the opposite direction to each other. This would result in the degree of disparity produced by an object which is farther away than the test object. The test object therefore appears to have receded from the inspection object. A similar argument would hold whatever the plane of fixation and for the other effects reported by Köhler & Emery.

But Köhler & Emery suggest two rebuttals of this hypothesis. They point out that the third-dimensional effects are not destroyed by monocular observation of the test object after binocular inspection. In this case the test object has only one cortical representation and even if this be displaced by satiation it has no partner in relation to which this displacement could render it disparate. They admit that this point may not be entirely convincing and, indeed, it is arguable that when a subject is set by instruction to see differences in depth, a change in the difference in image positions of the inspection and test objects in one eye may be a sufficient cue to a change in depth.

Their second attempt to refute this interpretation was an experiment in which the subject stereoscopically inspected alternate presentations of disparate images to the two eyes. This should build up separate patterns of satiation in the two cortical layers. However, when two appropriate non-disparate test patterns were subsequently presented to the two eyes no after-effect was observed. This arrangement, the authors claim, fulfills the conditions of Wallach's hypothesis while eliminating the three-dimensional appearance of the inspection object, which they regard as the major factor in producing the effect. An appearance of depth can in fact be created by stereoscopic alternation of disparate views at particular speeds but these authors' failure to give details about procedure makes it impossible to decide whether they in fact eliminated the appearance of depth. That they were successful is suggested by their failure to get the effect whereas they got it quite readily when the same two disparate views were presented simultaneiously in the stereoscope. But even if they have succeeded in undermining Wallach's suggestion their success has posed just as great a problem for them. For, granting that the appearance of depth in the inspection figure is normally the important factor, nevertheless, it would be predicted from satiation theory that the conditions were present in the above experiment for normal two-dimensional after-effects and that the resulting displacements should have produced cues which would have been interpreted as changes in depth indistinguishable from the third-dimensional figural after-effect.

The most plausible explanation for Köhler & Emery's finding of a third-dimensional figural after-effect is that it is reducible to a frontal plane after-effect without reference to retinal disparities: when two figures of the same size are placed at different distances on the visual axis of a subject the retinal projection of the farther one is enclosed (and hidden, if they are presented simultaneously) by that of the nearer one. Considering these projections one would predict that after fixating the nearer, larger one the farther, enclosed one should suffer an apparent shrinkage which could be interpreted by the subject as a recession in depth. Conversely fixation of the farther one should increase the apparent size of the nearer one which would consequently appear to approach the subject. Thus fixation of an intermediately placed stimulus could make the farther one recede from and the nearer one approach the subject. This is precisely what Köhler & Emery reported.

The obvious test of this hypothesis is to have the size of the figures vary directly with their distance from the subject in such proportion that the retinal projection of any given figure encloses that of any nearer figures, i.e. the opposite relationship to that obtaining when the figures are the same size. Then if the explanation is correct fixation of the intermediate fugure should produce apparent shrinkage and therefore recession of the nearer figure and should cause the farther figure to increase in apparent size and to approach the subject, these predictions being opposed to those of the third-dimensional theory.

Köhler & Emery consider this suggestion, but report observations in which a test figure placed in front of an inspection figure and, even in this position, apparently smaller than it, appeared even smaller after the inspection period but nevertheless appeared to be displaced towards the subject. They give no details of procedure or subjects. The finding if it were confirmed would not only discredit the reduction of the effect to a two-dimensional one but would also demonstrate the strength of the effect since these results suggest that it is strong enough to overcome the size-distance relationship which one would expect to hold in this situation.

Osgood & Heyer (1952) appear to accept most of Köhler & Emery's data as they, strangely, accept most of the reported findings of Köhler & Wallach. But they strongly support a two-dimensional interpretation in the interests of parsimony. They use a similar test to that adopted by Köhler & Emery but do not describe their experiment much more adequately than the earlier workers. They merely state that their subjects were naive, that the expected reduction in apparent size (of a test figure in front of and smaller than the inspection figure) was usually reported, but that when a displacement was noted "it was generally farther away." This result if confirmed would support the reduction of depth effects to frontal plane effects.

It is strange that on the basis of a single negative instance Köhler & Emery chose to reject this interpretation in favour of one which on their own admission they cannot assimilate into satiation theory. Although there is no satisfactory theory of frontal plane after-effects it is a less disturbing state of affairs than having two related sets of phenomena apparently requiring separate explanations. Thus it was decided to test the two-dimensional interpretation using the method of Köhler & Emery and Osgood & Heyer but applying it more rigorously than they appear to have done. First it was necessary to establish the depth effect using the original arrangement of figures of the same size, so that the results could later be compared with those obtained with figure sizes which lead to opposed predictions by the two- and three-dimensional interpretations.

# VIII EXPERIMENT II: THIRD-DIMENSIONAL FIGURAL AFTER-EFFECTS

## Method

The experimental conditions were closely similar to those used in Köhler & Emery's successful demonstration of the effect. The subject sat on the stool with the back of his head resting against a wall. The stimulus figures were mounted at eye-level on a table four feet high. A fixation point consisting of a white cardboard disc one quarter inch in diameter was mounted on a thin wire 13 ft. in front of the subject. On either side of the fixation point and one inch above the table horizontal steel rods were mounted on bearings which permitted them to rotate about their long axes. The two rods converged approximately towards the mid-point between the subject's eyes. The stimulus figures were three, three inch, white cardboard squares rigidly attached by means of thin black stems to the horizontal rods. Two of these - the inspection figure (I.F.) and the test figure (T.F.) were mounted on the same horizontal rod at an angular separation of $90^{\circ}$. The T.F. was at the same distance from the subject as the fixation point and the I.F. eleven inches farther away. Stops were placed so that the horizontal rod could rotate only between stable terminal positions in which either the T.F. or the I.F. was vertically orientated. The comparison figure (C.F.) was mounted on the other horizontal rod at the same distance as the T.F. and fixation point. Stops were placed so that it could be rotated between a vertical and a horizontal position.

A low black screen was placed in front of the apparatus to conceal from the subject both the horizontal rods and the stimulus figures when they were in the horizontal position. Two additional black screens were suspended by runners from a rail. The experimenter could rapidly move these screens apart or together by means of an arrangement of cords and pulleys similar to that used to control household curtains. At their widest separation the screens cleared the outside edges of the stimulus figures by several inches; at its narrowest the gap between them exposed only the fixation point. A large matt blackboard was placed behind the array, and the illumination - daylight from one side counterbalanced by artificial lighting on the other - was so adjusted that the various screens in front merged with the back-board to form an almost homogeneous background for the figures.

The subject was instructed to keep his head steady and to maintain constant fixation on the white disc throughout the experiment. He was told he would be shown two white squares one on either side of the fixation point and he should report as quickly as possible whether the one on his right (C.F.)

appeared nearer to him, the same distance away, or farther away than the one on his left (T.F.). The screens were then drawn aside and T.F. and C.F. remained exposed until S. had made his judgement, a period of never more than about three seconds. The figures were then covered for ten seconds - long enough to give the impression that the stimulus distances might be altered. Three such control readings were taken. Then I.F. was exposed alone, eleven inches behind the position of T.F. and the subject was required to fixate the disc continuously for two minutes. Towards the end of this period S. was told that he would shortly be shown two figures again and he was asked to make similar judgements to those he had made before. The array was briefly screened while C.F. and T.F. were rotated into the exposure position. Three test readings were taken. At all times T.F. and C.F. were objectively equidistant from S.

Eight of the department's staff served as subjects. None had any detailed knowledge of figural after-effects or of the expected outcome of the experiment.

## Results

The number of responses of each type - backward, same and forward - given by each subject is shown in Table 4 for both pre- and post-satiation trials. The responses refer to the apparent position of C.F. as compared with T.F.

Table 4: Responses to the comparison figure relative to the affected test figure before and after inspection.

| SUBJECT | CONTROL | | | TEST | | |
|---|---|---|---|---|---|---|
| | Backward | Same | Forward | Backward | Same | Forward |
| A | 1 | 2 | | 1 | 2 | |
| B | 2 | 1 | | 3 | 0 | |
| C | | 3 | | | 3 | |
| D | | 1 | 2 | | 2 | 1 |
| E | 1 | 2 | | 1 | 2 | |
| F | | | 3 | | | 3 |
| G | 3 | | | 2 | 1 | |
| H | | 3 | | 1 | 2 | |
| Total | 7 | 12 | 5 | 8 | 12 | 4 |

Satiation theory would predict that T.F., lying directly in front of the position of I.F., should appear displaced further forward, in relation to C.F., after inspection of I.F., i.e. that the number of "backward" responses should be higher and the number of "forward" responses lower in the test situation. In fact, the slight difference between the results in the two conditions is in the opposite direction. The largest net difference shown by any individual subject was only a shift of one response to an adjacent category.

It might be argued that our failure to reproduce the effect was due to the qualitative nature of the experiment and the subsequent crudeness of measurement. But it was a qualitative test which convinced Köhler & Emery of the validity of the effect using a similar apparatus involving almost identical distances; and when they proceeded to make quantitative measurements they reported effects at these distances ranging from 2.5 cm. to 10.5 cm. Displacements of this magnitude should be clearly discriminable.

Köhler & Emery do not report the temporal relationships obtaining in their qualitative tests but in their later experiments they used a number of inspection periods each followed by only one judgement. It is possible that the effect of the satiation could largely dissipate during the half minute required for three judgements in the present experiments. On the other hand the effect of increasing the length of the satiation period is known to be a prolongation of the effect rather than an increase in its magnitude (Sagara & Oyama, 1957).

Köhler & Emery do not specify the number of subjects used in the preliminary qualitative tests but only four were used in taking the quantitative measurements. In the absence of any independent confirmation of their results the validity of the effect must remain in doubt. Since we failed to reproduce the effect we could not proceed to our projected test of the suggestion that the figural after-effect in depth effect could be reduced to a two-dimensional effect by considering the spatial relationships within the two-dimensional projection of the depth array.

# IX EXPERIMENT III(a): AFTER-EFFECTS IN THE PERCEPTION OF RELATIVE DEPTH

Apart from the studies of Kohler & Emery (1947) and Bergman & Gibson (1959), already reviewed, research has been negligible in the field of stereoscopic fatigue, the effect of prolonged stimulation by a depth array upon the perception of other patterns in depth.

The nearest any worker appears to have come to this situation is Lit (1959) in his study of the effect of fixation conditions on stereoscopic acuity. He used the Howard-Dolman apparatus in which the subject adjusts the distance of a variable rod until it appears level with a standard rod. In one of his conditions Lit had the subject fixate the standard rod while the variable was moved. It is of interest to note that this condition produced a poorer level of stereoscopic acuity than conditions in which the subject either fixated the moving rod or was free to fixate either at will. But in none of his conditions was there prolonged fixation of a constant arrangement of rods.

We sought to ascertain whether the prolonged fixation of lines at particular degrees of separation in depth had a systematic effect on the subsequent perception of their depth relationship and in particular to provide a situation in which predictions from satiation theory would be opposed to predictions from a Gibson type adaptation theory.

The Satiation Hypothesis

If the inspection pattern consists of two rods with a particular depth relationship and in the test period one of them remains in the same position while the other is moved to a position closer to or farther away from the subject than its previous position then it should appear even closer or even farther away, thus affecting its relationship to the stationary rod. This should apply even when the inspection rods are level. It seems clear that Köhler & Emery would predict this, and it seems more reasonable to investigate possible figural after-effects in a situation involving relative rather than absolute depth, since the visual system has very little sense of absolute depth. In order for a single plane inspection figure as used by Köhler & Emery (1947) to have any influence in depth it is necessary for the visual system to be able to localize it fairly accurately and in so far as it succeeds it means that the attempted reduction conditions are not complete and that the subject is using uncontrolled cues to relative depth, since this is the only way such localization could take place. It is better to use relative depth explicitly, with the cues under careful control. In any case Köhler & Emery for the most part use relative depth in their demonstrations. For example the inspection of a third-dimensional curve and subsequent judgement of similar curves in the same location is a parallel to the present arrangement. The mid-point of the curve constitutes a standard reference point.

Even without assuming the existence of third-dimensional figural after-effects dependent, as Köhler & Emery would have them, on the appearance of depth, it would be possible to make the same predictions from the consideration of retinal disparaties discussed on page 69 as an alternative interpretation of Köhler & Emery's findings.

A special case arises with an inspection pattern where the rods are level; this should cause rods in disparate positions to appear even farther apart and so reduce the variability of judgements of the point at which the two rods are level. But unlike disparate inspection patterns it should not produce any shift in the P.S.E.

An Adaptation Hypothesis

An alternative is that adaptation occurs in the higher centres which coordinate retinal disparity information. It could be that retinal correspondance - equidistance of the two rods - is a "norm" in a sense similar to Gibson's and that prolonged sampling of a disparity leads to its adaptation to the norm of non-disparity, and to a movement of the whole subjective scale in the same direction. Inspection of a variable rod in front of the standard should lead to a gradually increasing appearance of levelness, to an apparent displacement behind the standard of a truly equidistant variable, and to an apparent displacement of lines behind the standard to positions even farther away. A similar argument holds with all directions reversed when the variable inspection line is farther away than the standard. No effect would be expected to follow fixation of a pair of equidistant stimuli.

Künnepas (1960) investigating the psychophysical functions relating objective to subjective distance, concluded, "it is conceivable that, in analogy to adaptation to light intensity, temperature, etc., an adaptation of the subjective range to the stimulus range may change the exponent" (of the psychophysical function). Künnepas presented no evidence to support this but it is a statement of the present adaptation hypothesis.

Thus, in summary, in most cases the theories are in agreement about the direction of displacement to be expected. There appear to be two points at which their predictions diverge. The adaptation hypothesis holds that the whole range of test positions will be displaced after inspection of a disparate pattern; satiation theory holds that patterns more disparate than the inspection pattern and in the same direction will appear even more disparate whereas less disparate patterns, level patterns and patterns disparate in the opposite direction will all be displaced the other way. Also adaptation theory expects no effect from a level inspection pattern whereas satiation theory expects a decrease in the variability of judgements of that point.

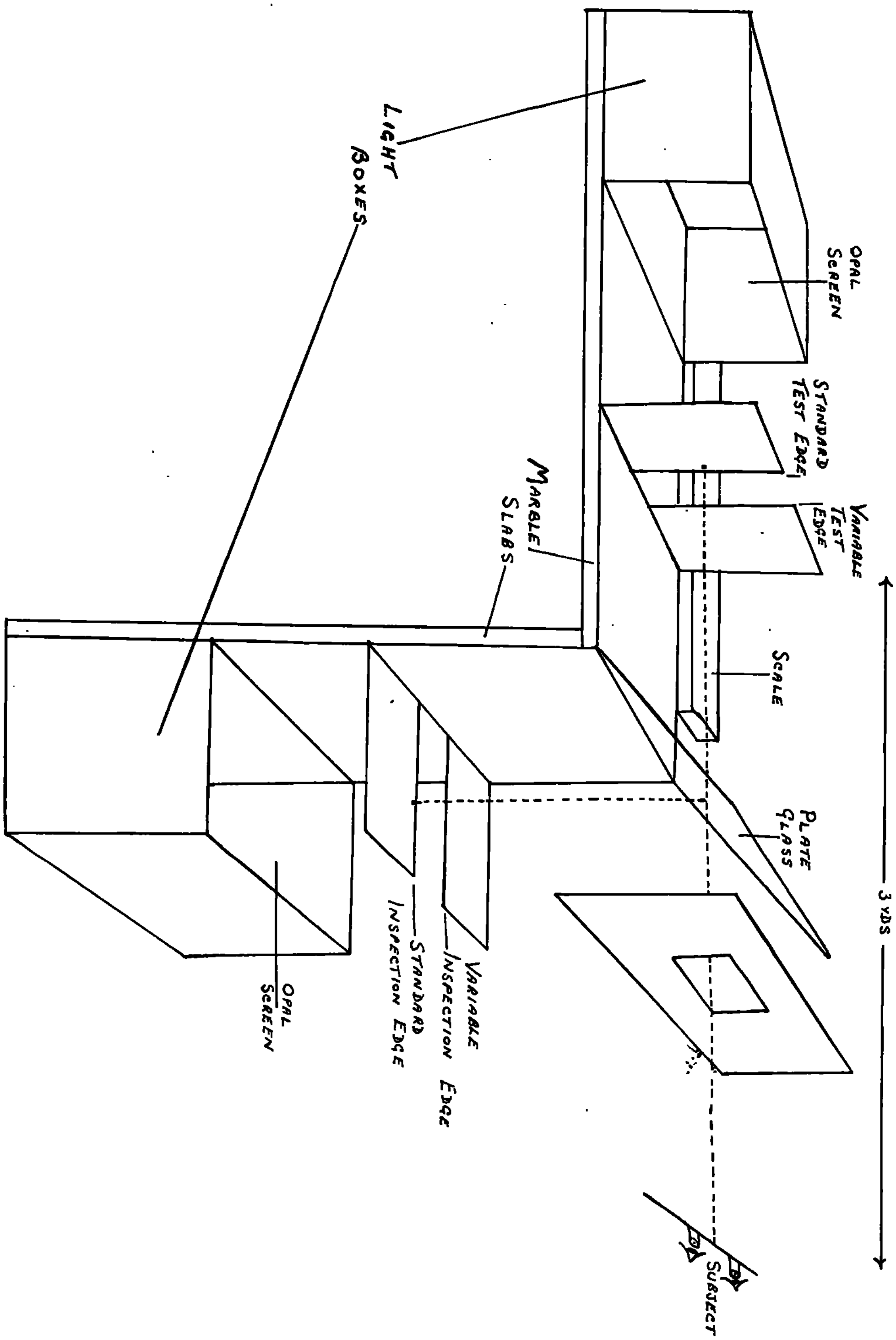
The present study attempted to eliminate all cues except retinal disparity. The figures were sharp black-white contours which had no thickness and therefore did not vary with distance. The subject viewed the contours through a constant aperture so that their projected height remained the same. Changes in convergence and accommodation were prevented by having the subject fixate a stationary standard contour while changes in relative depth were obtained by moving a variable contour. The arrangement was further simplified by moving the variable line along the visual axis of one eye so that the retinal location of both lines - the other being stationary - was constant in that eye, irrespective of the degree of separation of the lines. The projected separation of the lines on the other retina then varied as a function of their separation in depth. The two lines would appear level when the two retinal separations were equal.

Apparatus

There were two stimulus patterns, an inspection pattern and a test pattern. Each set consisted of a pair of black cards set parallel at right angles to the subject's line of sight and with a constant lateral separation of one and a half inches. The two sets were placed at right angles to each other and at $45^{\circ}$ to a semi-reflecting mirror placed between them, as shown in Fig. 4. An opal glass screen illuminated from behind was placed behind each pair of cards which thus formed vertical black-white contours and gave the appearance of an upright rectangle of light. When both screens were illuminated the two rectangles were exactly superimposed. The left-hand card of each set had a small hole close to its edge and half way up its visible height. These holes served as fixation points. There was also an alternative inspection figure consisting only of a fixation spot on a black ground.

Each opal glass screen formed one side of a 15 in. cubical box. On the back, inner surrface were mounted six 13 in., 60 watt tungsten filament striplights. The other innar surfaces were lined with mirrors which produced, by multiple reflections, an infinite surface of illumination. This gave an even illumination on the opal glass screen. The surface illumination of the first screen was 40 foot candles. The two screens were matched for brightness by covering half of each with black card so that the remaining halves could be seen side by side. Bulbs were removed from the second box until

Fig. 4: Apparatus for Experiment III.



there was a match. At this stage there was still no perceptible colour difference.

In front of the semi-reflecting glass was a black screen with a six inch square hole through which the subject could view the stimuli. The screen was carefully matched to the shade of black of the stimulus cards so that no contours were visible except the two inside edges of the cards and the top and bottom edges of the aperture.

The standard card containing the fixation point was stationary. The right-hand, variable card had a long screw threaded through its metal base and connected to a rotary drive. In this way it could be made to move along parallel guide rails towards or away from the subject to a maximum distance of four inches from the standard card. The motor speed control allowed very precise starting, stopping and reversing. Attached to the base of the variable card was a pointer which moved along a scale giving readings in sixteenths of an inch.

An electronic timer controlled the 20 sec. exposure of the inspection pattern and automatically re-exposed the test pattern at the end of the inspection period.

Procedure

The subject was seated six feet away from the standard cards. A chin rest, temple clamp and forehead stop held the subjects head firmly in position. Mounted on this head-rest were two artificial pupils, 2.5 mm. in diameter. The right hand pupil was fixed so that the right eye of each subject occupied the same position, directly in the line of travel of the edge of the variable card. The left-hand artificial pupil could be varied to suit individual inter-ocular distances and the convergence angle necessary to centre the field of view in the artificial pupil. The artificial pupil was centred on the subject's own pupil by asking him to centre the outline of the artificial pupil with a second concentric diaphram placed some distance from the artificial pupil.

The subject was told that he must fixate the light dot throughout the experiment. The first pattern he was shown he would inspect passively for two minutes. At the end of this period the pattern would change. In the new pattern one of the vertical edges of the rectangle would be clearly farther away than the other. This difference would immediately begin to diminish and he should give a signal as soon as the two edges appeared to be level. Thereafter the periods of passive inspection would be only 20 sec. The cycle would be repeated 20 times.

It was confirmed that the subject could see the test edges as clearly apart when they were at their maximum separation. Then the inspection figure was exposed. During each inspection period the experimenter read off the position of the variable test edge, reset it at the starting point and reversed the motor in readiness for the next reading. As soon as the test pattern was exposed the experimenter switched the motor to a speed which produced a movement of about one and a half inches per second of the stimulus. When the subject responded the motor was stopped and the timer switched on to give the 20 sec. exposure of the inspection figure.

Four different starting points were used for the adjustment in order to cancel out factors such as the delay between the subject's response and the experimenter's stopping of the motor and the personal criteria of the subjects in choosing the precise point in the region of uncertainty at which they were willing to respond. The starting points were three and four inches behind and in front of the standard edge and their order was mixed in such a way that each appeared five times in every series of 20.

The subjects were six male undergraduates, several of them studying psychology but none with any knowledge of this research. Each subject served in all four conditions. The conditions were presented in random order and were separated by at least an hour.

The inspection figures for the four conditions were as follow:

(i) Fixation point alone.

(ii) Variable edge level with standard edge.

(iii) Variable edge two inches in front of standard edge.

(iv) Variable edge four inches in front of standard edge.

Conditions (iii) and (iv) give the effects of different amounts of retinal disparity as compared with condition (ii) where there is no retinal disparity. Condition (i) is a baseline control for the effect of constant fixation without any figure, symetrical or asymetrical.

## Results

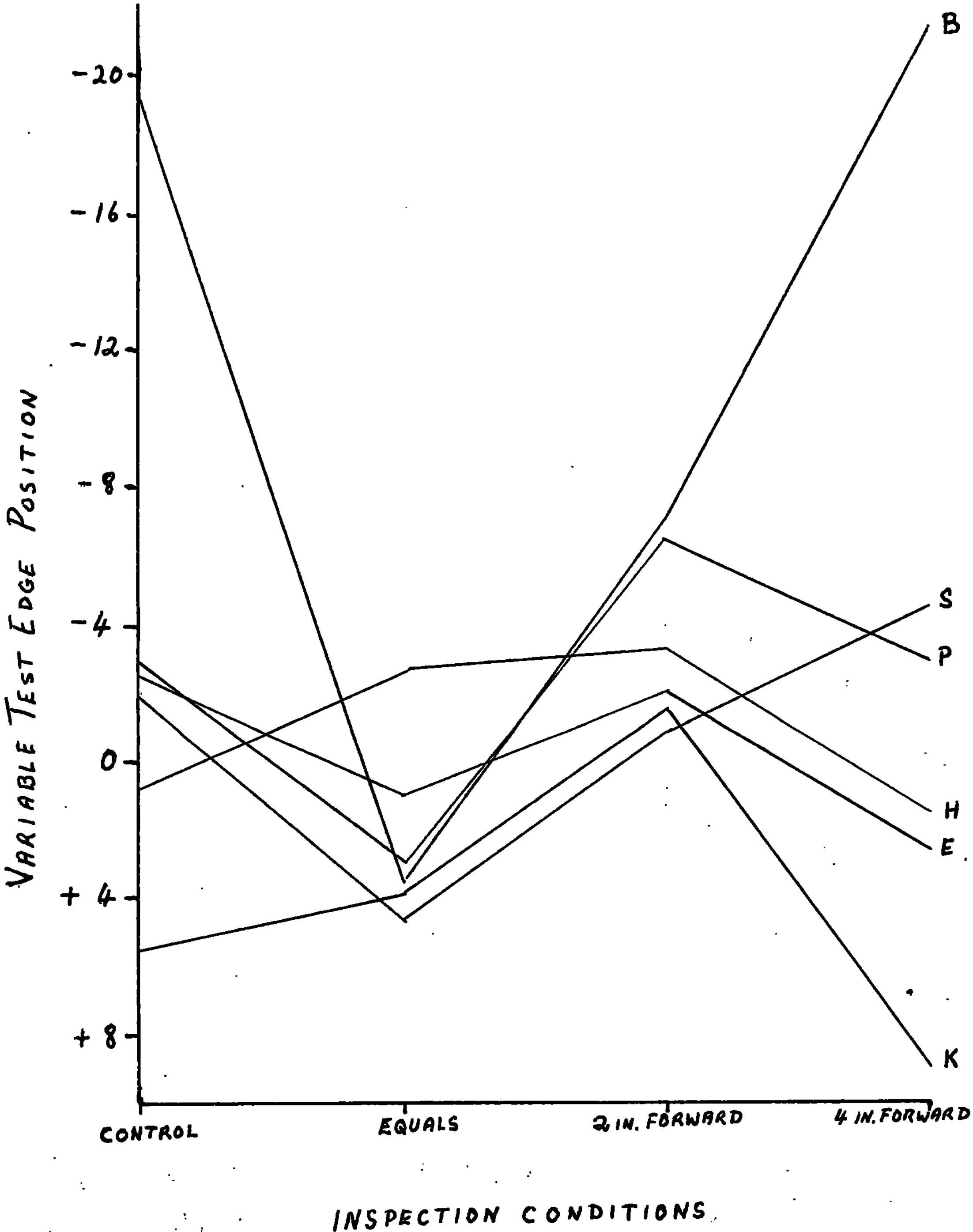
P.S.Es. were calculated for each subject in each condition as the mean of twenty readings. They are shown in Fig. 5. The means of the six P.S.Es. in each condition are given in Table 5.

Table 5: Mean P.S.Es. and standard deviations for conditions in 1/16 in. from standard edge, positive readings being closer to the subject, negative readings farther away.

| Condition | Control | Edges Level | Variable Edge 2 in. in front | Variable Edge 4 ins. in front |
|---|---|---|---|---|
| Mean P.S.E. | - 3.5 | 2.0 | - 3.6 | -2.7 |
| S.D. | 46.16 | 13.93 | 13.42 | 56.15 |

An analysis of variance shown in Table 6 shows that none of

Fig. 5: Experiment III(a): Points of subjective equality for conditions, measured from the standard edge, positive readings being closer to the subject.



the mean differences are significant.

Table 6: Analysis of variance for P.S.Es.

| Source | Degrees of Freedom | Sums of Squares | Estimated Variance | F | |
|---|---|---|---|---|---|
| Conditions | 3 | 128 | 43 | 1.4 | N.S. |
| Subjects | 5 | 470 | 94 | 3.00 | N.S. |
| Residual | 15 | 472 | 31 | | |
| Total | 23 | 1070 | | | |

In any case it would be difficult to interpret these figures. Disregarding the control condition with its large constant error the two inch and four inch conditions show mean P.S.Es. behind objective equality. This means that the test stimulus appeared farther forward than it really was, i.e. it was displaced towards the position of the inspection figure; there is no theoretical reason to expect a displacement in this direction.

When the means are written as deviations from the control mean, as in Table 7,

Table 7: Condition means as deviations from the control mean. Positive differences are towards the subject, negative differences farther away.

| Edges Level | Variable Edge 2 in. in front | Variable Edge 4 in. in front |
|---|---|---|
| 5.5 | - 0.1 | 0.8 |

the deviation in the four inch condition comes to be in the expected direction, but by far the largest shift of P.S.E. is the forward shift in the equals condition. No displacement was expected in this condition but in view of the large negative constant error in the control condition, an objectively level inspection figure will presumably appear to have its variable edge somewhat in front. Thus one would expect it to produce a displacement in the same direction as those in conditions (iii) and (iv). Indeed the direction in condition (iv) is the same but it is far from clear why the magnitude should be smaller than that for the less disparate "level" figure, or why, when the inspection figure had the intermediate disparity of two inches, there should be no displacement at all.

However, the differences are not significant and their directions do not demand any serious attempt at explanation. The large standard deviations and the obvious inconsistency demonstrated in Fig. 5 point up the unreliability of the data. This inconclusiveness is doubtless partially due to the crudity of the psychophysical method of adjustment: apart from its more commonly stressed disadvantages, in this case the adjustment of the test stimulus involved its travel through the position previously occupied by a similar inspection object, and when one expects an inspected pattern to produce displacements this may have a confusing effect.

## X EXPERIMENT III(b): AFTER-EFFECTS IN THE PERCEPTION OF RELATIVE DEPTH: CONSTANT STIMULUS METHOD.*

Two possible factors were suggested to account for the equivocality of Experiment III(a). The two- or three-second delay between the end of inspection and the completion of the judgement could be sufficient to reduce the effect to a level at which the present technique would fail to measure it. Secondly, the moving stimulus would provide the subject with more cues to depth and hence increase the veridicality of his judgements and lessen any distorting effect of the previous inspection. Since both these weaknesses stem from the use of the adjustment method it was decided to overcome them by resorting to an ultra-rapid technique of constant stimuli for carrying out a formally identical experiment. A further advantage of the method is that it makes it possible to assess the effect of a disparate inspection pattern on test patterns which are more disparate in the same direction - the second point at which the two theories diverge in their predictions.

### Method

The apparatus was the same as that used in Experiment III(a)

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* Conditions 2 and 3 in this experiment were the joint work of Mr. Howard and the author.

except that two further timers were employed to time a one-second exposure of the test stimulus and to give a warning click one second before that exposure. Since none of the time intervals was indefinite like the period for adjustment and judgement in the previous experiment, the timers were linked in a continuous cycle. The motor was no longer required to drive the variable test edge which was easily moved by hand into one of five positions: level with the standard edge, two inches and four inches nearer and farther away. The warning click was actually produced by a memory drum exposure device which presented to the experimenter one at a time a random sequence of the numbers one to five, representing the test figure positions. The subject was provided with a two-way switch with which he was instructed to signal immediately he saw the test pattern, whether the variable edge was in front of or behind the standard edge. This information was conveyed by means of small coloured signal lamps to the experimenter who had to note the response in one of five cells depending on the position of the last stimulus exposed. He then moved the stimulus into the position indicated on the memory drum for the next exposure. It was found that these tasks could be comfortably carried out during a ten-second inspection period.

The reduction in the time of each trial by this technique permitted an increase of the number of trials to 50 in each series, each of the five test figure positions appearing ten times. There was still an initial inspection period of two minutes. The inspection figures for the four conditions were the same as in the earlier experiment.

The conditions were identical with those in the previous experiment. They were presented in random order and separated by several days. The five subjects were students of psychology who had not taken part in the previous experiment and had no knowledge of the research.

Results

The raw data showed the number of "forward" responses made by each subject to each stimulus category in each condition. Responses refer to the apparent position of the variable edge relative to the standard edge. The total number of "forward" responses made by each subject in each condition was calculated and the means of the five totals are shown in Table 8 for each condition.

Table 8: Mean number of forward responses in each condition

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Condition (inspection figure) | Control | Variable edge level with standard | Variable edge 2 in. in front | Variable edge 4 in. in front |
| Mean | 25.6 | 25.8 | 12.8 | 15.6 |

An examination of these means suggests that fixation of a pattern with the variable stimulus in a forward position leads to a reduction in the number of forward responses, i.e., to an apparent backward displacement of the variable stimulus in the test patterns.

But a satiation hypothesis demands not a simple shift of P.S.E. but a displacement of test stimuli in both directions away from the position of the inspection figure, i.e., an increase in the number of "forward" responses to a stimuli in front of the inspection position and a decrease in their number to stimuli behind the inspection position. This should show itself as a significant interaction between conditions and stimulus categories. Hence it was necessary to analyse the number of "forward" responses between stimulus categories as well as between conditions and between subjects. The results of this analysis are shown in Table 9.

Table 9: Analysis of variance of "forward" responses

| Source | Degrees of Freedom | Sums of Squares | Estimated Variance | F | P |
|---|---|---|---|---|---|
| Stimulus Categories | 4 | 625 | 156.0 | 54.16 | <.001 |
| Subjects | 4 | 58 | 14.5 | 5.03 | <.01 |
| Conditions | 3 | 140 | 46.7 | 16.21 | <.001 |
| Cat. X subj. | 16 | 125 | 7.81 | 2.71 | <.01 |
| Cond. X subj. | 12 | 46 | 3.83 | 1.32 | N.S. |
| Cond. X cat. | 12 | 50 | 4.17 | 1.44 | N.S. |
| Residual | 48 | 138 | 2.88 | | |
| Total | 99 | 1182 | | | |

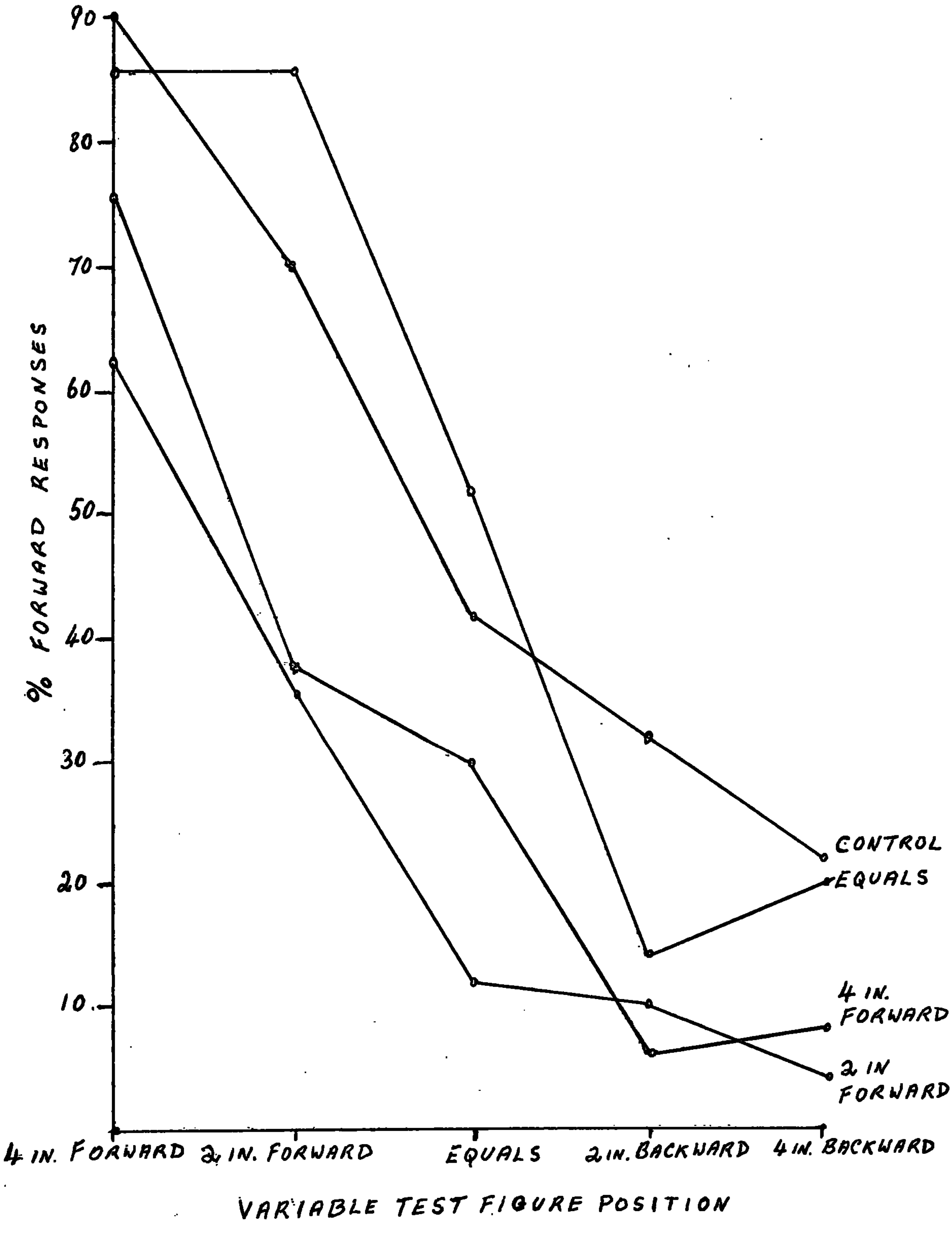
The highly significant contribution of stimulus categories was expected as they were chosen so that they would appear discriminably different to the subjects. There is also the highly significant difference between subjects usually found in this type of work. The interaction between subjects and stimulus categories is highly significant but has little meaning as the scores in each category are summed over all conditions. The absence of an interaction between subjects and conditions merely points to the consistency among subjects of the pattern of the conditions scores as opposed to the scores themselves which do show significant individual differences. There remain to be considered the two most important results, the main effect between conditions and the interaction between conditions and categories.

The difference between conditions is very highly significant. This clearly means that condition 3 differs significantly from conditions 1 and 2. (see Table 8). The difference between conditions 3 and 4 was subjected to a t-test using the residual variance from the analysis. It was found that t equals 2.62 which for 48 degrees of freedom has a probability between .01 and .02. The larger difference between condition 4 and conditions 1 and 2 must also be significant. We therefore conclude that the displacement induced by the four inch inspection figure while itself significant is still significantly smaller than that induced by the two inch figure.

This result further strengthens the adaptation hypothesis. One can assume that both effects - adaptation and figural after-effects - in general diminish in strength as a function of the distance between inspection and test figure. Therefore, in the present experiment, both mechanisms should have a greater effect on the stimulus categories immediately adjacent to the inspection figure position than on those farther away. In the two inch condition there are two categories adjacent to the inspected position - the "equal" category and a four inch category - compared with only one in the four inch condition. On the satiation hypothesis the direction of displacement in these two categories should be opposed; they should therefore cancel out, thereby reducing the overall size of the effect in the two inch condition as compared with the four inch. On the adaptation hypothesis, however, the direction of displacement in the two categories should be the same, so the additional category adjacent to the position of the two inch inspection figure should increase the overall magnitude of displacement in that condition.

The significant interaction between conditions and stimulus categories required by the satiation hypothesis was not obtained. The appropriate curves are shown in Fig. 6. The hypothesis requires that in the two inch condition a test stimulus at more than two inches forward (i.e. the four inch stimulus) should be displaced even further forward and that there should be a higher number of

Fig. 6: Experiment III(b): Conditions by Stimulus Categories



forward responses to it in this condition than in the control condition. This is clearly not the case. But the steepest parts of all the curves are those which pass through points representing the position of the inspection figure and this may indicate that test stimuli in the position of inspection figures and those that are adjacent to them are displaced away from one another. This effect is most striking in the case of the "equals" condition where the adjacent two inch test stimuli appear in one case as far away, in the other case farther away from "equals" than do the four inch stimuli. This certainly represents the expected reduction in variance, as is shown in Table 10.

Table 10: Mean points of subjective equality for conditions and the Probable Errors of the Limens.

Measurements represent the axial separation in inches of the variable edge from the standard edge, positive positions being farther away from the subject.

| Condition | 1<br>Control | 2<br>Equals | 3<br>Two inches forward | 4<br>Four inches forward |
|---|---|---|---|---|
| P.S.E. | 0.18 | 0.23 | - 3.24 | - 2.22 |
| $P.E._L$ | 0.98 | 0.82 | 0.91 | 0.88 |

It may be that these indications in favour of the satiation hypothesis would be strengthened by the use of more subjects and this addition is being planned. But at present we can only conclude that prolonged fixation of a depth array does have a systematic effect on the perception of similar arrays. The weight of our evidence suggests that this effect takes the form of a displacement of the whole subjective scale of relative distance, at least in the location of the figures. Inspection of a pattern in which the variable stimulus is closer to the subject causes an apparent displacement away from the subject of the variable stimulus in test patterns. All this seems to imply that non-disparity of retinal inputs should be regarded as a norm, not only in the sense that inputs are classified according to their relationship to it but also that the visual system tends to adapt to this norm any prolonged deviant input. Several subjects reported that an inspection figure initially giving clear disparity came in time to appear flat. The results show that subjects tended to judge the test figures on the basis of this assumption of equidistance in the inspection figures.

## XI CONCLUSION

Since the completion of this investigation an unpublished paper by Rich & Morant (1960) has become available which throws more light on the tilt after-effect than any previous work has done. With the subject adjusting a rod to the apparent vertical they plotted the displacement as a function of the tilt of the inspection rod, using ten positions between vertical and horizontal. They found that the curve reaches a maximum of two degrees displacement when the inspection rod is tilted $10^{\circ}$ from the vertical; then it falls to zero at $65^{\circ}$. Further increases in the tilt of the inspection figure give negative displacements (i.e. towards the inspection rod); these negative displacements reach a maximum and again fall to zero at $90^{\circ}$. Since the rods are pivoted about their centres displacement of the apparent vertical is bound to be zero when the inspection figure is tilted through $90^{\circ}$.

The prediction from satiation theory is that the displacement should reach a maximum when the inspection figure is quite close to the vertical (the distance paradox) and then slowly fall to zero at $90^{\circ}$. It should never become negative. Gibson's theory on the other hand, while agreeing on the approximate point of maximum displacement, predicts a steeper drop in the curve, crossing the zero baseline at $45^{\circ}$ and thereafter reversing the direction of displacement (the "indirect effect"). After reaching a maximum in this direction it again falls to zero at $90^{\circ}$. Rich & Morant show that their results are a fair fit of the algebraic summation of these two curves, reaching a positive maximum, falling to zero somewhat beyond the $45^{\circ}$ point and after passing through a negative maximum reaching zero again at $90^{\circ}$. Of course, precise parameters for the predicted curves are lacking.

This suggests that there are indeed two independent effects both operative in this situation. Unfortunately Rich & Morant used the adjustment method which is not the most suitable for after-effect work, and each point is the mean of only four readings on each of seven subjects and in some cases only three subjects. The work is certainly important enough to merit replication with the ultra-rapid constant method on more subjects. However, there can be little doubt that they have established the general shape of the curve and thereby validated their assumptions.

They further argue that the reason for the lack of any independent confirmation of the indirect effect is to be found in the widespread use of the Köhler-Wallach technique whereby a subject is asked not to set the test rod vertical but to set it parallel to a nearby vertical comparison rod. Assuming that the Gibson effect shows spatial transfer it would be partialled out since the test and comparison rods would be equally affected.

Using this technique they repeated their experiment and found the satiation type of curve with no reversal of the direction of displacement. This seems to verify the transfer of the Gibson effect though it would be surprising if it transferred fully. We are at present designing an experiment to find the degree of transfer with varying separation of test and inspection figures.

A further point cleared up by the work of Rich & Morant is the reason for the smaller size of the indirect as compared with the direct effect. Gibson had to postulate a certain flexibility in the system linking the vertical and horizontal axes. It is now clear that the direct effect is the summation of the satiation and adaptation components whereas the indirect effect is a measure of the difference between the components.

Like Morant's work, the present study has tended to underline the importance of adaptation phenomena as opposed to specific local disturbances in the field. In situations where both types of effect might be expected to occur - viz. the indirect effect and the effect of inspecting a depth array - we have shown that adaptation effects predominate even though there are indications that satiation may be an additional minor determinant of the responses. Our demonstration of the indirect effect provides additional evidence that Gibson's tilt after-effects cannot be predicted from satiation theory. We have also failed to confirm one of the most notable findings of the Köhler group, third-dimensional figural after-effect, despite our attempt to reproduce the conditions of the original experiment.

There is an ever-increasing volume of research into the perceptual distortions induced by various types of visual stimulation. It is becoming clear that there are at least three distinct sets of these after-effects. When a complex meaningful pattern such as a room or a landscape is inverted or otherwise transformed the subject comes in time to accept it as normal and to respond appropriately to it. Subsequently presented patterns in their normal orientation suffer apparent distortions appropriate to the acceptance as normal of the distorted patterns. These effects are characterized by their spatial generality and by the large angular displacements involved. They appear to depend on the meaningfulness of the patterns, at least in the sense that a pattern must be meaningful in order to appear upside-down, and probably also on the stimulation resulting from self-produced movement as the subject attempts to adapt to his unfamiliar environment. What is involved seems to be the establishment of new patterns of sensori-motor co-ordination after the old ones have been suddenly rendered inappropriate. As such the process can probably be best designated as one of learning, a parallel to the prolonged early development of basic perceptual-motor skills in the child.

The second group of effects also involve the acceptance as normal of inspected stimuli though in this case the stimuli are not distortions but rather deviations from the internalized norms of certain stimulus dimensions, notably tilt, curvature and movement. During inspection a tilted line actually comes to appear more vertical and a moving object to slow down, whereas the inverted room never appears upright but is merely accepted as normal. These normalizations induce in all other stimuli on the scale an apparent displacement in the same direction. These shifts are quite small, e.g. about two or three degrees in the case of tilt. Their degree of areal restriction is a matter for future research: they are certainly more localized than the first group of effects but, unlike figural after-effects, they can be obtained by uncontrolled inspection as well as by rigid fixation. Though applying only to a restricted range of stimulus variables the effects are well described by a theory closely similar to the adaptation-level model which has proved so successful in other fields. And recent work by Hubel & Wiesel (1959) and others has suggested the possibility of a physiological explanation. Working with cats these authors have demonstrated that in the striate cortex there are cells whose response is determined by the orientation of lines on a given part of the retina. Similarly there are cells maximally responsive to a particular direction of movement and unresponsive to movement in the opposite direction. All previous theories of movement after-effect have foundered for lack of a plausible direction-sensitive mechanism. However, this work has by no means provided a complete explanation of the adaptation phenomena: specific receptors have yet to be demonstrated for curvature; the vital role of the vertical norm has not been explained; and in any case these receptors have not been demonstrated in the human cortex.

Nor does Hubel & Wiesel's work in itself suggest an explanation of the third group of after-effects, the apparent changes in spatial position irrespective of orientation known as "figural after-effects." Nevertheless, it seems likely that a satisfactory theory of these phenomena will be of the same type, i.e. based on the interaction between distributions of excitation and adaptation in the cells of the visual cortex with the apparent position of a contour being determined by the firing ratios in the cells. Although the detailed model of this type advanced by Osgood & Heyer is probably inadequate it may turn out to be closer to the truth than the electrolytic theory of Köhler & Wallach. The main obstacle in this area is the lack of sound experimental evidence of the precise nature of figural after-effects. The reports of Köhler & Wallach have been widely accepted as the facts which any alternative theory must encompass. But as George(1953) points out, Köhler's work ".... is of a clinical character. No statistical treatments were applied and only small numbers of subjects were tested. Their evidence indeed would hardly be regarded as adequate in the realms of modern experimental design." The work would be better treated as a preliminary exploration throwing up suggestive hypotheses for future controlled research. The little independent work reported has created major difficulties for satiation theory. Far from being universal and easily detectable figural after-effects appear to be very closely dependent on experimental conditions and subjects, not only in their magnitude and direction but even for their existence. The occurrence of a phenomenon has certainly been established and a general operational definition provided, but quantitative specifications are almost totally lacking.

Much more is now known than formerly about the type of phenomenological changes which visual patterns undergo as a result of previous stimulation. But partly due to a "premature crystallization" of theory similar to that discussed by Maier (1954) in the field of learning, we are in a position to make detailed quantitative predictions only on a very restricted scale.

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