EDITORIAL STATEMENT

In the last twenty-five years psychoanalytic interest has ranged far beyond psychopathology and the therapeutic process. As Heinz Hartmann has put it, "We no longer doubt that psychoanalysis can claim to be a general psychology in the broadest sense of the word." The Editors of Psychological Issues believe that a new kind of journal is needed which will publish diversified source materials for a general psychoanalytic theory of behavior.

The Editors believe that relevant contributions can come from experimental studies as well as from clinical ones, from controlled developmental studies as well as from the genetic explorations of psychoanalytic therapy, and that investigations carried out without any concern for psychoanalysis may nevertheless contribute to the theory. In Psychological Issues, readers who are particularly concerned with psychoanalytic theory will therefore come into contact with important research not ordinarily presented in psychoanalytic journals.

Although the Editors have an important commitment to the advancement of psychoanalytic theory, they will try to make Psychological Issues interesting and relevant to investigators of all theoretical persuasions in psychology, psychiatry, and related fields. By selecting only monographs which confront fundamental psychological issues or that contain fresh and penetrating observations of phenomena, the Editors hope that the journal will be a meeting ground for all serious investigators of behavior.

The Board will consider only contributions submitted on invitation. There is at present no provision for consideration of unsolicited manuscripts.

The monographs of Psychological Issues will appear irregularly. They are sold mainly by subscription (four monographs for $10.00). Monographs are also purchasable singly and are priced individually.

Subscriptions should be sent directly to the publisher, International Universities Press, Inc., 227 West 13 Street, New York, N.Y. 10011. Editorial correspondence should be sent to the Editor, Dr. George Klein, Research Center for Mental Health, New York University, Washington Square, New York, N.Y. 10003.
PSYCHOLOGICAL ISSUES

GEORGE S. KLEIN, Editor

Editorial Board
MARGARET BRENMAN ROBERT R. HOLT
ERIK H. ERIKSON MARIE JAHODA
SYBILLE ESCALONA GEORGE S. KLEIN
CHARLES FISHER GARDNER LINDZEY
MERTON M. GILL ROY SCHAFER
ROBERT S. WALLERSTEIN
SUZETTE H. ANNIN, Editorial Assistant

Annual Subscription per Volume, $10.00
Single Copies of this Number, $4.00

CONTENTS

Introduction by JAMES J. GIBSON 5
Preface to the English Translation 14

Part I: The Formation and Transformation of the Perceptual World 19
Preface 21
Introduction 23

1 Summary of the Long-Term Studies 28
A. Inversion Experiments 29
B. Experiments Involving the Use of Prismatic Spectacles [Wedge Prisms] 34
C. Experiments with Colored Spectacles 42

2 Historical Introduction to the "Situational" Aftereffect 52
A. Side Effects in Studies Using Wedge Prisms 53
B. Studies of Severely Myopic Subjects 66
C. A Puzzling Color Phenomenon Occurring After Strong Prisms Were Worn for a Long Period of Time 68

3 Experiments with Half-Prisms 75
A. Design and Procedure 76
B. Quantitative Results 96
C. The Fading of Aftereffects 101
INTRODUCTION

James J. Gibson

At the Psychological Laboratory of the University of Innsbruck, in the Tyrolian Alps, a series of related experiments has been going on more or less continuously for the last thirty-four years. They are concerned with spatial perception or, better, environment perception, and this concern has a very long history at Innsbruck. It was here that Hildebrandt worked in the '90s, using his adjustable alley to measure the illusion of perspective. The central question of the later series is how things look, and how they eventually come to look, when the light to the eyes is altered by an optical attachment to the observer's head.

A familiar device of this sort is of very ancient origin. It is called a spectacles, or spectacles, that is, something through which the world is seen. It is so familiar that it is very apt not to be recognized as posing a scientific problem. We are accustomed to wear spectacles to "correct" our vision, or goggles to protect the eyes, or sunglasses to modify the intensity or color of the light. But the Innsbruck observers wore experimental spectacles. The aim was to discover what would happen to visual perception when the light entering the eye was systematically biased in some way and the process of perception was correspondingly disturbed.

Part I of this monograph, originally published twelve years ago and now fortunately translated, is by Ivo Kohler, the younger of the two men who designed and directed the Innsbruck experiments. It is a report of the first twenty years of research on the effects of prolonged wearing of distorting spectacles. The work was begun by T. Erismann and his students in the late '20s. Kohler began to collaborate with Erismann in the late '30s, and has continued the research. Kohler succeeded Erismann as Professor and Director of the Institute for Experimental Psychology at Innsbruck in 1956.
INTRODUCTION

James J. Gibson

At the Psychological Laboratory of the University of Innsbruck, in the Tyrolian Alps, a series of related experiments has been going on more or less continuously for the last thirty-four years. They are concerned with space perception or, better, environment perception, and this concern has a very long history at Innsbruck. It was here that Hillebrand worked in the '90s, using his adjustable alley to measure the illusion of perspective. The central question of the later series is how things look, and how they eventually come to look, when the light to the eyes is altered by an optical attachment to the observer's head.

A familiar device of this sort is of very ancient origin. It is called a spectacle, or spectacles, that is, something through which the world is seen. It is so familiar that it is very apt not to be recognized as posing a scientific problem. We are accustomed to wear spectacles to "correct" our vision, or goggles to protect the eyes, or sunglasses to modify the intensity or color of the light. But the Innsbruck observers wore experimental spectacles. The aim was to discover what would happen to visual perception when the light entering the eye was systematically biased in some way and the process of perception was correspondingly disturbed.

Part I of this monograph, originally published twelve years ago and now fortunately translated, is by Ivo Kohler, the younger of the two men who designed and directed the Innsbruck experiments. It is a report of the first twenty years of research on the effects of prolonged wearing of distorting spectacles. The work was begun by T. Erismann and his students in the late '20s. Kohler began to collaborate with Erismann in the late '30s, and has continued the research. Kohler succeeded Erismann as Professor and Director of the Institute for Experimental Psychology at Innsbruck in 1956.
The work is not widely known in America, but it is interesting and very puzzling. For readers who will find it strange, I should like to explain why I think it is so important.

To live with a radically distorted view of the world for a considerable length of time takes patience and requires more than the ordinary scientific curiosity. It also takes courage, for who can be sure, the first time, that the experience will not be damaging? Straton, to be sure, had inverted the vision of one eye for a week in the 1890s, and the aftereffects of this experience had been minor and transient. But in 1946-1947, as the reader will discover, Ivo Kohler went about his daily business in a thoroughly deformed and seemingly elastic visual world for no less than four months. The aftereffects were radical and prolonged. The experiment had no effect on his visual efficiency, however, and he now sees the environment just as you and I do. Nevertheless, in this culminating experiment with wedge-prism spectacles, he put his visual system to a test which has seldom been equaled for rigor. The results were conclusive.

My admiration for this achievement is the greater because, in 1929 and subsequent years, I persuaded a few devoted students at Smith College to wear wedges of glass in front of their eyes for periods of up to a week. (I myself never summoned the determination to wear them for more than three days.) We noted that motor behavior adapted promptly to this situation, as Wooster (1923) had already observed. We noted the phenomenal adaptation to curvature, which shook my theoretical confidence and led to an experimental program of my own. We even noted the adaptation to the spectral color-fringes on objects, and the subsequent unmoving afterimages. But we never discovered the full range of phenomenal abnormalities which adapt out in the course of a prolonged experiment, and then reappear in opposite form when the spectacles are removed. We never had to puzzle about the "situational aftereffects" that Kohler describes—the astonishing paradox of a retina that works in one way with the eye in one position and in another way with the eye in another position. No experimental discovery of this century is more completely at odds with the traditional theory of the neural projection of a retinal picture than this one.

The Innsbruck experiments are distinguished not only for long duration but also for having included the study of many types of optical disturbance. The possible ways of experimentally altering the input available to a human eye are extremely various, and have not even yet been fully exploited, but the list below is impressive. They all depend on some device attached to the head which can be said to be "spectacles" in a broad sense of the term.

1. Up-down reversal. This was accomplished by mirror reflection, using Eriksen's "nose mirror" in 1928, and the improved "forehead mirror" or visor in 1947. It can also be achieved by a right-angle or totally reflecting prism properly mounted in front of one or both eyes.

2. Right-left reversal. This requires a totally reflecting prism device. Kohler's work with this kind of reversal is described in the papers he refers to in his preface, especially in Koffka (1961). These reversals of the input available to an eye should be distinguished from inversion of the input by a lens system in the tradition of Stratton's experiment. The latter gives only a small field of view and has not been studied at Innsbruck.

3. Deflection with distortion. This is what wedge prisms do when mounted in spectacle frames. The deformations of pattern, curvature, and texture density of the displaced input are such as to yield distortions of phenomenal objects, and elastic motions whenever the head moves. All this is accompanied by spectral fringes at edges, analogous to chromatic aberration in lenses.

4. Shearing of the array on a midline. This is obtained by Kohler's "half-prisms," one half the glass being prismatic and the other half not. The two halves of the field of view are thus adjacent but discontinuous. Something analogous to but less radical than this happens in wearing bifocal eyeglasses.

5. Filtering of the illumination spectrum. This is obtained by ordinary colored spectacles. The alteration of light is considerable, but the disturbance to vision is negligible. The next is more interesting.

6. Bisecting the array with complementary colors. This means that each half of a spectacle glass, right and left, has a color contrasting with the other half. Hence, as the eyes move behind the glasses, the central retina of each is excited by strong successive contrasts. One might suppose this to put an impossible strain on the color-discrimination mechanism.

7. Providing an artificial scotoma anchored to the head. This
consisted of attaching an opaque or semitransparent circle (or line) to each spectacle glass near the center of its field. It is known that one becomes habituated to spectacle frames; is there also adaptation to such a scotoma?

I am tempted to compare these experimental alterations of light delivery to the eyes with certain others which were not tried out. No observer was asked to wear lenses which prevented accommodation by incurably blurring the retinal image. No one was expected to become adapted to spectacles made of ground glass. Plastic eye caps which scatter the light rays and yield a homogeneous field of view are even more frustrating than a blindfold, and my subjects refuse to wear them for long. The vision of the Innsbruck observers, thus, was more or less disturbed but it was not wholly frustrated. The implication is that light delivered by the spectacles to the eyes still carried information about the environment, but in an altered form. This information had not been destroyed, but only biased. The greatest value of the Innsbruck experiments may be in the evidence they provide for what optical information consists of.

The striking thing about these experiments, of course, is the degree to which the perceptual system accommodates itself to these transformations of the optical information. Given enough time, the distorted illusory appearances of surfaces, objects, edges, and spaces in the surrounding environment tended to disappear. The world began to look as it should, the way it did before the experiment. One might infer that perceptual awareness cannot possibly be psychophysically linked to the natural stimulus, for the latter remains distorted. But then, when the spectacles are removed, the illusory appearances return in equal force but of opposite kind. Hence one must infer that perception is now psychophysically linked to the unnatural stimulus, for otherwise it would return to normal immediately. The only way out of this dilemma, I suspect, is to reconsider what we mean by "the stimulus." It might be necessary to consider the nature of available stimulation and stimulus information. It is hardly possible to believe any longer, after pondering these experiments, that the eye works like a camera or that the retinal image is like a picture.

A distorted view of the world, then, when produced by distorting spectacles, is not incurable. The fact can no longer be doubted. But the important question is why and how it occurs. Kohler is just as much interested in this question as any other would-be interpreter of the fact, but more cautious. A very ancient and simple-sounding explanation is that vision conforms to touch, and touch is our best contact with reality. This was the essence of Berkeley's "new theory of vision" in 1709 and it seems to be perennially new. But it does not fit the facts, as many investigators have discovered. If anything, touch conforms to vision, and the explanation, even if true, would not be really simple, as Stratton himself came to realize. For touch is no more a direct intuition of solid bodies than is vision, and we are misled by the metaphor of "contact" with reality.

Another, more modern, type of explanation is that visual perception conforms to behavior, and that phenomenal experience rests upon motor performance. We see in accordance with what we have learned to do. This formula sounds attractive, but most all of those psychologists who are reluctant to talk about experience and who prefer the study of behavior to the study of sense perception or psychophysics. Kohler has never accepted this formula as a general explanation of his results, and the reader will see why. The restoration of the normal appearance of the world in these experiments can hardly rest on the restoration of ordinary motor skills. Kohler has shown that it depends instead on a fundamental change in the way the eyes register information behind the spectacles—a change in the very function of the exploratory adjustments of the hand and eyes and a correlated shift in the very quality of retinal sense impressions. The functioning of the ocular system is an activity, no doubt, but it is an exploratory activity not a performatory activity. Its aim is to achieve an optimum of stimulation, not to accomplish work, and it should not be called behavior in the ordinary sense of the term.

A bit of personal history may be in place here. Many years ago when I observed the adaptation to the curvature of the world resulting from prismatic spectacles, and the subsequent negative after-effect, the first control experiment I thought of doing was to omit the spectacles and simply look at a curved line for a long time, never touching it or making any movement. I was an empiricist and a great believer in learning and I expected to get no result from this experiment. But to my surprise the really curved line straightened out about as much as had a really straight line curved by
the prisms, and now a straight line looked similarly curved the other way. This phenomenon was unlike learning and more like sensory adaptation—more exactly, those dimensions of sensory adaptation that show successive contrast or opposite afterimgaes. So I became interested in perceptual dimensions, and found that a number of them behaved in this same fashion. There was a shift in the psychophysical correspondence along such a dimension, I concluded, because of a tendency for a persistent quality in perception to become the neutral or normal quality of that dimension. One could study it by prolonged application of an eccentric stimulus-value to a receptor-surface, as with visual fixation. It was a neat theory for certain aftereffects of prolonged stimulation, although it turned out not to explain the curious contour-displacements following fixation, the "figural" aftereffects discovered later and now much better known.

This theory of mine has appealed somewhat to the author of this book, for it takes into account the opposition of the aftereffects he obtained. But Kohler cannot accept it either as a full explanation of his results. Any theory of local adaptation in the retinal field fails hopelessly when it comes to explaining the "conditioned" or "situational" aftereffects.

Consider the nature of the spectacle-wearing experiment. The eyes move continually over the modified field of view; the head moves naturally to admit a new field; the observer goes from place to place as he does in life, except when he is doing the laboratory tests to measure habituation and rehabilitation. How different from the classical psychophysical experiment! The stimulus is not produced by the experimenter; it is obtained by the subject. The subject does not have to fixate a pattern or color; he looks around. The input is not an image; it is the light from an environment. The stimulus is not a controlled exposure to energy, or to an object, but the array and flux of ambient light. The stimuli are available to the subject, not imposed on him. He explores the possibilities for himself. Certain changes of stimulation are self-produced, not externally produced. Yet, with all this, is it a kind of psychophysical experiment, speaking generally? The experimenter has "isolated and controlled," in a sense, a variable of stimulation in the form of certain relations among the obtainable stimuli. He has systematically altered the available input. But the transformation has been intro-

duced at the stage of the spectacles, not at the stage of the retinal images. Accordingly the adaptation is to spectacles, not retinal images. The Innsbruck experiments involve the whole exploratory perceptual mechanism, not merely the retinal processes. There is a shift in psychophysical correspondence as a result of spectacle-wearing, but it is vastly more far-reaching than that obtained by fixating a color patch, and deeper than the kind I noted after staring at a curved line.

The experiment which persistently applies a sample of abnormal stimulation to a sense organ is one kind. The experiment which persistently alters the relation between stimulation and its environmental source is a different kind. In the latter case the sense organ is permitted to function perceptually, not just to excite sensations. The illusions produced by the persistent alteration gradually disappear. The perceiving of color, edge, straightness, surface, slant, motion, and objects does not merely become normal, it becomes distally focused, as Brunswik put it. Or as Kohler emphasizes in this book, perceptions tend to become correct. Veridicalizing is a better word for it than normalizing. In some experimental situations there is a drift of the quality of experience toward the neutral average of that experience, or the mean level, but in the spectacle experiment there is a trend toward reality. The world as a whole begins to look normal, not just the visual sensations of the moment. And this is why it has to be true that a retinal effect, or an aftereffect, is conditional upon eye-head posture. This explains why it is that Kohler could "condition" a subject so that whenever he looked at a thing with eyes left (head to right) it looked yellow and whenever he looked at it with eyes right (head to left) it looked blue. It had to be so if the subject, previously wearing blue and yellow filters in the left and right halves of his spectacles, were to see that thing as the same color with his head to the right as with his head to the left. And this radical type of adaptation of the ocular system in fact occurred, after a month or so.

The reason why the conditioned aftereffects of the Innsbruck experiments constitute so serious a challenge to perceptual theory is that the results destroy our accepted concept of the role of retinal images in visual perception. How can the same retinal image arouse different sensations in different states of the oculomotor system? Kohler's answer, in this book, is given in terms of the "total stimu-
lus situation." Let us examine this stimulus situation even more carefully. Perhaps it is the crux of the problem.

In ordinary life, the visual equipment is carried around in a body, which includes a head, which in turn contains eyes. All three are mobile, but the posture of the eyes depends on the head and that of the head on the body. There are three levels at which one can analyze the visual stimulus situation, that is, three levels of "totality." I would say that there are three kinds of stimulus array. First, there is the whole spherical array of ambient light, the optic array at a station point. This is the available stimulation at a locus in space. It is explored by head-turning. Second, there is the hemispherical array of light with a given head posture. It is the stimulation available without head movement and it is explored by eye-turning, that is, scanned by eye movements. Third, there is the conical array of light entering each eye with a given eye posture. This is the momentarily effective stimulus for an eye, focused as a retinal image, although the fine details of this array are registered only in the central region. It is often frozen in time by requiring fixation of the eye in laboratory experiments, but this is unnatural. The fact to be noted is that spectacles modify the second type of stimulus array since they are attached to the head. If experimental contact lenses could be worn, attached to the eyes, they would modify only the third type of stimulus array. And if a transparent helmet attached to the shoulders were to be worn, it might be possible to modify the first type of stimulus array.

It seems to me that the visual system must respond at different levels to all three of these kinds of stimulus array, from the most inclusive to the least. And the lowest system is subordinate to the higher ones, that is, retinal sensations do not constitute or add up to visual perception. The analogue of a retinal "picture," then, is profoundly misleading for an understanding of perception. Kohler has found that the pattern or color of a momentary retinal image can be irrelevant to perception in certain circumstances. If the sensitivity of the retina to pattern and color is linked to the posture of the eye relative to the head and spectacles, anesthetic system must be at work which combines the retina and its posture in a single exploratory organ. This organ responds to the stimulus array proper for it, and adapts to a lawful transformation of the array.

The whole history of optics, including both the science of vision and the science of light, is closely bound up with the design and use of spectacles for improving vision. They were the first optical instruments. One would have expected a science of spectacle-wearing to develop, but the fact is that it remains a practical art, partly a branch of medicine and partly an uninspiring applied field of physics and geometry. It took a psychologist to discover the possibilities of spectacle-wearing as an experiment in perception, and the outcome was the remarkable discoveries reported in this book.
PREFACE TO THE ENGLISH TRANSLATION

Since the original publication of Über Aufbau und Wandlungen der Wahrnehmungswelt a dozen years have passed. This is a long period measured in terms of the development of a science. Nevertheless, I have decided to let the old text stand almost unchanged for the present English edition. I should explain my reasons for doing so.

Obviously nothing could be changed in so far as the experiments are concerned. Experimental procedures constitute a historical fact which can be reported but never revised. But there were other reasons for leaving unchanged most of the 1951 edition. Let me first explain that in our Austrian Institute at Innsbruck there were always difficulties in getting all the foreign publications we needed. This situation became even worse during and shortly after the war. Since this was the period during which the main experiments were performed and during which the monograph was written, the marks of that situation can be found throughout the text. In order to remove such deficiencies completely it would be necessary for me now to reformulate many passages of the monograph and, also, to supplement all the comments and criticisms of other related research work which had either been neglected or which had not yet been written in 1951. But it was not the intention of the editor to publish such a revision, and hence we came to a compromise. I have tried to reformulate only a few passages in order to make them clearer and I have eliminated a small number of overloaded footnotes. But I have been given the opportunity to write this preface in order to take note of the further development of the Innsbruck research since 1951, and also to refer to some of the other investigations that seem to be closely related to our work.

For the first purpose, I would like to direct the attention of the reader to the experiments performed since 1952 dealing with right-left reversing spectacles. This reversal is achieved by mounting a large right-angle prism in front of each eye, the light passing through both faces of the right angle. The results of these studies seem to supplement and to clear up some of the most puzzling results of the older experiments dealing with up-down reversing spectacles. Discussions of these matters include my paper on habituation (1953) and, as an up-to-date summary of all experiments in which there was any kind of inversion or reversal, Kottenhoff's (1961) monograph.

As for other experiments since 1951 using wedge prisms or other distorting optical devices there are only a few publications, mostly in the form of notes or summaries. The most extended paper was published by Kohler and Pirsaek (1960), treating the effects of prolonged wearing of astigmatic glasses in connection with research on the vertical-horizontal illusion. Some remarks about other distorting effects on spatial perception appear in Kottenhoff's monograph mentioned above. Kottenhoff, when a graduate student at Innsbruck, performed a month-long experiment wearing a kind of Ames-glasses. Some recent investigations using wedge prisms are outlined in two papers by me (1961a, 1962a). This work is being continued by Hach (1962) with the support and sponsorship of an American research contract.

Besides the continuing experimental work, some efforts have been made to contribute to contemporary psychological theories. For these efforts, see Kohler (1956, 1957, 1960, 1961b, and 1962b). Some of these articles have been translated into English at the Cornell Department of Psychology and a few are still available in a mimeographed form, entitled "Implications of the Innsbruck Experiments on Systematic Alteration of the Optic Array by Noncorrecting Eyeglasses."

Coming to the second purpose of this preface, to list the related research work, it seems impossible to do so in any satisfactory way because there are so many relations between the Innsbruck investigations and other work. Hence the following will be only a small selection from the possibly related studies, as they appear to me subjectively.

The first name I have to cite is J. J. Gibson, not only because of his parallel work in experiments with wedge prisms (1933), but even more because of the advantage we got by coming in contact with his theoretical treatment of adaptation and aftereffect (1937),
and also with the basic ideas of his perceptual theory (1950). When searching for explanations, it often happened that we found explicitly expressed in his writings what we implicitly had in the backs of our minds. Since he himself is writing the introduction to the present edition, I have nothing more to add.

Another close contact, which at times reached the level of a personal collaboration, was with J. G. Taylor. Stimulated by our results as well as by the problems behind them, Taylor has the merit of having repeated the spectacle-wearing experiments and of performing new variations of them. The results, together with an extended statement of his theory, have just been published (Taylor, 1962). My comments on Taylor's work need more space than I have at my disposal here, so that they had better be published elsewhere. Only a few remarks may be permitted. Adopting a strict behavioristic theory, Taylor vehemently rejects any kind of adaptation conceived in terms of the afferent nervous system and generated by prolonged stimulation, without taking into account behavior and its alteration as a consequence of manipulating the environment. Thus, his concept of adaptation, strictly speaking, is one of behavioral adaptation.

In his experimentation, Taylor has treated situational learning so as to show that in the same visual field, independent of eye and head movements, one area has become adapted while another has not, the former being just the area where manipulations were observed with the spectacles on. Furthermore, he was able to show that the adaptation to the experimental spectacles was not blocked in the case of intermittent wearing of the spectacles for only a part of each day. The aftereffects in such a case remain completely inhibited; that is, the subject was able, at the end of the experiment, to behave correctly either with or without the spectacles. The same was said to be true for perception.

As important as these findings are, I do not see how they falsify a theory of "automatic processes of physiological adaptation in the visual system" (Taylor, 1962, p. 220). From my point of view, the fact of situational adaptation opens the visual system to the influence of a wide range of other sensory or sensorimotor conditions, provided only that they are marked enough, and that they regularly coincide with a specific visual stimulus. Adaptation, in such cases, necessarily results in the destruction of a uniform perceptual response. The visual system, if differentially adapted, might not appear to be "equally implicated," as Taylor puts it, even in the case of the same visual field. As I would emphasize, Taylor's contribution consists rather in extending the limits of complexity with which the visual system can be shown to adapt its own adaptation. It can include adaptation to other conditions, such as repeated manipulation or motor training.

In any case, either Taylor's position or my own would gain if confronted with the so-called "reafference principle" of von Holst and Mittelstädt (1950), and with Held's work on adaptation (Held and Hein, 1958; Held and Schlang, 1959; Held, 1961, 1962). They have stressed the importance of motor components in adaptation, especially in cases where motor activity generates reafferent signals as a necessary consequence of the activity. Reafference or "feedback" tends to become quickly and completely adapted with respect to the perceptual response. At the same time, in a physiological sense, it works as an automatic controller of the motor activity in question. Many striking phenomena of this sort occur when subjects wearing experimental spectacles move the head or body. A theory to explain the elimination of such "reafferent noises" would have a close relation to both of our points of view.

Another investigation which seems to be in close relation to our work is that of Werner and Wapner (1949, 1955). They have attempted to include our results in the framework of the "sensory-tonic field theory" of perception. Also important is Helson's (1948) work on "adaptational level." Various articles dealing with "sensory conditioning," including some aspects of the recent Pavlovian development on conditioned changes in perception, are also related, as I have previously noted (Kohler, 1956).

Another contact arises in connection with cybernetics and information theory, as represented by Attneave (1954, 1959) and MacKay (1957), both of these being extremely stimulating for any theory of perception.

Not the least is the relation of our work to some aspects of the Gestalt view of perception, although my attitude toward this is somewhat ambivalent. I do not deny what is called "organization" in perception, but I believe we have found a way to change this organization by prolonged exposure to certain kinds of stimulation. In so far as the latter shows a high degree of order or regularity
("redundancy") in the visual field or in the correlation between motor actions and optical consequences (such as alterations in size, form, spatial direction, or color) the conclusion may be allowed that what changes perceptual organization in these cases may be the same mechanism that built up perceptual organization in the first place. What I, therefore, am suspicious of is the autochthonous character of perceptual organization, not the fact itself. Among the attempts to reduce Gestalt laws to stimulation or to behavior or both, the concept of redundancy as the proper stimulus for perceptual organization is most promising, and has increasing importance. When Drever (1961), discussing the theory of Gibson, argues that "the trouble is that the information is coded, and we need some sort of schema which, as it were, enables us to break the code," I feel that experiments reported here seem to demonstrate one of the possibilities of such a schema.

Much could be said about W. Köhler and Wallach's "figural aftereffects." The literature includes a prolonged discussion aiming at a satisfactory theory of such adaptation, which I cannot describe in detail. A few of the most important names engaged in that discussion are J. J. Gibson, J. A. Deutsch, C. E. Osgood and A. W. Heyer, K. Smith and R. Held.

In conclusion, I feel most indebted to Dr. George S. Klein for undertaking to publish Über Aufbau und Wandlungen der Wahrnehmungswelt as a monograph in Psychological Issues. As a consequence he had to suffer many embarrassments with my slowness in checking translation and with the difficulties of long-distance communication between two continents. It was his perseverance and patience which finally made possible the present edition. No less grateful am I to Dr. Harry Fiss who solved the difficult and exhausting task of translation and who has made a careful check of my proposed changes and comments.

I may not conclude without noting gratefully my enjoyment of a Fellowship at the Center for Advanced Study in the Behavioral Sciences, which gives me a complete vacation from all the duties one has to suffer at his home university. This opportunity enabled me to finish my part of the work on the monograph without further delay.

Stanford, December 1962

Part I

THE FORMATION AND TRANSFORMATION OF THE PERCEPTUAL WORLD
PREFACE

For several years our Psychological Institute, under the guidance and initiative of Professor Erismann, has been conducting a special type of investigation of perceptual phenomena. References to these experiments have appeared in the literature from time to time (Arch. ges. Psychol., 95, pp. 457, 515). Now these studies have progressed sufficiently to warrant publication of their most important results.

The studies typically require subjects to wear special kinds of noncorrecting spectacles for long periods of time, as in Stratton's well-known experiments. They involve the use of reversing mirrors, prismatic and half-prism spectacles, and the more recently developed two-toned spectacles.

Several experiments involving the use of prismatic spectacles were conducted at about the same time that ours began. However, these experiments were always of short duration, and concerned only with the main phenomena: (1) tilt (e.g., Brown, 1928), and (2) curvature (e.g., Gibson, 1933). There have been no studies, as far as we know, which took longer than a month, which concerned themselves with the more subtle aspects of adaptation, and which used half-prism and two-toned spectacles.

My interest in this line of investigation dates back to 1939, at which time Professor Erismann introduced me to the work which had already been done (Rohracher, 1932, unpublished Ms. a, b; Schuler, 1933; Miller, 1936). Since then, our concerted efforts have been directed toward verifying and replicating previous findings and discovering new phenomena. In so doing, we have modified earlier procedures by improved methods of observation and measurement, and by doubling and even tripling the duration of the experiments.
The reason we have waited this long to publish our results is that we wanted to be absolutely certain about the validity of our observations; furthermore, our theoretical thinking needed to catch up with our empirical findings. Finally, there were such problems as the postwar paper shortage and difficulties in distribution.

With the help of Professor Rohracher, the completed manuscript was presented to the Austrian Academy of Sciences, which, on December 6, 1950, voted to include the manuscript in the Proceedings of the Division for Philosophy and History. We owe special gratitude to Professor Meister and to the Friends of the Academy of Sciences, whose subsidy made immediate publication possible.

Innsbruck, January 1, 1951

ivo kohler

INTRODUCTION

Stratton's (1896, 1897) studies on upright vision led to a new and promising experimental method in psychology: the method of "experimental disturbance," as it may be called. Studies of perception are distinctive in that the experimenter is often left with final facts which he then tries to explain in as plausible a manner as possible by means of anatomical, histological, and physiological data. Usually he has to content himself with speculations about how things "might be," and finds it impossible to strengthen his hypotheses by further observations. This is the kind of impasse into which studies of the inverted retinal image and related phenomena had fallen. The method of experimental disturbance helps to resolve this problem by making it possible to study percept formation as it occurs. The observer actually watches the process unfold, and from his observations infers how a completed percept became what it is. An entirely plausible assumption is made here: factors which help a system overcome a disturbance are no different from those which play a role in normal development.

In using this method, Stratton discovered that seeing things right side up does not depend on the inversion of the retinal image. He found that other determinants of normal vision are effective even when the retinal image is not inverted. This suggests that those factors which cause observers to see things upside down (while wearing inverting spectacles) are also ones which are fundamental to normal upright vision.

We used the method of experimental disturbance not only so as to repeat Stratton's experiment,3 but also in order to study perception of shape, size, movement, and color. All experiments in which

3 Strictly speaking, Stratton's experiment was not replicated in these studies.

—Ed.
a refracting, distorting, or discolored optic medium is placed before the eyes for a prolonged period of time are nothing but large-scale disturbance tests of normal vision. By observing how the sensory apparatus copes with this disturbance, we are able to formulate valuable hypotheses about the structure and development of normal percepts. This approach to vision has two advantages: it opens up an unlimited reservoir of data, and frees the theoretician from the constrictions imposed by ad hoc physiological and anatomical considerations. In fact, it puts the psychologist in the position of setting the pace for the physiologist.

In the present work our object is to deal exclusively with the most important phenomenon which many years of our research have uncovered: the *situational aftereffect*.

It should not be too difficult to imagine that perceptual transformations can be induced by exposing the visual apparatus to long-term experimental stimulation. We call these transformations "aftereffects." They usually appear soon after the subject has begun to wear the experimental spectacles, and are most pronounced toward the end of the experiment. In fact, changes occur as soon as the eye is stimulated. The nature of the change of course depends on the type of spectacles worn, and encompasses any or all of the visual qualities: brightness and color perception as well as perception of size, form, and movement.

Perceptual transformations of this kind could easily be explained if we were dealing with single, isolated stimuli of unusually long duration impinging on only one retinal area. Such an area reacts to this stimulation by becoming more or less sensitive to light or color. A connected consequence of such stimulation is a change in the "subjective standard"; that is, for example, someone who fixates a curved line for any length of time will soon perceive it as less curved, and a line which at first appeared to be straight will now bend in the opposite direction. Similarly, acute and obtuse angles tend to become right angles, while unequal and symmetrical intervals as well as distorted figures tend to become more even. Subjective standards and sensitivity to light and color are never constant; fluctuations can always be produced, and these can be quite extreme, as the prism experiments will show. It is obvious, therefore, that a subject whose standards have been experimentally altered will acquire an entirely new perception of the geometry of his environment. The abnormal perceptions which he experiences are simply the result of sensory changes which themselves are reactions to the experimental stimuli. In this connection, Hering's theory of autoplastic and alloplastic equilibration in the assimilation of nervous substances serves as a superb model.

This is not the whole story, however. What is puzzling is the discovery that the effects of past stimulation occur *intermittently*, being present at one time and absent at another, but always in strict dependence on certain properties of the stimulus situation which are normally without significance for the sensory quality under investigation. This strongly suggests that there exist traces of past stimuli which are variable, and that such varying degrees of change can take place in the same retinal area and in response to the same stimulus. Traditional theories of sensation cannot explain this at all, since, according to them, aftereffects should not have occurred in the first place. Nor are we in any way helped by the explanation that experiences in other sense modalities lead to a new interpretation or "correction" of these sensations.

Enmeshed as we were in these perplexities, we had no choice but to continue along the lines already pursued. If the observed phenomenon did in fact possess general validity, then perhaps the means of gaining access to it could be simplified. It was this reasoning which led me to replace the prismatic and half-prism spectacles with the two-toned spectacles. My hunch proved to be correct: the aftereffect occurred again, as predicted. I repeated this experiment several times, and extended its duration to two months.

Erismann (1947) presented the first summary of the results of this experiment at the 1947 convention of the German Psychological Association in Bonn. At that meeting he proposed that the observed phenomenon be called the *situational aftereffect*. The term, which had been carefully chosen, is an apt description of what we had actually observed: that the occurrence of nonoccurrence of an aftereffect regularly coincides with the presence or absence of certain other conditions belonging to the same total stimulus situation. Hence the term *situational aftereffect*.

Personally, I feel that the time is ripe for another step. I think
we can now actually speak of conditioned sensations, analogous to the "conditioned reflexes" of the efferent system.

To the naive observer, the effects of prolonged wearing of our spectacles appear to be peculiar sensory disturbances. After having worn the prismatic spectacles for several days, a subject will perceive straight lines as curved, right angles as distorted, parallel lines as diverging; the ground appears tilted, plumb lines no longer seem to hang straight, etc. The observer will further note that such deviant sensory responses have the characteristics of conditioned reactions: they occur or do not occur, although the same visual stimulus is always impinging on the same retinal area. It is as though the particular retinal area had not one but a whole series of subjective standards of reaction for the same visual stimulation. The selection of the appropriate standard, however, is never arbitrary: it always depends on the presence or absence of certain concomitant conditions varying in the same total stimulation. Thus an observer who is unfamiliar with a subject's past will undoubtedly interpret his complicated sensory disturbances as "conditioned sensations," and not as "aftereffects." While we, the experimenters, will understandably emphasize the "aftereffect," the naive observer will tend to regard the "conditioning" aspect as the crucial factor.

I think it is extremely important that we achieve a synthesis of these two points of view. One should be aware that sensory abnormalities which appear only in certain conditions can be experimentally produced. We know from our experimentation what past stimuli will result in what "conditioned" sensory alterations. If we find that the same stimuli impinging on the same receptor organs nevertheless result in variable sensations, and furthermore that these variations are regularly accompanied by the presence or absence of some otherwise ineffective environmental factor, then we have reason to suspect that a situational aftereffect is operative. In all cases, it would behoove us to look for regularities in the occurrences of past stimuli; for it is these very regularities which give rise to situational aftereffects. The reason for the concurrence of

certain stimuli and certain other factors may be found in the life style of the subject, or it may be that the experimenter actually intended such a concurrence. It should not surprise us therefore that the aftereffects of such regularities have a regularity of their own. One may say that a subject, without realizing it, has certain "latent" afterimages which become "dominant" as soon as certain previously experienced aspects of a situation reappear.

It is probably safe to assume that our distortion experiment has uncovered an adaptive process of general validity. The time-honored constancy hypothesis now appears in a new light. Observations which so far could not be accounted for by separate, ad hoc formulations, or had to be regarded as exceptions, can now be accounted for by a simple and more parsimonious principle.

Although our aim in this work is to present only those results which are directly relevant to the main phenomena, occasional reference to other experiments will be made to further the reader's understanding. Therefore we will first present a general survey of the major studies done since 1933 and their most important findings. Forerunners of the situational aftereffect will be found in Chapter 2, which will clear the way for the main contribution of this work—the description of the experiments with half-prism and two-toned spectacles—in Chapters 3 and 4. The thread of the theoretical discussion, begun in the introduction, will be taken up again in the fifth and final chapter.

---

8 The reverse can also occur: different stimuli and stimulus patterns impinging on a retinal area can give rise to the same sensations. This can be illustrated by the fact that variously distorted visual stimuli cause correspondingly different sensations only in the early stages of wearing the experimental spectacles. In connection with such phenomena it is most interesting to study the reafference theory represented by von Holst and Mittelstädt (1950).
SUMMARY OF THE LONG-TERM STUDIES

The following summary includes only those studies in which the subject was required to wear spectacles continuously for five days or longer. Shorter studies were also undertaken, but mainly in the early phases of experimentation. Some experiments had to be interrupted prematurely; this occurred when some subjects complained of dizziness or nausea, became depressed, or could not stand the pressure of the spectacles against the nose or ears.

I want to extend my warmest thanks to all subjects for their cooperation; they all gave their very best, regardless of the duration of the experiment. The demands made on some of them were almost intolerably hard. Even before the spectacles were put on, they all had to undergo exhausting tests: the apparatus had to be fitted and measurements had to be taken during normal vision; then the spectacles were put on, subjecting the subject to a host of novel and confusing experiences. To avoid collisions, stumbling, or false moves, the subject had to maintain extreme caution and constant vigilance. To help the subject overcome this first critical stage and to assist him in adapting to this new set of circumstances, the services of a solicitous and protecting companion were often required. The subject was required to keep a daily record of his experiences. Every day, for hours on end, he was given tests to assess the progress of his adaptation. On the last day the subject's private life ceased altogether and became completely subordinated to the science of measurement. All this would have been enough in itself, but there was more to come. Once the spectacles were removed, the subject had to cope with all sorts of aftereffects. These were so strong at times (causing dizziness and nausea) that the assistance of a companion was again necessary. And naturally, the experimenter did not want to miss the opportunity to measure the gradual cessation of the aftereffects. This often required the subject to be available for weeks after termination of the experiment proper.

In the interest of clarity, the following experiments have been subdivided into three groups: (a) inversion experiments; these are essentially replications of Stratton's experiments; (b) studies involving the use of prismatic and half-prism spectacles; and (c) studies with special colored spectacles.

A. INVERSION EXPERIMENTS

A thoroughgoing inversion experiment has not been attempted since Stratton's day (1896, 1897). His results and conclusions appeared so flawless to his contemporaries that no one even bothered to replicate them. Consequently, there followed a hiatus of more than twenty-five years.

The first to break it was Ewert (1930). Ewert also went a step further. Stratton had been concerned only with monocular vision; Ewert experimented with binocular vision, using spectacles especially prepared by the Spencer Lens Company. Although operating with narrow fields of vision and double images arising from nearby objects, Ewert did succeed in completing several long-term studies. However, he showed surprisingly little concern for what appears to be the major problem: the genesis of veridical perception. Since he contented himself with merely observing overt behavior, he must have assumed a one-to-one relationship between adaptive behavior, such as correct prehension, and veridical perception. However, we know that behavior can be adaptive in spite of inverted visual impressions. Thus, the assumption that adaptive behavior depends solely on an approximately correct view of the world cannot be made without further qualifications.

1[Kohler calls the effect of his optical devices "inversion," as did Stratton. But it might better be called "reversal," since the effect is to reverse either right-left or up-down, but not both. A lens or lens system such as Stratton used reverses both meridians of an image. Kohler reversed only one of the meridians, using not lenses but mirrors or prisms. It should be noted that the phrase "upside down" is ambiguous: it may mean either Stratton's (and Ewert's) inversion or Kohler's up-down reversal.—Ed.]
In 1927, W. Stern investigated veridical perception with right-angle prisms which inverted visual images. Unfortunately, his method caused the field of vision to narrow even more, and gave rise to intrusive peripheral reflections. It began to look as if the technical difficulties encountered in this kind of experimentation were of such magnitude as to foredoom any hopes for further progress.

In 1928, however, a major breakthrough occurred with Erismann's discovery that visual images could be inverted with the use of mirrors. The effect was the same as that created by any puddle of water in the street. By using a mirror instead of lenses or prisms, Erismann was able to produce inversions without left-right reversal. The mirror was made of metal and attached below the eyes in a horizontal position. In this way the field of vision could be increased by increasing the size of the mirror, without exposing the eye to unreflected light. Of course, beyond a certain optimal size, the device became cumbersome; furthermore, this arrangement also had the disadvantage of obstructing the subject's view of his feet and the ground below him. Nevertheless, the arrangement did enable the experimenter to conduct experiments of several hours' duration in the laboratory.

Krüger (1939) also used mirrors to invert visual images. However, his apparatus—consisting of several mirrors—does not seem to lend itself readily to continuous long-term experiments. Although his study contains noteworthy observations (we shall refer to them again), Krüger, like Ewert, overlooked the essential problem.

In 1947, Erismann's apparatus was adapted for use outside of the laboratory, a step made possible by means of a relatively minor but nevertheless significant technical modification. Upon the suggestion of one of our subjects, Dr. W. von Kundratitz, the mirror was attached to the forehead, that is, above the eyes instead of below the eyes. This suggestion turned out to be extremely valuable. It was now possible to double the size of the mirror. The mirror could easily be attached to the forehead by means of a frame mounted on the head, and this made it possible for the subject to view his own feet as well as objects near his body. The entire device could be covered by a cap and, when worn outdoors, was no more conspicuous than some oversized visor (see Plates 1 and 2, p. 47).

The visual field measured approximately 40° by 80° from side to side.

Snyder and Prenko (1952), of the University of Wichita, reported an investigation in the course of which a subject continuously wore spectacles similar to Ewert's for no less than thirty days. However, here too it seems that the experimenter was primarily concerned with overt behavior rather than with a possible correction of vision. Another relevant and very interesting investigation, this one by a Russian, has been reported in Universum (1950, No. 2). According to this article, patients suffering from cataracts regained their sight when their corneas were used as focusing screens for projecting real images. By the time these images reached the retina they were right side up. This, however, did not disturb the patients, who, so the author maintains, soon began to perceive objects as right side up. Apparently, inversion of the retinal image is not a necessary prerequisite for veridical perception.

Now for our own experiments:

1. February, 1947. Duration: 6 days

The spectacles used in this study had been designed by the subject himself, Dr. von Kundratitz. At first, this subject saw everything inverted, could not grasp objects without making errors, was extremely unsure of himself, and had to be escorted at all times. After three days, marked improvement was noted in all respects. On the fourth day, the subject went on a bicycle trip; on the last day he went on a skiing excursion (see Plate 2). During all this time, however, his perceptions were only sporadically right side up; things appeared right side up only when they were simultaneously touched, when a plumb line was used, or when they happened to be in the subject's immediate vicinity. During a simulated fencing match, the subject parried all blows correctly, even though the opponent was seen upside down. Immediately after removal of the spectacles, in favorable conditions—i.e., when the visual field was narrowed down and the background was uniform without containing reference points for up and down—the subject occasionally saw upright objects as inverted, but only for the first few minutes. For the next two days, the subject reported having apparent movement experiences and slight spells of dizziness.
2. February, 1947. Duration: 9 days

Correct veridical vision was achieved by subject M. after wearing the experimental spectacles for nine days. After an initial period of disruption, the subject's behavior became adaptive in a remarkably short time, even though the visual impressions continued to be inverted for a while. After four or five days, however, his vision also underwent a remarkable change: it seemed as if the verticality dimension had "gotten lost." To illustrate: two adjacent heads, one upright, the other inverted, were both perceived as upright. Gradually, more and more objects appeared right side up. After the spectacles were removed, however, objects appeared to revert to their previous upside-down position—this without any apparatus covering the eyes or in any way obstructing the visual field: for a few minutes people and furniture seemed suspended from the "ceiling," head downward. Even half an hour later, while taking a walk outside, the subject reported that the reflection of a house and tree seen in a puddle appeared considerably more upright than the house and tree itself. Short periods of disorientation and inverted vision occurred for several days after the experiment proper, particularly soon after awakening in the morning. As before, the adjustment of overt behavior preceded the correction of vision.\(^3\)

Erismann, in collaboration with Rohracher, carried out a series of shorter experiments from 1928 to 1933. Although they used less suitable devices, their observations were of great value to the present study (see Rohracher, 1932, unpublished Ms. a, b).

\(^3\) Incidentally, the wearing of the spectacles also brought about disturbances in the position of eyes and head. While wearing the spectacles, it was necessary to raise the head and eyes somewhat. As time went on, however, the corresponding kinesthetic sensations ceased and the subject no longer experienced the position of his head and eyes as unusual. All the more surprising, therefore, were his sensations after removal of the spectacles. Now that the subject was forced really to look straight ahead, in order to take in the entire scene, it seemed to him that he was looking down, or that the floor was giving way under him. This caused him to maintain for a while a peculiarly crooked position (since it was easier for him to assume the previously "normal" position of his eyes, thereby lowering his head by about 30°). Such alterations in kinesthetic sensitivity are not infrequent; where they determine a person's sense of orientation, their role is of crucial importance. This becomes evident when a subject, who has just taken off his prismatic spectacles, reports a certain fixation point as being straight ahead when it is actually located at his side, precisely because he experiences looking to the side as looking straight ahead.

3. August, 1950. Duration: 10 days (123 hours)

This study focused on the period of transition during which upright vision first begins to emerge. What are the causes of this process, and how does it unfold? We made the following observation: when the subject (M. in this case) was permitted to reach for and touch an object in his immediate vicinity, a new integration immediately took place; the object, first seen as inverted, now suddenly appeared to be right side up. (The experience of this "reversion" was somewhat similar to Schröder's [1858] well-known stair illusion.) The same result was obtained when the subject touched the object with a stick. In both cases, the subject's hands were the first objects reported seen in an upright position. Simultaneous sensations of touch thus appear to be one of the determining factors of the phenomenon. Another factor seems to be the experience of gravitational pull. When the subject was presented with a weight attached to the end of a line, he correctly perceived the relative position of the weight (to the line) as soon as he took the end of the line in his hand; and once the pendulum was seen correctly, the perception of more distant objects also became veridical. When the subject experienced a strong gravitational force by driving uphill in a car, the landscape righted itself perceptually. Familiarity with objects proved to be a third determining factor involved in veridical vision. A candle, at first seen in an inverted position, wick downward, was seen right side up as soon as it was lit. The same effect was observed when the object was a burning cigarette: in this instance, it was the direction of the smoke that indicated to the subject which part of the visual world was "up" and caused the percept to correct itself.

Another line of approach we used was one in which the subject was deprived of all clues that could serve as reference points for veridical perception. For example, the subject was seated in front of a uniformly illuminated white screen. We then introduced various objects into this neutral field. These were held in place by means of wires or sticks, so that the experimenter's hand was not exposed. The subject now had to rely solely on his immediate impression when judging whether, for example, a bottle was right side up or upside down, or the apex or the base of a triangle was "up."
A simpler procedure was just to let the subject read; if he read an M as a W, then we knew at once that his vision was inverted, etc. In this investigation we found that after five days the subject’s adaptation had progressed to a point where perceptual errors hardly ever occurred. Two or three days were enough for overt behavior to become normal. (The entire experiment has been recorded on film.)

B. Experiments Involving the Use of Prismatic Spectacles [Wedge Prisms]

1. January, 1933. Duration: 10 days

The subject (S.) wore binocular prismatic spectacles whose angle at the apex was 15°, the bases arranged to the left. All signs of behavioral difficulty (e.g., errors in prehension) disappeared after only one day. A day later apparent visual motions disappeared, curves began to flatten out, and figures became less distorted. Six days after the subject had begun to wear the spectacles, he went on an extended skiing trip in the course of which he rescued a fellow skier who had had an accident. After ten days of continuously wearing the spectacles, all objects had straightened out and were no longer distorted. The subject then removed the spectacles. Immediately, impressions of curvature, distortions, and apparent movement set in. The subject complained: “What I experienced after I took off the spectacles was much worse than what I experienced when I first started wearing them. I felt as if I were drunk.” Aftereffects continued for four days.

2. February, 1933. Duration: 12 days

Upon the suggestion of Professor Erismann, the same subject now wore a pair of spectacles of which only the bottom halves were prisms, the top halves being ordinary glass. The strength of the prisms was 10°. The object of this study was to develop per-


ceptual integration in the presence of disconnected and displaced images (see Plates 16-20, p. 50). After twelve days, such integration occurred sporadically. Following removal of the spectacles, a vertical luminous line was variously seen as two lines (monocularly!), in fragmented form, or in an oblique position. Unfortunately, the subject paid too little attention to his eye movements and to the position of his head. These factors, as we found out later, have an important bearing on this phenomenon.

3. April, 1933. Duration: 22 days

This time, the subject (S.) wore a monocular prismatic spectacle with a 15° angle. It was noted that the perceptual aftereffects were transferred to some degree to the other eye, which had been covered during the entire experiment. Otherwise, the same effects were observed as before (in January). Concerning curvature, the aftereffect was noticeable for a few weeks.

4. September, 1933. Duration: 18 days

Professor Erismann was the subject in this experiment. He wore a pair of binocular prismatic spectacles with a 15° angle. Although his adaptation was somewhat slower and not as complete as that of subject S., the results were of great value to us because this was the first time that the origin of variable aftereffects was observed. Some aftereffects were noted even after weeks: for example, curvatures were still noticeable for as long as twenty-three days of post-experimental vision.

5. June, 1936. Duration: 5 days

Binocular prismatic spectacles with an angle of 15° were used in this study. This time, however, the procedure was modified in the following manner: when, after two days, an aftereffect was clearly present, the subject put on a pair of compensatory spectacles, which he wore for another three days. (These were somewhat weaker prismatic spectacles which served the purpose of correcting for the aftereffect.) The question which we wanted to answer was whether the aftereffect would remain constant, although corrected. It was expected that if the corrected aftereffect decreased only a slight amount, all straight lines would immediately become
curved again. Unfortunately, the study was never completed, because the subject (M.) was not present during the last two days and the necessary tests could not be performed to confirm his impressions.

6. January, 1941. Duration: 36 days

The subject (the author himself) wore a monocular prismatic spectacle with a 15° angle for a period of twenty-three days. During this period, vision became almost completely adapted to the spectacle, especially for objects seen straight ahead and in the center of the field. Apparent movements, distortions of angles, and disorientation disappeared almost completely; on the other hand, straight lines continued to be seen as more or less curved. For ten days after this initial period, the author then wore prisms with a 4° angle which compensated for the aftereffect of curvature. As a consequence, objects appeared completely straightened out. Other aftereffects, however, such as apparent movements, distortions, and anomalies of orientation, were not fully corrected since they were stronger than the compensating prism. Somewhat later the bending resumed, while the other aftereffects, for which the prism had been too weak, were now increasingly corrected until the 4° prism became too strong for them also. We therefore concluded that aftereffects persist in a constant way only when they are kept overcorrected, that is, when a remnant of "overstimulation" in the form of curvatures, distortion, obliquity, asymmetry, etc., remains. Following removal of the corrective spectacles, what little remained of the curvature aftereffect persisted most tenaciously for several months. A similar, though not as pronounced, effect was noted in the other eye, which had been covered while the spectacles were being worn.

7. January, 1941. Duration: 6 days

The subject (K.) wore a 20° monocular prismatic spectacle. The right eye remained uncovered because of poor vision. The procedure was essentially the same as that of the other studies which have been described. The curvature aftereffect lasted three to four days.

8. January, 1941. Duration: 5 days

This study was undertaken to investigate the possibility of creating adaptation when the bases of the prisms were rotated 90° from the left side to the bottom of the frames. In these conditions horizontal lines became curved: the ceiling and floor appeared arched, and did so in the stage of the aftereffects. In the former experiments when the prism bases were arranged to the left, the bending and the aftereffect of curvature were restricted to the vertical dimension, that is, to lines parallel to the cephalocaudal axis. Since oncoming objects appeared further away than they actually were, this subject was particularly endangered; it was therefore necessary to provide especially careful guidance, a responsibility which was alternately assumed by two other subjects wearing spectacles. However, even in this case, such close supervision was necessary only during the first day. The subject became adapted after only a few errors. Once the spectacles had been removed, however, errors in locomotion and prehension recurred. The direction of these errors was the opposite of that manifested during the first day of wearing the spectacles. The same was true of the direction in which horizontal lines now appeared to be curved. Slight aftereffects remained for several days.

9. February, 1941. Duration: 9 days

The subject (G.) wore a monocular prismatic spectacle. Initially, the angle was 20°, but it was increased to 30° for the last fifteen hours of the experiment. This subject reacted in a special way: while there was very little adaptation to curvature, apparent movements and errors in prehension disappeared almost entirely. Nevertheless, there was a distinct bending aftereffect once the spectacle was removed. This lasted for only a few seconds, but reappeared with increased intensity whenever she closed her eyes. As a result of this peculiarly unstable aftereffect, the visual images of this subject had an extremely variable quality: straight objects—for

---

4 There are, of course, individual differences in the degree and rate of adaptation. Jaensch and Madowksy's investigations (1932) are relevant to this issue. They demonstrate that adaptation to perceived curvatures proceeds more slowly with "dissociated" than with "integrated" subjects. The latter are also more likely to experience strong aftereffects, which, however, are more short-lived.
example, long and heavy steel pipes—curved and straightened out while the amased subject was in the very act of looking at them. It took several days for her vision to stabilize.

10. September, 1946. Duration: 8 days

The subject (N.) wore a monocular prismatic spectacle with a 20° angle. The other eye was covered. Again, all the usual phenomena occurred. The emphasis in this study, however, was on the effects of prismatic deviation on perceptual orientation. For this reason we were primarily interested in studying errors of prehension, alterations in the optical median, and asymmetry of eye-head-body posture. When wearing prisms, the subject is always forced to move his eyes and head in a direction different from that in which he is reaching, so that there is a marked discrepancy between the position of head and torso of which the subject is completely unaware. This subject was no exception. He thought he was looking straight ahead when actually his head was turned 6° to 9° to the right of the body median. When this posture was corrected, the subject experienced a distortion to the left of his head versus body. The errors in visual direction disappeared to the same degree that this “torision” developed during the first days of the experiment. After removal of the prism the head posture quickly returned to normal. The bending aftereffect, however, was still occasionally present for five days.

An interesting feature of monocular studies is that once normal vision has been restored, the sensitivity of the eye which had been covered is drastically altered: for several days thereafter, there is an increase in sensations of brightness, contrast, and color as compared to the uncovered eye; in binocular vision, perceptions of depth are enormously heightened.


This was a binocular study in which the author served as the subject. Starting with 15° spherical prisms, further distortions were induced by reversing the prisms and thereby turning the convex side of the prisms toward the eyes. This was followed by a ten-day study of aftereffects, using compensatory prisms. During the final month of the study, the angle was increased once more, to 20°.

SUMMARY OF LONG-TERM STUDIES

This experiment, the first of such long duration, was significant for other reasons too. In the first place, the aftereffects obtained were of optimal strength. In the second place, it gave rise to a number of peculiar aftereffects which I have already referred to as "situational." Not only curvatures, distortions, deviations, apparent movements, etc., were found to leave traces in the sensorium, but also the variations in intensity of these disturbances. It is known that the deflection of rays by a prism is minimum when the subject is looking through the center of the prism. As soon as the subject deviates from this line of vision, either horizontally or vertically, the distortions increase: angles become even more acute or obtuse, and lines which were close to being perpendicular or horizontal now appear markedly slanted. Furthermore, the quality of the perceptual alteration depends on the direction in which the subject's line of vision deviates. Thus, the same object appears thin when viewed through one side of the prism, and broadened when viewed through the other side; objectively horizontal or vertical lines are displaced one way when seen from below and another way when seen from above. And all this takes place for the same retinal area, the center of normal, accurate vision. The question therefore arises: what are the aftereffects of so many different and contrasting sensory influences?

The situational aftereffect provides the answer; it is an aftereffect whose characteristics depend on particular conditions, in this case on the direction of the line of vision. Thus, the separation between two poles was decreased when looked at from the left, and increased when looked at from the right. Earlier, during the wearing of the spectacles, the reverse had occurred. In other words, what we have here is a special kind of negative aftereffect: it occurs only when the total situation is the same as in the one in which the prism-induced alterations originally occurred. This principle is applicable to all other aftereffects as well: those involving deformations, obliques, apparent movements, etc. Whenever head and eyes are turned after removal of the spectacles, additional perceptual anomalies occur; these are exactly opposite to the ones which occurred in the same conditions of eye-head posture while the prisms were being worn. The experience is most uncanny; it is as if phantom prisms with a refraction exactly opposite to that of the experimental spectacles were before the eyes.
The most impressive, but also the most puzzling, phenomenon which I observed was a particular aftereffect which entered the domain of color theory. Since prisms are known to deflect short-wave rays more than long-wave rays, they are capable of breaking up white light into its chromatic components. It is for this reason that our subjects were exposed to a rich array of rainbow fringes which, in accordance with well-known principles, appeared to be adjacent to all contrasting contours: depending on the direction in which a dark area changed into a brighter one, the colors of these rainbows were sometimes yellowish-red (comprising the long-wave sector of the spectrum), at other times bluish-green (comprising the short-wave sector of the spectrum). However, as time went on, this phenomenon gradually became weaker, and after several months of wearing the spectacles it disappeared altogether (provided the illumination was not excessively bright). Apparently, the so-called chromatic aberration of the ordinary (uncorrected) prisms had been exactly compensated for by some physiological or psychological factor. Equally strange was the aftereffect: now, in conditions of normal vision, a reversed chromatic deviation appeared; it seemed as if the subject himself had acquired the ability to split white light into its chromatic components. Careful examination (using yellow sodium light), however, revealed that this was a special kind of afterimage phenomenon: we found that this splitting also occurred when the light was monochromatic. Whenever a brightness difference was discriminated, the complementary part of the half-spectrum appeared at the region of transition. Whenever the short-wave part of the spectrum appeared while the spectacles were being worn, the long-wave part of the spectrum was now subjectively present, and vice versa.

The other results of this study, including those of the interpolated compensation experiment, agreed with the previous ones. Aftereffects continued to interfere with normal vision for weeks following removal of the spectacles. It was further noted that those aftereffects which had taken longest to build up were the ones which persisted longest.

Gibson (1933) was the first to mention this phenomenon. Using prisms, he obtained it after only a few days, but added that Hering's theory of afterimages cannot account for it.

12. April to June, 1947. Duration: 50 days

This was a binocular half-prism study in which the author again served as the subject. Details of the procedure are contained in Chapter 3. The following is only a brief summary.

The spectacles were constructed so that upward vision had to pass through a prism with a 10° angle of refraction (base left). Downward vision was normal (see Plate 15, p. 50). In other words, the upper half of the spectacles distorted vision in the manner which has already been described, while the lower half permitted normal vision. The question we sought to answer was whether adaptation would be possible in these conditions.

The initial results gave a negative answer to the question. The instant the subject looked down (through the clear part of the spectacles), whatever progress he had made in adapting to the half-prism was immediately undone by the appearance of the aftereffect and the consequent contrary visual experience. Since obviously little is gained by exchanging one illusion for another, one can hardly speak of a purposeful adaptation in this part of the experiment.

After approximately ten days the subject noted a slight differential increase in the intensity of the aftereffects (curvatures, distortions, errors in prehension, and especially apparent movements) when looking up as compared with looking down, when he was not wearing the spectacles. Gradually, this difference was also noted when the subject wore the spectacles: there was an increase in adaptation to the prism but without concomitant disturbances of normal vision, that is, the initial aftereffects when the subject looked down ceased. In other words, the subject's vision had become differentially adapted to both conditions.

The subject's experiences after removal of the spectacles were consistent with those preceding it: depending on the direction of the subject's gaze, the same stimuli, that is, stimulus patterns, gave rise to different sensations of spatial forms, even of colors (namely, effect of color dispersion through prisms). What had first been an "unconditioned" aftereffect ("unconditioned" because it followed only a certain kind of impingement on the retina) was now a "conditioned" aftereffect, depending on the facilitating or inhibiting action of the subject's eye-head position as a new contributing factor. This "semi" aftereffect was especially noticeable in relation
to visual orientation and the perception of movement when adaptation to the half-prisms was complete.

I observed still another form of adaptation. Since rays passing through the prism are deflected sideways in relation to the clear portion of the glass, objects occupying the entire visual field appeared bisected, and the two parts were out of line with each other (compare Exp. 2, p. 34). The subject adapted to this illusion by developing a special kind of eye movement: while the subject had the experience of looking up and down, he was actually looking diagonally. By doing this, he was able to perceive the object as continuous, whereas actually the half-prism spectacles divided the image and displaced its component parts. As soon as the subject stopped moving his eyes, however, the discontinuity of the image immediately became apparent. The acquired eye movements persisted even after removal of the spectacles and gave rise to opposite illusions.

It should be mentioned, however, that these illusions were not as enduring as the ones described earlier, some of which lasted for as long as two months. After a while, however, they lost their conditioned character.

C. Experiments with Colored Spectacles

1. January, 1947. Duration: 20 days

The subject (A.) wore a pair of spectacles of which the left halves were colored blue and the right halves were colored yellow. Thus whenever the subject looked to his left, everything appeared blue, and whenever he looked to his right, the world appeared yellow. The lines dividing the two fields were in the center of the spectacles and coincided in binocular vision (see Plate 21, p. 51). In the course of the experiment, it was noted that both colors subjectively faded away. This suggests that the same retinal areas became simultaneously adapted to complementary color stimuli. This fact was confirmed when the spectacles were removed; now the fovea clearly was selectively sensitive to color, the sensitivity being determined by the direction in which the subject happened to be looking. Looking to the right resulted in increased sensitivity to blue (a "situation" in which yellow had previously been the predominant color);

looking to the left, on the other hand, was followed by increased sensitivity to yellow. Although this situational aftereffect was weak, it nevertheless lasted for eleven days.

2. February, 1947. Duration: 22 days

The subject in this study (A.'s brother), who was nearsighted, wore his own spectacles, each lens of which he agreed to have marked with a black dot. The dot had a diameter of one centimeter and was located slightly below the center of each lens. During binocular distance vision, the two dots coincided. Since this artificial scotoma forced the subject to keep his head in an unaccustomed position while reading, it irritated him a great deal at first. The black spot in his visual field was annoying at other times also. After a while, however, the subject became quite used to it, even though no perceptual changes occurred: the black spot continued to be present. Nevertheless, a positive, that is, an even darker, aftereffect was noticed several times before and after removal of the spectacles, for example, in a dark room just before the subject fell asleep. However, the aftereffect was not strong enough to be investigated further.

This observation, the only one of importance in this particular study, appeared to have a parallel in an illusion which several of our subjects reported after the removal of whatever experimental spectacles they had been wearing: it seemed to them that their visual fields contained dark rims and temples, as if they were still wearing the spectacles. The illusion occurred independently of eye movements, so that any part of the frame—rims or temples—was directly visible.

3. March to April, 1947. Duration: 8 to 19 days (with a two-week interruption)

The spectacles used in this study were ordinary spectacle glasses (0 dioptr), covered with a red, transparent diagonal stripe made of celluloid, one centimeter wide. The two colored stripes coincided binocularly and created the plastic illusion of a red beam diagonally cutting across the visual field. With time, however, the colored stripe began to fade away. When the spectacles were removed, a peculiar aftereffect appeared: whenever the subject
happened to look at an achromatic stimulus object located in that part of the visual field formerly occupied by the red “beam,” he faintly saw a green-colored afterimage. This phenomenon persisted for three to four days.

4. June, 1947. Duration: 19 days

The author wore two different sets of spectacles in this study: a pair of completely blue-colored spectacles in the morning, and a pair of completely yellow-colored spectacles in the afternoon. The spectacles were exchanged every day at 1 p.m. As a consequence of wearing these spectacles, the world appeared at first unusually and unpleasantly discolored. By the time the spectacles were exchanged, however, the color had become barely visible. In fact, there were moments when the subject saw everything as yellow when looking through the blue spectacles, and vice versa. This always happened when he entered a dark place after having spent some time in a bright one. Gradually, the rate of adaptation increased, and the color of the spectacles began to fade away as soon as they were put on. But a situational aftereffect never occurred. All that remained after removal of the spectacles was an increased sensitivity to yellow, which persisted for a few days. Nor did this sensitivity in any way depend on the time of day.

Apparently, variations in the timing of stimulation (especially when the time intervals are long) do not serve as a condition for the production of situational aftereffects.

5. August, 1947. Duration: 27 days

This time, red-green spectacles, modeled after the yellow-blue spectacles, were used. The colored sections were arranged in such a way that the subject saw everything as green when looking down, and red when looking up. Again, the colors gradually faded away; but only after an initial stage of mutual enhancement of complementarities, in keeping with Hering’s theory. When the spectacles were turned upside down, on the other hand, both the red lower and the green upper visual fields seemed much more saturated. The remainder of the experiment yielded results consistent with expectations. A slight situational aftereffect occurred for as long as twelve days following removal of the spectacles: colors as well as grays appeared to be “warmer” in the lower than in the upper half of the visual field. The aftereffect was even more pronounced when the field of vision was reduced, for example, when the subject looked through a tube or was asked to discriminate surface colors. At times, the effect was so accurate that, depending on the position of head and eyes, the subject could see the line dividing the two colored afterimages.

6. May to June, 1948. Duration: 60 days

The author wore a pair of yellow-blue spectacles, as described above. The results not only confirmed the earlier ones, but, because of the longer duration of this study, also yielded a number of refinements which threw additional light on the genesis of the situational aftereffect. For details of the procedure, see Chapter 4. What follows is merely a brief summary.

Initially, the aftereffects of the two filters canceled each other when the subject shifted his fixation from one field to the other. The complementary color then appeared abnormally intense. This successive contrast gradually disappeared; color intensity became constant and no longer increased with shifts from field to field. The afterimages for each color remained, so to speak, in each field and were no longer carried over.

Another observation was that changes in eye movements facilitated adaptation to the two-toned spectacles to a greater extent than changes in head movements (the eyes being fixated). This observation is of interest because the retinal effects of both types of movement should be the same. The subject, who spent a good portion of his waking time reading and writing, was in the “habit” of preferring eye movements to head movements, and this apparently enhanced the aftereffect for this particular situation.

Both colors had become equally faint by the time this experiment neared the end. Quantitative tests with the spectacles on indicated a 50 per cent adaptation. For free vision, however, the deviation in color perception was considerably less, which is probably due to the very close connection between the aftereffect and the situation eliciting it. Simply wearing the empty frames with a fine thread halving each field was capable of facilitating the aftereffect. Be that as it may, when the subject took off his spectacles, he
had the impression that objects to his left were bathed in warm, yellowish candlelight, while objects to his right tended to take on colder colors. This illusion moved with the subject’s head movements (as formerly the spectacles had), but not with eye movements. The gradual disappearance of this aftereffect could be observed for weeks.
The world of the prismatic spectacles. Plates 4-14 show the various kinds of distortions brought about by the prismatic spectacles, depending on whether the gas through the prisms is directed: straight ahead (Plates 4 and 10), left (Plates 5 and 11), right (Plates 6 and 12), upward (Plates 7 and 13), or downward (Plates 8 and 14).
Plate 15
Plate 16

Plate 17
Plate 18

Plate 19
Plate 20

Plate 21
Half-field colored spectacles: blue filters on the left, yellow filters on the right. This kind of spectacles was used in one experiment for sixty days.

The world of the half-prism spectacles (looking "straight ahead" through the dividing zone of the spectacles).
HISTORICAL INTRODUCTION TO
THE “SITUATIONAL” AFTERRIGHT

It is always an unpleasant occurrence when empirical findings are brought to light which theory tells us must be rejected. This, to some extent, was the dilemma in which Hering’s theory of sensations put us. As the duration of our experiments increased, so did the incidence of side effects which could no longer be explained away as errors or inaccuracies of observation. But what about the theory? Was not that too based on “facts”?

A thorough analysis of our data made a solution to this problem possible. To begin with, there is an important distinction to be made between the initial and the final stages of long-term studies such as ours. Once such a distinction is made, it immediately becomes clear that the theory explains only the findings of the early stages of the experiments. (This should not surprise us, since we know that the theory was in fact based on relatively short-term studies.) Furthermore, it is only after several days (sometimes weeks) of experimentation that the first side effects are observed. Their occurrence therefore constitutes a “contradiction” only if we, the experimenters, commit the error of “extrapolating.” Indeed, the temptation is only too strong to generalize from short-term studies to long-term studies, whatever their duration; and this is exactly what the theory does.

Short-term studies may have demonstrated conclusively that the sensory effects of successive, complementary stimuli impinging upon the same retinal area neutralize each other (and that neither dissimilation nor assimilation can occur without interference). However, they tell us nothing about the results which would be obtained if conditions were different, for example, if the duration of stimulation were considerably longer. In fact, I would go so far as to say that the results of long-term studies have greater generality, and that those of short-term studies apply only to the initial stages of experimentation.

Be that as it may, it was easy for us to understand the incredulity of the physicists, the physiologists, or the psychologists, when they heard about our results. As a matter of fact, we shared their incredulity. To the physicist, the idea must seem preposterous that a subject, wearing the same spectacles during an experiment, should experience different sensations even though conditions on the retina remain constant. The physiologist or the psychologist probably would be less reluctant to admit the possibility that changes in sensory experience may result from repeated retinal stimulation; he would probably attribute such changes to changes in retinal sensitivity or spatial relations based on the so-called “spatial values.” He too, however, would look at us askance if we were to introduce the notion that concrete aftereffects remain when the same retinal area is subjected not only to different but also to opposite or, as in the case of color vision, to complementary stimuli.

To illustrate how our understanding developed, I shall first discuss certain “side effects” observed in the usual wedge-prism type of experiment. I shall then take up the results of some of Professor Erismann’s studies of severely myopic subjects. I shall conclude this section by describing the dispersion aftereffect, which took even us by surprise.

A. SIDE EFFECTS IN STUDIES USING WEDGE PRISMS

Three things must be considered in carrying out experiments with prisms: (1) the optical peculiarities of the prism; (2) the alterations occurring in the retinal images of the prism-covered eye; and (3) the resulting perceptual illusions experienced by the subject. The last point is of particular importance. It has to be cleared up whether the illusions correspond to the altered retinal images or not, and subsequent measures of adaptation must be based on precise pre-experimental values.¹

¹ A special matching technique was used for the purpose of measuring degree of adaptation. Subjects who had reported at the beginning of the experiment that straight lines looked curved, right angles distorted, and that lines of equal length
Let us start with the first point. The material used for our prism was crown-glass of medium weight, with an index of refraction of 1.55. The experimental spectacles were then ground out of wedges (Fig. 1) consisting of this material. AB is the base of the prism, C the apex.

According to a simple formula, the deflection of light (deviation) of a prism equals approximately one half the angle at the apex. Thus, a 20° prism will displace a perceived object by 10°.

The more distant the object, the greater the displacement. At arm's length, the error amounts to about 10 cm.; near the feet, it is more than twice that amount; objects still further away are displaced by several meters, the angle of deviation remaining the same, etc. This explains the subject's initial errors of prehension, his uncertain gait, especially when crossing over a curb, and the carousellike apparent movements experienced upon approaching or leaving the scene.

Another characteristic of prismatic refraction of light is the decomposition of light into colors (dispersion). This occurs because short-wave light is deflected somewhat more than long-wave light. In physics, such dispersion spectra are produced by having light from a narrow slit strike the prism. Such was not the situation with our prism wearers; rather, their visual field contained many adjoining light and dark areas which produced a type of one-edged slit source of light. Viewed through prisms, such contrast-rich contours appeared surrounded with fine colored bands. If such a slit was open to the right (Fig. 2a), the long-wave half of the spectrum was seen. If the slit was open to the left (Fig. 2b), the short-wave part of the spectrum appeared.

These fundamentals of deviation and dispersion are not sufficient, however, to explain the various alterations of retinal images induced by the prismatic spectacles.

In discussing deviation, we were considering only a single ray, the so-called principal ray. This ray enters the prism straight on and passes through its center. Strictly speaking, however, this is a special case, involving only minimal deflection. For rays entering the prism at an angle, the deflection is greater; and it is precisely those rays which tend to accumulate in the subject's eye, particularly on the periphery of the retina.

If this were not so, we could never understand why a straight line appears curved when seen through a prism. The illusion

---

1 For our purposes, we found it best to describe the prism refraction with prisms based to the left. Where binocular vision was required, the strength of the prisms equals.
makes sense only if we consider that the ends of the line enter the prism at an angle and are therefore deflected more than the middle portion of the line. This holds true of both vertical and horizontal lines, although the latter do tend to change in another way. The phenomenon of contraction on the left and expansion on the right can be explained on the same basis. The phenomena may be compared to a flock of sheep heading toward the right, with those in the center moving more slowly than those on the periphery: soon, those left of center will be crowding against each other, while the remainder of the herd will be much more loosely packed. When curvature accompanied these phenomena, as in the case of rays entering the prism at an angle, then not only do vertical and horizontal contours appear slanted, but right angles become more distorted as they approach the periphery of the visual field and thus parallel lines no longer seem parallel.

Fig. 3a

Fig. 3b

Figures 3a and 3b illustrate this point. Figure 3a shows two perpendicular axes with their four quadrants. Figure 3b shows what Figure 3a would look like seen through a prism. Note the curvatures, the variously distorted right angles, slanting of the lines, contraction in the left and expansion in the right field. Another effect, not shown here, is that the borders of all vertical lines would appear colored (viz. Fig. 2b).

It should be apparent by now that physical and optical considerations are rendered considerably more complex by the incidence of oblique light rays and the consequent increase in deviation. Only when these circumstances prevail do distortions occur within

---

8 In his *Handbuch der Physiologischen Optik*, p. 290 ff., Helmholtz deals extensively with the mathematical aspects of the refraction of light entering prisms at an angle.

---

an image. Where they do not prevail, objects are only displaced, and their inner proportions remain unaltered.

We now come to a further complication, one whose significance became clear to us only as a result of our experiments, especially the longer ones.

So far, our reasoning leads us to assume that the subject's retinal image ought to correspond to Fig. 3b. Accordingly the fovea ought to correspond to that area which is being stimulated by the principal ray, i.e., by minimally deflected light. As we approach the periphery, the degree of distortion should gradually increase. Finally, as we reach the periphery of the retina, the light rays should be most slanted and maximally deflected. This assumption leads to the conclusion that stimuli impinging on the retina in the course of an experiment must be *constant but also characteristically different* for each retinal area. Fig. 3b illustrates this point: each of the four quadrants evidences a different kind of distortion.

On the basis of the above conclusion, one is tempted to predict that sensory adaptation in the case of spatial perception will vary locally—that is, the retinal spatial values corresponding to distal spatial relationships will be different for each retinal area. One could conceptualize this in terms of a decrease in subjective standards where images contract, an increase in subjective standards where images expand, alterations in the subjective measurement of angles, of straight lines, and so forth. Such aftereffects are quite different from those which one would expect to result from voluntary eye movements, in which case all kinds of changes would be valid for all retinal areas.

The temptation to predict localized retinal changes becomes even stronger when the obtained aftereffects actually contribute what appears to be supporting evidence. The results are so gratifying that one is only too likely to consider the experiment completed. Not that I wish to belittle the importance of such findings. On the contrary, they clearly indicate that the laws of adaptation, contrast, and afterimages are as applicable to color vision as they are to subjective standards of size and shape. Gibson (1937) was quite justified when he drew this analogy.

Our initial adherence to a "local" theory thus appears to have been quite reasonable. We had some doubts about it even then, however. For one thing, we did not feel that the stimulus situation
had been analyzed to our satisfaction. Furthermore, we were unable
to explain why contraction and expansion aftereffects, for example,
should depend on the position of the head and eyes. What puzzled
us most, however, was the impression that the effects we obtained
could not be explained by any kind of constant illusion of size or
distance depending on stimulation impinging on specific retinal
areas (as in Kundt’s partition experiment); what we found was the
building up of variable standards occurring on the same stimulation
within the same retinal area. It was such “side effects” which eventu-
ally forced us to reformulate our predictions.

One thing soon became clear to us: the intensity and variety of
retinal distortions which can be obtained (depending on where the
subject is looking) are far more numerous than Fig. 3b indicates.
What we failed to realize in the early stages of experimentation
was that the effects which struck us most were relevant only to
one specific “situation”: the subject’s preferred mode of vision—
that is, looking straight ahead. As the study progressed, however,
we found traces of other, hitherto unnoticed aspects of the situa-
tion in the subject’s sensorium. Furthermore, these aftereffects
appeared in spite of the substantial complexity and variability of
their respective preceding sensory impressions.

It became evident that we had left out an important ingredient
from our earlier analysis of the prismatic stimulus situation: the
free movement of the eyes in relation to the spectacles. Any devia-
tion from the primary position of the eyes (straight ahead) appar-
ently resulted in entirely new and highly complex image properties.
Thus, it was the fovea which at times became the locus for obliquerays, and the peripheral areas of the retina through which the prin-
cipal ray passed. A constantly increasing decentering of the optical
system of the spectacles complicated matters even more.

To clarify these optical relationships, I resorted to an artificial
eye—a camera—attached a prism to it, and systematically studied
the effects of all movements of which the normal eye is capable
(Plates 4-14, pp. 48-49).

Plate 3 shows a rectangular network of parallel lines taken at
a visual angle of approximately 20°. Plates 4-8 show what this
picture looks like in different conditions when a prism is placed
before the lens opening.

Plate 4 corresponds to the visual image obtained in the primary
position (eyes straight ahead). To achieve this effect, the prism
was placed upright and centered on the lens. Note that, with
the exception of the periphery, the effect differs little from the one
obtained without a prism, and is identical to the one illustrated
in Fig. 3b, which encompasses the entire visual field (and not just
a middle segment of 25°, as this illustration does).

Plates 5 and 6 show the effects of a slight rotation of the prism
around its vertical axis, and correspond to the effects of looking
left and right through the spectacles. In one case, the image con-
tracts; in the other, it expands.

Plates 7 and 8 show the effects of rotating the prism around its
horizontal axis, and correspond to the effects of looking up and
down through the spectacles. Note that both horizontal and vertical
lines are now slanted, and that right angles are highly distorted.

Plates 9-14 were obtained in the same manner and in the same
sequence. They indicate the same relationships between eye move-
ments and visual images in a more realistic setting.

It follows from these demonstrations that the photographic
method is capable not only of elucidating retinal images but also
duplicating what the subject actually experiences immediately
after putting on the spectacles. By looking at these illustrations
and basing his own retinal images on them, the reader himself enters
the “world of the prism.” He and the experimental subject thus
share the same experiences, that is, the same occasional intrusions
of secondary localization-motifs: barrel-shaped curvatures of gradi-
ents; illusions of depth resulting from the distortion of angles and
convergence of intervals; the warping of slopes, etc. Since illusions
of depth accompany prism-induced sensations as well as the sub-
sequent aftereffects, there is no need to make special allowances for
them in the course of the experiment. Besides, as adaptation to
curvatures, distortions, slanting, and apparent movements increases,
they subside. We are justified in assuming, therefore, that, in the
beginning of the experiment, there is a close correspondence
between newly formed retinal images and the perceptual transfor-
mations accompanying them.

Let me add that a continuous series of transitional impressions
is always interposed between images. When the head is turned and
the eyes remain fixated on some object, the proportions of the object
change from one extreme to the other. This explains why the sub-
ject experiences the world around him as “rubbery” and the feelings accompanying a walk on the street as “drunken.”

I trust that the above illustrations of the relationship between eye movements in relation to the spectacles and transformations of the visual image have clarified the nature of the prismatic stimulus situation and of the subjective impressions obtained immediately after putting on the spectacles. All subsequent phenomena of adaptation can now be classified either as adaptation to prismatic influences characteristic of all images, or as adaptation to those influences which vary according to specified conditions (eye movements). Our theorizing will therefore depend on what influences have been brought to bear on a particular situation.

Let us return for a moment to Fig. 3b. It is now evident that our earlier considerations are applicable only to the special case in which stimulation of retinal areas is constant or at least repeated. Curvatures are an example of such a case, since they are common to all images (Plates 4-14). Another example is the deflection of the whole image, which is always to the same side. On the other hand, in the case of intervals, angles, and the direction of lines within an image, we are dealing with an area—still foveal—which, in the course of the experiment, is subjected to countless contrasting stimuli. And it is precisely here that our previously expounded theory of adaptation fails us. In fact, the theory requires us a priori to exclude aftereffects of any kind.

*Relative frequency* of stimulation would be a more precise term. If a record were to be kept of the direction of curvature (whether left or right) and the index of strength of all the curvatures (for example, 0 to 10), the results would be kept as constant or repeated. The resulting value could then be regarded as a measure of the total value of the stimulus effect of the spectacles. It indicates the extent to which the initial curvature effect of the spectacles has been disrupted by the prism.

If the same observer now reported a curvature of +3 as “straight,” then the distortions would no longer be present, since, according to this new standard, the observed curvatures would once more be “symmetrically” distributed. Our subjects did just that when they kept reporting increasingly curved lines as “straight.” Not that they did so consciously; for some physiological reason, they could not help themselves. Their original subjective “standard” for curvatures had actually changed.

Such global changes in subjective standards, however, are only a minor part of the problem which confronts us here. The real difficulty begins when we consider that subjective standards are apparently capable of changing in various directions at once. This always occurs when the prismatic distortions (relative to a single retinal area) are not constant but vary according to the situation.

Let us assume, for illustrative purposes, that the prolonged wearing of prismatic spectacles leads to a magnification of objects as an aftereffect and that the prolonged wearing of magnifying spectacles will reduce the size of perceived objects. Is it not to be expected that alternating between the two pairs of spectacles will bring about no changes? What could be logically more absurd than enlargement and size reduction occurring simultaneously as aftereffects?

None the less, this is precisely what the subject experiences when perceiving intervals, angles, slanting of lines, apparent movements (within images), etc. The same objects appear now enlarged, now reduced in size, and in the same retinal (foveal) area. One moment they slant to the left, the next they slant to the right. Right angles are transformed into acute angles one minute, while a minute later they are transformed into obtuse angles. Now something seems to move in one direction, now the same object moves in the opposite direction. In these circumstances, how can any predictions at all be made about aftereffects?

This is the core problem which the present investigation seeks to solve. Basically, it concerns the limits of adaptation of the sensory apparatus. If complementary (or opposite) stimuli impinging on the retina are equal in frequency and duration are incapable of manipulating whatever in excitability or in spatial relations based on the spatial values, then we cannot speak of adaptation (in the sense of perceptual change) to the above-mentioned variable effects of the prismatic spectacles. To speak of adaptation to the effects of half-prism spectacles or of two-toned spectacles would be even more preposterous.

Fortunately, the facts of the case are different. The first indication of this was given by the studies with prismatic spectacles—insensitive instruments which were still far from ideal for this sort of investigation.

The daily notes taken by Professor Erißmann, who served as the subject in the fourth of this series of studies (p. 36), contain many references to and reflections on this subject. The problem of the stimulus situation is also treated with much greater care than in the first three studies of this series.

* First day of experimentation:

> "I put on the spectacles this morning at about nine o'clock. . . ."
I am particularly impressed by the movements observable in the visual field and accompanying bodily motion. They are even more striking than the curvatures. . . . The changes in the shape of objects are also conspicuous: the walls take on the shapes of rhombuses and rhomboids; the sheets of paper, the books, the table top, and the cup turn elliptical. As I opened the typewriter, it made a complete rotation from right to left, and for a moment I was afraid the radio would topple down. . . . The corners of the room are either too acute or too obtuse—depending on the position of the head. . . . The thick part of the prism acts like a concave glass, making all objects appear thinned out; on the other hand, the thin part of the prism creates the opposite effect, giving all objects a much thicker appearance. Head motion around the vertical axis gives rise to movements on the horizontal plane, lowering of the head to a right upward and left downward movement, and vice versa."

A while later, Professor Erismann no longer reported having these sensations. Or was it that he selectively no longer attended to them? Here is what he says on the tenth day of experimentation:

"The sensations of movement have become less pronounced. I am hardly aware of them now. I think this is because they are not part of the environment on which my attention is focused. Even when I do notice them, it is in a highly subjective manner. . . ."

At the same time that the subject reports diminished awareness of subjective changes in proportions as a function of head and eye position, he begins to report impressions which are entirely new. Thus, while he reports fewer instances of objects appearing thicker or thinner, or slanting lines, and of angular distortions, he now also informs us of experiencing minor visual disturbances when he is not wearing any spectacles. These disturbances are opposite to those which occurred while he was wearing spectacles.

"I forgot to mention that yesterday, while I was not wearing the spectacles, I noticed a slight displacement of the wall in front of me while moving my head up and down, the direction of the displacement being opposite to the one occurring with the spectacles. Furthermore, the edges of the wall seemed to be sloping. I get a fleeting impression of this even now. The rotation is more pronounced at a distance. . . ."

"When I turned my head to the right, I had the impression of movements to my right, specifically of an expansion of the field. When I turned my head to the left, the field seemed to contract. This occurred in precisely that region which the prismatic spectacles had previously enlarged."

Thirteenth day of experimentation:

"The lower visual field is now practically free of any movements and transformations. Even with the proper set, I hardly ever notice them there."

On the fourteenth day of experimentation, Professor Erismann classified his impressions up to this point in two groups: "(1) Those which are in awareness but which are experienced as being subjective in nature. In other words, they are considered as images and not as objects existing in reality. (2) Those which remain outside of awareness, even when one looks for them. Both occur during normal vision and as a function of head and other movements."

The second group, of course, is of most interest to us. Erismann offers the explanation that "standards of width in the periphery have become so transformed that subjective widening no longer takes place." By this he means not only that spatial values in the periphery of the retina have become so altered as to make all distances appear equal, but also that a single retinal area has assimilated different subjective standards which vary according to the position of head and eyes. Without such an explanation, one could never account for the absence of contractions and expansions while the eyes are moving.

After removing his spectacles, Erismann described the following "conditioned" aftereffect (as I would call this phenomenon today):

"A rectangle seen from above and appearing in the lower visual field is distorted into a rhomboid shape with an elongated lower left and upper right axis." (An effect opposite to that induced by the prism, as shown in Plate 8). "If, on the other hand, the rectangle appears in the upper visual field, then the phenomenon does not occur." (Note that in both cases the same stimuli impinged on the same retinal area. It may be asked why, instead of no effect, an opposite effect was not obtained the second time. This is what Plate 7 would lead us to expect. My explanation would be that the phenomenon shown in Plate 8 occurred more frequently than the one shown in Plate 7. Since the subject was much more likely to look down—while walking, reading, or writing—than up, he must have adapted more to the first than to the second "situation."
Erisman's comments about the thirteenth day of the experiment support this line of reasoning.

Prism study 11 (p. 38), which took 124 days, clearly demonstrates the existence of variable aftereffects. Even at the beginning of the experiment the subject (K.) was very attentive to the variable prism effects:

"During visual fixation, every movement of my head gives rise to the most unexpected and peculiar transformations of objects in the visual field. The most familiar forms seem to dissolve and re-integrate in ways never before seen. At times, parts of figures run together, the spaces between them disappearing from view; at other times, they run apart, as if intent on deceiving the observer. Countless times I was fooled by these extreme distortions and taken by surprise when a wall, for instance, suddenly appeared to slant down to the road, when a truck I was following with my eyes started to bend, when the road began to arch like a wave, when houses and trees seemed to topple down, and so forth. I felt as if I were living in a topsy-turvy world of houses crashing down on you, of heaving roads, and of jellylike people. A far cry indeed from the frame of mind one finds oneself in when putting on the spectacles for the last time. Then it is easy to smile at these images.

On the final day of the study, K. reported as follows:

"With a few minor exceptions, the peculiar visual experiences which I had when I first started to wear the spectacles have all but faded away; so much so, in fact, that it is now necessary to put on an additional pair of prisms in order to re-create those first chaotic experiences. In spite of the prisms and spectacles, the world is back to normal.

After K. took off the spectacles, he wrote:

"It seems as if I were now looking through a prism with opposite refractory properties. Actually I am not looking through any prism at all! All the more reason to marvel at the absurdity of these illusions!

"Although I am not wearing any spectacles, the room I am in looks like a strange celler vault. As long as I remain immobile, moving only my eyes, everything remains stationary and invite exploration. The walls appear even more curved than before, when I was wearing the spectacles, and they curve in the opposite dire-
tion; the floor is even more slanted; the angles more distorted; and bands of many colors embellish the scene. And what an uncanny scene this is! As soon as I move, however, this vault begins to play tricks on me, and behaves in a most erratic manner. Perhaps I should not say erratic, for every transformation is the exact opposite of its predecessor during those days when I first wore the spectacles, many weeks ago. Even transformations which I had not noticed then clearly show their aftereffects now. In fact, it is these aftereffects, occurring without spectacles, which tell me what the earlier prism situation really had been like. If it were not for this relationship between the present and the earlier stimulus situation, the sensations which I am having now would make no sense to me whatever.

"As I begin to move and walk about, the room begins to move too. What I am experiencing are the apparent movements of the objects around me. As I approach one of them, it seems to move to the right. I reach out for it and touch—air: my arm has completely missed it, passed to the left of it.

"Even more peculiar are the relative changes inside the room. When I move my head (vertically or horizontally), not a single point remains stationary in relation to another point. If a certain point moves along with me in the visual field, then some other point will infallibly move in the opposite direction, as if indicating to me in no uncertain terms that it is not the least bit bound by what the other points happen to be doing at the time.

"The world I am in seems to have become a total chaos of continuously changing distances, directions, movements, and Gestalten. Nothing remains stable and the experience is so confusing that I am unable to detect what laws these transformations abide by. I wish I had a ruler, so that I could figure out what these relationships are. If, for example, I found that the ruler becomes bigger in the left and smaller in the right visual field, that, when seen from below, it becomes an acute angle and, when seen from above, an obtuse angle, then the changes would no longer be random, but lawful.

"Without such a device, everything remains without rhyme or reason. There is no such thing as a size or a movement; as soon as I move my body or my head, any object is apt to become smaller or larger, stationary or mobile.
"These constant incongruities of motion, size, and direction defy any form of logic. The attention they command is irresistible. Dizzy spells and feelings of depression are the inevitable outcome."

What is the significance of all this? The reader may well ask at this point. My answer would be that the experiences which we have just been described mark the first unequivocal demonstration of the aftereffects following variable prismatic stimuli. These aftereffects have a long developmental history. Most of them have been quantitatively evaluated. The usual kind of quantitative evaluation of curvatures, distortions while looking straight ahead, deviations of the visual median, contraction or expansion, has proved to be insufficient for all the aftereffects. Some of them we had to study under different head-eye positions. A new kind of method had to be invented. Thus, the investigations were really a learning experience for us, at times a totally unexpected one, as, for example, in the case of the subjective bands of color. But before I go into this, let me report the following important finding.

B. STUDIES OF SEVERELY MYOPIC SUBJECTS

Spectacles which correct for near- or farsightedness also involve "prisms" and can be used to study aftereffects.

Concave spectacles act like prisms whose apexes converge in the center of the lens, while the bases are located in the periphery. Thus, looking to the left through concave spectacles should have the same effect as looking through prismatic spectacles with a left base; in both cases, straight vertical lines should appear curved to the left. The reverse should occur when looking to the right through concave spectacles, in which case the effect should be the same as looking through prismatic spectacles with a right base; straight vertical lines should appear curved to the right. To the myopic subject, in other words, the world will appear deformed in different ways, depending on his line of vision. His fovea is subjected to countless impressions of contour curved one way or another. Only when he looks straight ahead are his impressions veridical. This raises an intriguing question. Assume the existence of an aftereffect. What will be the nature of this aftereffect following years, even decades of such stimulation? What sort of "habituation" to distortions induced by looking sideways can we expect? Will it take the form of not being aware of the distortions, or will the distortions actually no longer be perceived? What happens when the spectacles are taken off? Will there be an opposite aftereffect?"

To obtain an answer to these questions, Professor Erismann asked his subjects to judge a straight vertical line in different conditions of eye and head position. When the line was presented medially and seen through the spectacles, it was described by the subject as "straight"; however, when the line was displaced laterally, to either side, so that the subject had to look at it sideways, it was described as "curved." These findings, of course, could be explained on the basis of dioptric principles. What we were most interested in finding out, however, was what would happen when subjects did not wear their spectacles. Again, we found that the line looked straight when presented medially and curved when presented laterally—but with this difference: the line now curved in a direction exactly opposite to the previous one. When the line appeared directly in front of the subject but the subject turned his head to the left or to the right, the same phenomenon occurred. We therefore concluded that even though the stimulus (straight line) always impinged on the same retinal area (specifically that region where vision is most acute), the subject experienced it variously as curved to one side or to the other.

In "Das Werden der Wahrnehmung," Erismann states:

"The subjects continuously fixated the line with the macula lutea, turning only their heads to the left or to the right; and yet, even though the line was always exposed to the same retinal area, its form varied according to the position of the head. . . . In other words, the same stimulus transmitted by the same macula lutea gave rise to different sensations, depending on the way the head or torso was turned! Here was an unequivocal demonstration of a situational effect and of an aftereffect; not only did it warrant, it necessitated further and more painstaking research with our prismatic spectacles" (1947, p. 80).

F. B. Hofmann's comments (1920, p. 109f.) are worth noting here. He begins by mentioning a phenomenon with which ophthalmologists are only too familiar and which is a frequent cause of complaint by patients when they first start wearing powerful glasses. What bothers these patients is that everything in the periphery of their visual field looks distorted as soon as they glance sideways. "However, the complaints gradually disappear," Hofmann continues, "after the spectacles have been continuously worn for some time. The patient becomes accustomed to the spectacles and no longer notices the changes in his visual image."
C. A PUZZLING COLOR PHENOMENON OCCURRING AFTER STRONG PRISMS WERE WORN FOR A LONG PERIOD OF TIME

Without any further discussion, I am now going to quote directly from the record of the 124-day prism study.

Twelfth day: "Mention has already been made of the dinness that characterizes vision through prismatic spectacles. . . . I would now like to describe in some detail another important characteristic of prismatic vision: the dispersion bands. As I have already stated, every prism decomposes white light into a spectrum; as a result, the edges of bright objects appear to have reddish or bluish colors. They usually go unnoticed, but they are clearly distinguishable when an effort is made to see them. . . ."

"Since I paid very little attention to them at first, it is difficult to say whether or not the phenomenon subsided in the course of the first day of experimentation. When I removed the spectacles, however, I noticed various small boundaries running along the edges. The impression was particularly striking late in the evening, and came quite unexpectedly. Even on purely theoretical grounds I was unprepared for the fact that afterimages could result from the many-colored edges of the objects which I had seen. I might have expected that fixating the yellowish edges of the crossbars on the window could give rise to a transitory afterimage; but on what basis could I have predicted the appearance of a clear-cut afterimage after the fovea had been bombarded thousands of times by short-wave and long-wave spectral bands?"

"It was about 10 P.M. I had taken off the spectacles and given them to someone else to let him look through them. I asked him to describe everything he saw. While he did so, I compared my own impressions with his. He began by reporting curvatures; then he mentioned apparent movements; these were followed by reports of distortions; then he described the table where we were sitting as slanting. Finally, he casually mentioned that the edges had colored bands. He was referring to the vertical beam on the right side of the window, which was illuminated by the light on the ceiling and stood out in sharp contrast from the rest of the window, which was dark. I asked him what the color was, but before he told me. . . ."

I clearly noticed—without spectacles—that it was a yellowish-red, belonging to the long-wave extreme of my spectrum, and that it appeared on the outermost edge of the white crossbars. I was so struck by this observation that I seized the spectacles and put them on myself. Lo and behold, the edge glimmered in a beautiful, saturated blue. I tried this experiment over and over again, until late into the night, on all kinds of objects. The result was always the same. Whenever I looked at an edge without the spectacles, I saw a dim yellowish-red or bluish-violet band; as soon as I looked at it through the spectacles, the edge took on a complementary hue."

Thirteenth day: "To make sure the whole thing was not just a dream, I repeated the same experiment the following morning. It had snowed during the night, and the white light reflected from the snow, when seen through the spectacles, made everything appear in many different colors. When I looked at the snow without the spectacles, all vertical edges seen against this background became tinged the same way as the day before. I had not dreamed this up after all. The color bands were not as clear and wide as they appeared when seen through the spectacles in identical conditions, but they were decidedly above threshold. . . ."

"How is such a phenomenon to be explained? Improbable as it was, I could confirm it again and again. As I sat in the train looking out at the landscape fleeting by, the right colors always appeared on the right edges, whether the scene was familiar or not."

Fourteenth day: "I finally came to the conclusion that an alteration must have occurred in the shape of the lenses of my eyes, very much in the manner of a prismatically distorted magnifying glass whose right side is more inclined than the left. Only this way, I thought, could I account for the decomposition of white light into its various spectral colors by my lens, for the fact that I could see nothing more than what was already contained in the retinal image, and for all the distortions which I had perceived when not wearing the spectacles. An experiment had to be devised to test my assumption. There was only one way to go about it: to see whether the same effects would be obtained in light so homogeneous that even the strongest prism could not transform it into a spectrum."

"The results of this attempt were unequivocal: even in homogeneous sodium light, I saw with or without spectacles the same color bands which in normal daylight I could see only without spectacles.
This evidence clearly indicated that the phenomenon in question was a purely subjective one, that is, a specific kind of afterimage. Further confirmation was obtained on the fifteenth day of experimentation, when I found that a 3° prism was sufficient to compensate for color aftereffects but that a 6° prism was necessary to compensate for the aftereffects of curvature and distortion. If the lens of the eye had undergone a prismatic alteration, as I had assumed, then the same correction would have sufficed for all sensory disturbances.

Sixteenth and seventeenth days: "The colored edges are becoming more and more distinct during normal vision. The optimal conditions for their appearance, however, depend on whether or not the spectacles are worn. Thus, while bright daylight enhances the spectral effect enormously when the spectacles are worn, the reverse holds true for the afterimage, which is enhanced by darkness. However, this relationship holds only within limits: when, after dusk has set in, all colors have disappeared, the colored aftereffect vanishes as well. The optimal condition apparently is provided by dim electric light."

"This morning, for example, while I was washing myself, the play of colors was especially vivid. The rims of the large china washbowl I was using were shining with extraordinary brilliance, as if illuminated by fluorescent lights. The right side was tinged reddish-yellow, the left bluish. It looked like a precious stained-glass window and reminded me of those bright and clear winter days in which all contrasts become so sharply intensified. When I put on the prismatic spectacles, however, the whole display was gone. The bowl, in the semidarkness of the shadow which my head cast over it, had lost all signs of its former splendor. In the condition of reduced illumination, as now, my afterimages had the same strength as the prismatic dispersion bands with the spectacles on would have in the same conditions. Therefore, with the spectacles on, they were not visible now, since they had been exactly canceled out by my aftereffect...."

"I cannot emphasize enough that none of my observations were forced. The color bands appeared whether I looked straight at them or not; they were there before I closed my eyes and after I opened them again; and after a whole night's rest, they promptly reappeared in the morning on any bright object which I happened to be looking at."

"An extraordinary degree of stability characterized these afterimages. Contrary to the descriptions of all known afterimages, the ones which I observed did not fade in and out, were not disrupted by eye movements, and did not lose their sharpness when veiled by some opaque object. They were even capable of producing other afterimages of the Hering type! These appeared whenever I fixedated one of those phantomlike edges for a while, but their duration was short."

Fiftieth day: "The dispersion bands are now so distinct during normal vision without spectacles as to dispel any doubts about their existence. In fact, their intensity and variety in artificial light (indoors, evenings) now closely resemble the brightness of the sun's spectrum. (What I mean by this is that they are as articulated as if I were wearing the spectacles in broad, sunny daylight.) On the other hand, when I wear the spectacles in an artificially lighted room, the dispersion bands are totally absent, except when I look closely at the source of light. With a further reduction in illumination, however, as in the corners of the room, colors do appear again, but they are complementary to the dispersion bands. This is my aftereffect. Not only does it compensate for prismatic dispersion in these circumstances, it actually surpasses it."

"When I wore the spectacles in the movies, they did not bother me in the least bit. I was in for a great surprise, however, when I decided to take them off. The black and white picture on the screen suddenly changed to Technicolor! All contours and lines, especially at the boundaries, were suddenly embellished by clearly visible bluish and yellowish bands. (The phenomenon was limited, however, to vertical and oblique lines; it did not appear on horizontal lines or on surfaces.) The effect was the exact opposite of the one that prevailed during the first few days and weeks of this study; furthermore, it now occurred only when the spectacles were not worn. Some form of sensory equivalence must have succeeded in eliminating the effect...."

The above demonstrations of the dispersion aftereffect clearly show that the situational aftereffect is a phenomenon which also occurs in the realm of color sensitivity. Furthermore, they indicate that the situational aftereffect is "conditioned" by those incidental stimuli which were regularly present in previous situations. In accordance with Hering's schema, processes of dissimilation and
assimilation in the visual substance have been “stored up,” that is, they have become associated within certain peripheral conditions. What the senses “remember”—if I may use this expression—is not a general approximation of past stimuli but “details”; that is, specific impingements which occur only in specific situations become discretely “conserved.” Thus, a certain set of conditions disrupts the equilibrium of the senses in one way, while another set of conditions disrupts it in another. This peculiar state of the senses can persist for some time.

The results of our careful investigation of this kind of aftereffect can now be summarized in detail.

1. Subjective coloring of edges is apparent only when brightness contrasts exist, and depends on what direction the brightness gradients have. For example, the transition from bright to dark will appear as blue when the spectacles are worn, but will be seen as yellow when the spectacles are not worn. If you now change the background, reversing the brightness gradient, then blue reappears.

2. Aftereffects do not occur when the brightness contrasts on the retina are cephalocaudal, in which case the edges are horizontal, with the head held in the normal position. In these conditions, no dispersion effects are noticeable, even when the prisms are worn.

3. Color afterimages remain part of the object. They can be observed at will foveally as well as parafoveally, up to an angle of about 30° on either side. During steady fixation, these aftereffects can even produce temporary afterimages of the Hering type, as if the observed contours were “actually” colored.

4. When the observer walks around, the colors on the edges change exactly following the rules mentioned above.

5. Different adjacent colors show the color phantom only when there are brightness contrasts, regardless of how much they contrast in hue.

6. If a contour is set off against a bright background in relation to the left eye and against a dark background in relation to the right eye, then the left eye will perceive a blue and the right eye a yellow aftereffect in the same area. In binocular vision, these two aftereffects will compete with one another.

According to Hering’s theory, opposite aftereffects occurring in the same retinal area are bound to clash. Our results show that such clashes are far from inevitable, that they are in fact prevented by the occurrence of the respective situational conditions. At no time, not even during stimulation, did we observe complementary colors or opposite distortions to be simultaneously active in the same retinal area; they always occurred in succession. Furthermore, they occurred (within the total stimulus situation) according to definable principles and determined the specific course which the aftereffects were to follow. It is therefore meaningless to speak of aftereffects as if they could all be lumped together. Thus, the contradiction posed by Hering’s theory is nonexistent.

We agree that a line cannot appear to be both long and short, both straight and bent, both in motion and motionless, and that an edge cannot be simultaneously seen as yellow and blue. But it is possible for such differences to appear in quick succession as a function of rapid intervening changes in the situational “conditions.”

Hering’s theory is incompatible with empirical facts precisely because it ignores the possibility that sensory reactions can be conditioned, even though such conditioning may take place only after a long period of stimulation.

Because our results were at odds with existing theory, their publication was delayed for years. We felt it was necessary to obtain further, more convincing confirmation.

This is not to say that some results of our prism studies could not have been published as an earlier date. I am referring to the studies involving the “mirror spectacles” worn on the head and their contribution to our understanding of the compensatory effects of reversing the entire visual field (in relation to the body median); and to those prism-induced aftereffects which, as in the case of curvatures, occurred as a result of constant stimulation.

If these had been published, however, we would have had to disregard an equally important aspect of the prism situation—the aftereffects of variable stimuli. This we were reluctant to do because, as I have shown, partial answers to this question already existed. These could not have been omitted even from an incomplete presentation of the results. And since we did not wish to present conclusions which were merely tentative, we decided in favor of further experimentation.
The crucial issue which now confronted us concerned the effects of varying, i.e., opposing, stimuli impinging on the same retinal area. Furthermore, the variations had to be regularly associated with special accompanying conditions. Only this way could we expect a gradual differentiation of an adaptational process.

EXPERIMENTS WITH HALF-PRISMS

The half-prism experiment of 1933 (Exp. 2, p. 34), the first of its kind, was inspired by past observations that prolonged wearing of prismatic spectacles resulted in pronounced aftereffects. This led Professor Erismann to explore the possibility of "suppressing" visual distortions by letting subjects practice as much as possible without spectacles. His reasoning was that since in real life we often get used to many contrary things, it should be possible for a subject to become simultaneously accustomed to prismatic and nonprismatic vision. The occasion marked the first clear positing of a "situational" aftereffect. However, it was not until the half-prism spectacles were developed that a formal investigation of the effect could be launched.

Naturally, only a very special kind of adaptation, one specific to the half-prism situation, could be expected to undo the distortions resulting from the spectacles. This meant that the aftereffects too had to be of a specific nature, for if they generalized to all visual experiences, nonprismatic vision would also become distorted. What was needed therefore was not adaptation but some sort of "semiadaptation." I am not talking here about a situation in which the spatial values in the upper half of the retina are altered under the influence of the prisms, while reactivity in the lower half remains unchanged. I am talking about a differential adaptation occurring in one and the same area of the retina, since the eyes are free to move in any direction behind the spectacles. Thus the success of the experiment hinged on the subject's ability to bring about such an adaptation.

At first, the prospects for achieving this objective were anything but encouraging. They seemed so unlikely, in fact, that the investi-
gators did not even let themselves think in terms of a sensory adaptation to the situation; instead, they thought that some kind of change in the subject's "attitude" would be involved. They assumed that somehow he would gradually become "habituated" to, that is, learn to "ignore" or "overlook," his sensations when looking through the lower half of the spectacles (where the prisms were located at the time).\footnote{The assumption was not made without a certain amount of discomfort, for it was difficult to explain certain prismatic aftereffects, for example, curvatures, which were so clearly sensory in quality, solely on the basis of their having been interpreted or worked over in some fashion. After all, the effect was the same as if the various retinal elements had been surgically transplanted, as is sometimes done in cases of pathological metamorphopsia. Consequently, the notion of a specific mutual reorientation of spatial values began to have considerable appeal to us. It made the inevitability of these effects more understandable.}

Unfortunately, the results of the 1933 study were ambiguous. The study was too short, the subject's observations were too inaccurate, and the design and procedure of the study had been inadequately planned. Furthermore, the study was too limited in scope; it concerned itself only with the problem of artificially interrupted visual images (see below). Not that this was a trivial consideration; but it did fall considerably short of encompassing the entire situation. In any case, the results failed to clarify even this relatively minor point.

A successful half-prism study, one which was planned with much greater care, was not undertaken until many years later. It is this study (Exp. 12, p. 41) which I shall now describe in detail. I will first present the design and procedure, together with many excerpts taken from the report of the subject's actual experiences. I will then present the quantitative results, and in a final section discuss some observations made after the spectacles had been removed.

\section*{A. Design and Procedure}

The half-prism spectacles used in this study (Plate 15, p. 50) consisted of two spherically cut (convex-concave) prisms with a $10^\circ$ angle at the apex. The prisms were inserted in the upper portion of the spectacle frames, bases to the left; the lower portion was plain. When the subject looked straight ahead, the lower horizontal edge of the prism bisected his visual field. A special nose attachment was an added safeguard.

As before, I simulated the appearance of the situation with a camera. I was able to produce a facsimile of a retinal image by placing a prism in front of the camera so that it covered only half of the lens opening. Of course, the picture corresponded to an image which could have been obtained only by looking straight ahead through the spectacles.

It should be kept in mind that the present situation is far more complicated than the earlier one. What was previously applicable to the whole-prism situation now holds true only in the special case of the subject's looking up.

In looking up, a change takes place in the position of the eye in relation to the dividing line between the prismatic and nonprismatic portions of the spectacles: the dividing line is displaced downward and becomes practically invisible. Consequently, almost the entire retina is now subject to prismatic stimulation in a manner with which we are already familiar. Depending on the direction in which the subject is looking, objects will seem to contract (looking up to the left) or expand (looking up to the right), or their slopes or angles will tend to fluctuate (looking at the uppermost edge or at the dividing line).

When the subject looks down, on the other hand, the dividing line is displaced upward and again all but vanishes. Now the entire retina is subject to normal, unimpeded rays, and the subject's vision is undisturbed.

When the subject looks straight ahead, a new kind of peculiarity of the image is noted. As Plates 16-20 (p. 50) show, a break in continuity occurs: the upper part of the image is suspended above and to the right of the lower part. This phenomenon is due to the fact that the images transmitted by the prisms are displaced to the right of the images transmitted by the plain portion of the spectacles. In this situation, then, half the retina is subject to prismatic stimulation, while half is subject to normal stimulation.

The half-prism spectacles are shown in Plate 15 (p. 50). The object in the background is a crayon. Note the lateral displacement of the portion of the crayon seen through the prism relative to the portion appearing in normal vision.

Plate 16 shows lateral displacement of parts of a geometric design seen some distance away through the spectacles. The deviation of the prism amounts to about $5^\circ$ of visual angle; in other words, its
absolute magnitude increases as objects are further away (see Plate 20, p. 50). Note the double images in the vicinity of the dividing line between prismatic and normal vision; it is here that the prismatic and the nonprismatic images vaguely merge into one another. It is also evident from the illustration that the top parts of the images are distorted (but not excessively, as these are only 10° prisms).

Plates 17-20 (p. 50) represent real life situations. Take Plate 18 (p. 50), for example, which portrays a real footpath alongside of its illusory counterpart, and try to put yourself in the place of the subject, who reports as follows:

"I am always walking too far to the right and therefore keep sliding off the left curb. I am obviously doing this because I am going by the illusory 'prism walk' which, naturally, points in the wrong direction."

In Plate 19 (p. 50), the dividing line is so situated that the lateral displacement of the heads amounts to exactly the separation of the bodies. Plate 20 (p. 50) shows the peculiarly protruding and bulging appearance of some buildings. No wonder the subject felt alarmed, thinking that they would cave in at any minute.

We now formulated two questions for further investigation.

1. What will be the fate of the usual prismatic aftereffects when the subject is able to test reality through the plain portions of the spectacles? Will the result be different aftereffects, depending on the subject's line of vision? An enormously complex process of sensory adaptation is implicit in this question, a process which becomes even more complicated when we consider that looking through the prismatic portion of the spectacles alone results in widely differing images, depending on whether the light rays hit the eye from the left, from the right, from above, or from ahead (see Plates 4-8 [p. 48] and 10-14 [p. 49]).

From the very beginning, therefore, our daily tests were carried out in four different ways. (By "tests" I mean perceptual analyses of curvature, angularity, tilt, apparent movement, optical and tactile medians, etc.). We tested separately for upward and downward vision, and for vision with and without the half-prism spectacles. This precaution was necessitated by our assumption that spatial vision, effected by stimulation of one and the same retinal area, was likely to proceed along multiple tracks, according to head and eye position.

Thus, every test yielded four values which, in the day-to-day course of the study, showed up as four separate curves. Of these, two were of particular interest to us: the curves for upward and downward vision without the spectacles. A difference between the two curves indicated the presence of "situationally" aftereffects; no difference between the two curves, on the other hand, meant that no such effects had occurred.

2. The second question concerned the fate of the half-images, broken apart and displaced along the dividing line of the spectacles. The subject had to be particularly alert in this part of the investigation. The images appeared only when the subject was looking approximately straight ahead (in relation to his head) or when he looked to his left or right (the elevation being the same). Was a compromise to be expected? If so, then the spatial value of one half of the retina would (only under these conditions) have to be displaced in relation to those of the other half by an amount equal to the deviation value of the prism. Furthermore, the displacement would have to occur quite independently of the earlier changes in spatial values accompanying upward and downward vision.

Daily measures were taken of the space between double images and of the magnitude of the perceived discontinuity. Thus, any merging of the double images into one, as well as any instances (aftereffects) of opposite discontinuities occurring without spectacles, would be clearly detectable. Actually, the results did not confirm this. I shall return to this point later on.

Having made these preliminary remarks on the formulation of the problem and the design of the study, I would now like to describe the rest of the procedure, quoting excerpts from the daily reports of the subject.

First day: "The very first experience I had with the half-prism spectacles was as expected: whenever I looked through the prism halves, the picture I saw was distorted; whenever I looked through the plain sections of the spectacles, the picture was undistorted.\(^2\) When I looked through the transitional area of the spectacles, I}

\(^2\) am assuming that the aftereffects from a previous study were no longer present and could not be reactivated in the present study. This, however, was not entirely the case.
saw a rather hazy picture around the edges of the prism, the region of light dispersion. Double images also appeared in the same area, and contributed to my annoyance. ... When I am walking on the street, it is the region around the dividing line, situated three or four meters ahead of my feet, which I look at most often. When I am writing or reading, on the other hand, the dividing line lies above the book or notebook and therefore does not interfere. When I am typing, it lies on approximately the same level as the keys, so that I type in the lower field and read the typed lines through the upper.

“Gradually, a kind of division of labor evolves: I am beginning to prefer the nonprismatic part of the spectacles for nearby objects and for everyday kinds of manipulations, while for distant objects and for a general sense of orientation I am developing a preference for the prismatic part of the spectacles. However, I am absolutely sure of myself only when I am looking through the nonprismatic part of the spectacles. For example, if I spot a door knob through the prism and quickly reach for it, then I am sure to miss it by reaching too far to the right. Or, I will always put my foot in the wrong place while walking up a steep incline—a circumstance due to the fact that the area around the feet can be seen only through the prismatic part of the spectacles, even when the head is held normally.

“Occasionally I am confronted by something very surprising. The people I meet on the street appear to be cut in half, the upper part of the body (head and chest) floating next to the lower. Instead of walking on their feet, the people in front of me have their feet walk alongside of them, to their left. When I am being introduced to someone, I find that he has two heads (region of double images) and I am at a loss about which of the two I should greet.

Fifth day: “My ways of looking at things have undergone a further ‘division of labor.’ I now avoid more than ever the area around the dividing line, and whenever possible, look up or down rather than straight ahead—even if I have to move my neck to do so.” (As we shall see later, this factor proved to be of considerable importance in answering the second question which was formulated for this study.)

Tenth day: The following is a brief summary of the experiment thus far.

“All images continue to be displaced laterally, with one exception. While formerly objects clearly moved back and forth as a result of my tendency to alternate between the prismatic and nonprismatic sections of the spectacles, they now seem to have achieved considerable stability. My eyes seem to have learned to anticipate the very movements needed to get the object into fixation. However, as soon as I take notice of the dividing line, the fixation point begins to move around once more.”

It is becoming clear that the second question had not been properly formulated. As the above report indicates, the subject was doing his best to avoid the very thing he should have done and which was most crucial to an understanding of the problem—looking in the direction of the dividing line. In the absence of past experiences of this kind, an aftereffect could not be expected to occur.

Fortunately, a phenomenon I call Punktspringen¹ was a saving factor here. True, the subject usually did avoid the midsection of the spectacles; nevertheless, there must have been countless occasions when he did pass the dividing line, even though each such transition must have felt like an earthquake to him. The question we really should have asked ourselves, therefore, is: how does the

¹ A report on apparent movements of images between the surrounding sphere and the periphery of spectacles by P. B. Hofmann (1920, pp. 111-112) substantiates this finding. Hofmann postulated that if a subject follows such a moderately fast-moving object with his eyes, a jerky movement should be noted at the transitional zone between outside and inside the frame of the spectacles. “In fact, my prediction was confirmed by subjects who briefly wore concave spectacles. When I wore them, I too noticed an abrupt acceleration of movement right in the transitional zone; however, only in indirect vision. When I carefully pursued the object, an impression blended into the next so smoothly that I was unable to notice any jerkiness at all.”

The difference between Hofmann’s and our observations is that while Hofmann’s subjects only occasionally reported apparent movements of points, for our subjects the phenomenon was an everyday occurrence. The reason for this difference is to be found in the fact that the dividing line of our spectacles cut squarely across the middle of the visual field. Thus, our subjects were much more likely to become visually adapted than Hofmann’s.

Hofmann concludes that the processes involved here are “learning phenomena similar to those involved in the inhibition of apparent movements in cases of oscillopsia.”

(Tr., literally, “point jumping.” The approximate English equivalent of this term is “apparent movement of fixation points.” It is connected with up-and-down movements of the head or eye, and is described in detail elsewhere.)
visual apparatus come to adapt itself to this jumping effect? A hint of this is already contained in the above-cited report.

"With respect to the other adaptational phenomena—adaptation to curvature, distortion, apparent movement, tilt, etc.—I am now able to make out three separate stages. At first, there is a general disorientation; as adaptation to the prismatic situation begins, vision through the plain sections of the spectacles becomes distorted. . . .

"Thus, the first stage is characterized by a rapid progress of adaptation to the prismatic world which, since it involves only certain circumscribed areas of the retina, causes distinct aftereffects to appear in the unobstructed part of the visual field whenever the eyes move. The longer I happen to be looking up at something, the greater the tendency of objects to appear curved in the opposite direction, distorted, tilted, etc., when I subsequently look down.

"In the next stage, adaptation to the half-prism spectacles has become stabilized; but the aftereffects (when looking down) fluctuate a great deal, depending on whether I was previously looking up, through the prism, or down. If I was looking up, then the aftereffects will be stronger; if I was looking down, then the prismatic world will appear as distorted as it did at the outset. . . . It seems that in both stages receptor elements tend to react with uniformity." (Meaning without respecting the additional situation of head-eye position.)

"As time goes on, I am becoming aware of the fact that my perceptual experiences are increasingly veridical. In other words, I no longer see marked distortions when I am looking through the prism, and only weak aftereffects are present when I am looking through the lower section of the spectacles. I am especially surprised to find none of the apparent movements which initially annoyed me so much whenever I looked through the prismatic part of the spectacles. Looking down likewise fails to elicit that kind of distortion. . . .

"When I remove the spectacles, however, a marked shift occurs in the previously uniform functioning of the visual apparatus. No longer are the sensations resulting from a stimulus the same for upward and downward vision. . . . This marks the beginning of the last—and most fascinating—of the three stages. . . ."

I am not going into the details of the subject's observations, which now follow. They run the whole gamut of phenomena which occurred whenever he looked up or to his right or left: curvatures, distorted angles, "parallel" lines which diverge, tilted lines, apparent movements, even contraction and expansion of objects. They also present evidence which suggests that the strength of the dispersion aftereffect is to some extent dependent on eye movements.

I do wish to point out, however, that all the effects the subject observed when he was not wearing spectacles fluctuated a great deal, and that these fluctuations were determined by the position the eyes happened to be in at a particular moment. If he happened to be looking where the prisms used to be, then the aftereffects affecting his entire visual field were stronger than if he happened to be looking where no prisms used to be.

After about a month of experimentation, the subject was able to give definitive answers to both of our experimental questions. Since the report is rather lengthy at this point, I have taken the liberty of selecting what I think are the most relevant portions of it. Since I myself was the subject, no undue bias should result from this procedure.

I will first take up the problem of discontinuity of images and the related effect which I have called Punktispringen.

Whenever I deliberately looked through the transitional zone of the spectacles, the images immediately broke up into two parts, an upper and a lower, mutually displaced from one another by about \(^5\). This was exactly what had been observed on the first day of the experiment. Thus, we cannot say that any adaptation had taken place in the sense in which we are speaking of it here.

Punktispringen was an entirely different matter. For hours on end, I was able to manipulate objects, write, read, and walk around with the spectacles on, without the slightest bit of interference from
jerky apparent movements. Even when I was "set" to watch for these jerky motions of objects in the transitional zone between prismatic and nonprismatic vision, I was hardly able to notice them.

"I began to notice that once I had placed myself so that I was directly facing an object, it no longer mattered which way I was looking at it through the spectacles; the object kept its position. It was completely irrelevant whether I looked at it through the prisms or through the plain part of the spectacles. . . ."

It should be added here that this same attempt brought about quite different results on the first day of the experiment. A fixation point located a few meters away appeared to be "straight ahead" when seen through the prism; but as soon as the subject raised his head or lowered his eyes, the point was somewhere else. In order to bring the point back to its former position, he had to take an entire step to the left. The position of every single point in the subject's environment thus depended on whatever his head or eye position happened to be at the moment.

Now, however, the reverse was true. When the subject looked at a point while at the same time moving his head up and down, the point no longer jumped. It remained stationary even when it crossed the dividing line of the spectacles—provided it did so neither too slowly nor too rapidly. We found an answer to this puzzle when the subject removed his spectacles for a short time and repeated the same experiment without them.

"Now that I was not wearing my spectacles, the fixation point immediately began to jump as soon as I moved my head up and down with moderate speed. It remained 'straight ahead' when my head and eyes were turned in one direction only.

"I also noticed that when I scanned, without the spectacles, the entire length of some straight vertical object, such as the edge of a door, I was no longer able to focus on it. It always moved unexpectedly to the left or to the right of my line of vision, depending on how I was looking at it, from below or from above. When I redoubled my scanning efforts, the result was even more peculiar: I now had the feeling that the line of my eye movements was not vertical but diagonal, running from top left to bottom right. . . ."

"I have actually come to the point of experiencing objectively vertical eye movements as 'diagonal,' and objectively diagonal eye movements as 'vertical.' . . ."

This last observation provides an explanation for the unification of broken and displaced images when eye movement comes into play.

The first experimental question, it will be recalled, had to do with the relationship between eye movements and aftereffects; in a sense it pointed to the entire problem of visual adaptation to the total half-prism situation. If we now consider this question in the light of the above observations, we come to the conclusion that no aftereffect is independent of concomitant eye movements. This does not mean that such "half-aftereffects" have completely resolved the problem of the half-prism situation. However, they have overcome it to a degree—at least the errors have not increased during downward vision; on the contrary, some of them seem to be in a stage of decrease.

In order to study in greater detail the fluctuations of aftereffects as a function of eye movements, we used special "auxiliary spectacles" which were not spectacles at all but an empty frame. The subject reported:

"A wire horizontally strung across the middle of each of the empty eyepieces divided the visual field in half. Two flaps, attached to the sides, further served to simulate the half-prism situation and to facilitate the appearance of aftereffects.

"If I now substitute these auxiliary 'spectacles' for the prismatic ones and stand facing the edge of a door, then the edge bulges out convexly toward the right. Although the effect is qualitatively the same whether I am looking at it through the upper or the lower halves of the eyepieces, it is stronger when seen through the upper halves."

Following these observations, the subject proceeded to study, in like manner, rectangular forms, horizontal, vertical, and parallel lines, etc. Always the aftereffects were stronger when seen through the upper half of "the spectacles"—this even though the glass was missing from both eyepieces so that the retinal images were the same in all cases.

Of all the effects noted in the half-prism situation, those involving the visual median and apparent movements showed the greatest amount of adaptation. Errors in prehension rarely occurred now, whether an object was seen from below or above, directly or in-
directly. Moments of confusion did occur, when the subject happened to look right through the transitional zone of the spectacles, but these were extremely rare, as the subject usually avoided looking in that direction. Apparent movements occurred only if there were changes in the proportions of prismatic images. Thus images still tended to expand and contract when the subject moved his head to the left or to the right while looking up, and angles still varied somewhat when he looked all the way up to the top edge and down to the bottom edge of the prism. The effect resembled the distortions induced by pulling at an elastic rubber plate on which a picture has been painted. It should be pointed out, however, that the "rubbery" impression was not nearly as distinct as it was during the early stages.

All other apparent movements, even those which were initially most prominent, were now gone. Those jerky movements which used to be present whenever the subject moved his body while walking were now totally absent; the scenery remained stable regardless of whether the subject looked up or down through the spectacles. Gone also was the tendency of objects to move sideways whenever their distance from the viewer changed—a feature which was particularly striking at the beginning. Let us pretend, for a moment, that the spectacles in Plate 15 (p. 50) have been moved back a bit, away from the crayon. It is easy to visualize what would happen. The part of the crayon which is seen through the prism would now be displaced even more to the right. If the spectacles were moved forward again, closer to the crayon, the part seen through the prism would be displaced toward the left. Now suppose the spectacles were to touch the crayon: the crayon would appear as one continuous piece. This was exactly what the subject used to experience whenever he quickly approached an object or drew away from it. The experience was particularly vivid when the subject rode a bicycle. This is the way he described it:

"The part of the road ahead of me which I saw through the prism part of the spectacles kept veering to the left while I was moving (decrease in deviation upon approach); it looked like a conveyor belt in constant motion. Just ahead of the front wheel, however, no such movement was visible (nonprismatic part of the spectacles)."

On the thirty-seventh day of the experiment, however, the subject no longer saw any apparent movements at all. "I can now approach any objective in a straight line and it won't budge, even when not seen through the prism (which transition happens quite abruptly when bicycling)."

This last comment adds to our understanding of Punktspringen. Had the phenomenon remained, it would have seriously interfered with the subject's efficiency, since looking up and down in rapid succession is an intrinsic feature of bicycling.

The following observations were made a few days later, while the subject was riding his bicycle without spectacles. The part of the road which formerly was seen through the prismatic part of the spectacles now resembled a conveyor belt veering to the right. The subject felt as if the earth were "a huge disk which rotated clockwise, with its center below my body." No lateral movements, however, were visible in the area immediately ahead of the front wheel. Furthermore, the dividing line separating that part of the field in which apparent movements occurred from that which contained no movements coincided exactly with the former dividing line of the spectacles, and thus varied as a function of head and eye position. Lowering the head combined with raising the eyes led to an expansion of the area containing apparent movements; raising the head and lowering the eyes caused it to recede and eventually to vanish.

To summarize: the same laterally motionless stimulus now induced sensations of lateral movement as well as sensations of no movement in the same retinal area. Whether one or the other sensation occurred depended entirely on whether the retinal area had

---

6 A paradoxical situation occasionally arises in experiments of this sort when adaptation to circumscribed apparent movements has progressed further than adaptation to distortions of shapes. When this occurs, one distortion succeeds another without, however, being accompanied by any sort of movement. The reverse may occur after removal of the spectacles. Then contours are often seen as moving relative to one another, while at the same time evidencing no changes in the intervals between them. Negative afterimages of movement often present similar paradoxical phenomena. They suggest that while movements and changes in intervals certainly go together in a physical sense, they need not do so at all in a psychological sense.
previously been stimulated in similar conditions by laterally moving or stationary stimuli. The apparent movements seen without spectacles were the exact opposite of those formerly seen with the half-prism spectacles.

Forty-seventh to fiftieth days (final days of the experiment): “I have gotten so used to the spectacles that they seem to have become part of me.” (In fact, when they have been worn for such a long time, they are taken off with utmost reluctance, since their removal immediately ushers in the topsy-turvy world of aftereffects.) “Only when I make a special effort to look through the transitional zone of the spectacles does the picture break up. Otherwise, all impressions remain uniform, no matter which way the eyes move and no matter how intently I observe.”

Although the subject could still make out prismatically induced distortions when he made a conscious effort to look for them, they were not nearly as striking as they had been, and sometimes even failed to appear. This is remarkable—and the experiments with colored spectacles to be described later will show why even better—for the following reason: it shows that adaptation was greatest in those situations in which stimulation was most intense.

For weeks the subject had been busily typing, while wearing the spectacles. All that time, the keys were visible through the plain parts of the spectacles, while the platen with the sheet of paper was visible through the prism parts. At first, the subject noticed that the spaces between lines were uneven and seemingly diverged in different directions. Then they were even again—but only as long as the subject maintained a normal sitting position in front of the typewriter. As soon as he got up and looked at the lines with his head lowered, they diverged once more. Since this was an uncommon situation, adaptation did not occur. It is really incredible to think that a subject can become differentially adapted to every single variation of a situation in the course of an extended study. More about this later.

In general, the state of the subject’s vision was now such that neither looking up through the prism nor looking down resulted in any notable distortions or errors. In each instance, the retinal images were different, yet no such difference existed as far as the corresponding sensations were concerned. This means that the retinal areas must have “learned,” to a degree, to react in the same way to different stimulations.

Most peculiar impressions took place, however, when, after fifty days of experimentation, the subject removed the spectacles:

“While, in general, the perceptual changes were not as drastic as those which occurred after the wearing of fully prismatic spectacles, they were nonetheless extremely interesting. In the earlier studies, aftereffects occurred only when I looked to the left or to the right. Now, however, they also occurred when I happened to look up or down. In other words, the number of aftereffects had doubled. Looking up or down causes the entire picture to change, down to its finest details. Looking to the left or right causes objects to tilt, contract, or expand. The most striking aftereffects are the apparent movements. If I look up at an object, fixating it with my eyes, and move my head or my body only the slightest bit, the apparent immediately starts swaying in a most peculiar manner. On the other hand, if I look down at something, everything remains motionless, no matter how much I move around (except when I move unusually fast, or when my head and eye movements are exaggerated).

1 We are touching here on the controversial problems of perceptual “constancy.” We usually speak in terms of size, shape, angle, and color constancy of the tendency of objects to remain motionless even though we, the observers, move our eyes, head, and bodies. How is it, then, one may ask with justification, that objects do not lose their constancy in our experiments? While space does not permit me to answer this difficult question in great detail, let me say this much: a process very similar to that of constancy occurs during our experiments. It will be recalled that marked perceptual changes initially resulted from the change to prismatic stimulation. There occurred pronounced disturbances in the constancy of size (consider the contractions and expansions observed by our subjects), of shape, of angularity (changes in the proportions of prismatic images), of position (apparent movements of all sorts), and yes, even of color (dispersion effect). With good reason subjects described these striking inconstancies in such drastic language as a “robbery world.”

Our subsequent observations, however, afforded us a unique opportunity to witness in detail a gradual elimination of these inconstancies and a return to perceptual constancy—despite continuing variability of stimulation (even within the same retinal area).

Let it also be stated that the above could only have occurred by virtue of the “conditioning” of the aftereffects created by stimulation from various earlier situations.

How much of this applies to the usual type of constancy phenomenon remains an open question and a major area for further research (see Chapter 5).

This part of the record, as well as some of the excerpts mentioned earlier, also appears in Krismann (1947). I am introducing it here because this is a major highlight of the experiment which can be described much more effectively in terms of the subject’s direct experiences than by any prosaic summary.
"Let us say I am walking beside a wall, and looking up at it. Then the wall starts swaying, as if I were a giant trying to tread through deep mud. Now suppose I am looking down at the same wall (without straining my neck too much): the wall remains perfectly still and solid, and no movements of mine can possibly alter that fact.

"If I walk at my usual pace, keeping my head still, the sidewalk starts to shift to the right two or three feet ahead of me, while the part of the sidewalk immediately ahead of me remains unchanged. But if I lower my head while walking, then all of the sidewalk ahead of me bends to the right. Walking along the edge of the sidewalk at the right side of the street is impossible with the head held in a normal position; I am always about five centimeters too far to the left, so that I can't manage to stay on the sidewalk. By normal position of the head I mean a slight lowering of the head, so that my eyes are slightly raised. When the head is in this position, the sidewalk is falsely perceived, that is, it appears displaced to the left. If I did not stumble as a consequence of my false reliance on my vision, I would never know about this perceptual error. When I keep my eyes lowered while walking, I make no errors.

"Writing about these first impressions in retrospect does not do them justice. The experience is most uncanny. You are walking along, not worrying about a thing, since you can clearly see which way the street ahead of you goes. Then, all of a sudden, you know something is wrong. You could swear some mysterious force is trying to play a mean trick on you by always changing everything around at the last moment... You get to the point where you cannot take anything for granted any more. It is not your vision you blame, though; far from it; your confidence in your vision has not been a bit shaken by all this. No, it is the world you blame, the world swirling at your feet, which is trying to make a fool out of you. As for the apparent movements—why should I think that they originate 'inside of me' rather than 'outside'? After all, don't they make the world look as if it were being shaken up by one earthquake after another? This is what makes those first impressions so unique.

"Shakes too change according to whether they are seen from above or below. A wall to my right arches over toward me; a wall to my left recedes from me. But if I raise my head and look down at it, then the edges straighten out and the walls right themselves. Horizontal lines change in the same manner.

"Curvature aftereffects are especially tricky. After fully prismatic spectacles are worn, all edges bulge out uniformly. Now they have two bulges. Not only does the entire length of the edge bulge out slightly to the right, but superimposed on it is another bulging outline. This extra bulge, however, occupies only the upper third of the edge, forming the main bulge of an already bulging line. If I move my head, the location of this bulge changes too. Thus if I slowly lower my head, the bulge descends, and comes to rest at a point further down along the edge.

"The apparent movements which I observed while walking appear in intensified form when I ride a bicycle. A few feet ahead of me, the road looks absolutely steady (no lateral displacement); but about two meters ahead of me and further on in the distance, the road rapidly veers off to the right. This often causes me to swerve to the left and off the road altogether."

The following investigation corroborated the above observations. It is possible to "compensate" for the aftereffects of a prismatic study by wearing correspondingly weaker prisms. The power needed to compensate for the aftereffects is a measure of their intensity. Since aftereffects vary in intensity, several compensatory spectacles are needed, one for each aftereffect. At least this was true of the fully prismatic studies. Now, however, the problem was even more complex; now two compensatory spectacles were needed for each aftereffect, a relatively powerful one for "upward vision" and a relatively weak one for "downward vision." The difference amounted to approximately one prismatic diopter for aftereffects of curvature, distortion, contraction, expansion, tilting of vertical and horizontal lines, and the rubbery-movements aftereffect. Compensating for errors in the case of the visual median required a difference three times as large. Looking down eliminated apparent movements in the entire visual field (when approaching or drawing away from an object). A compensating prism was not necessary. Looking up required a prism with a 7° angle at the apex. Investigations of subjectively colored bands (resulting from the dispersion of the half-prisms) proved to be particularly revealing. Here too separate spectacles were needed to compensate for aftereffects accompanying upward vision and for those accompanying
downward vision. It so happened that the subject once mistakenly picked a pair of spectacles which were too weak to compensate for upward vision and somewhat too powerful to compensate for downward vision. He noticed that, depending on the position of his head, the same vertical edge turned yellowish at one time, bluish at another. The striking thing about this is that, objectively, retinal dispersion conditions were constant, and that differences in the position of head and eyes determined the appearance of the prismatic effect in one case and its overcompensation in the other. The subjective phenomenon of colored edges, already complicated enough as it is, now turns out to be affected by eye movements. The difference was slightly below one prismatic diopter.

We also carried out a separate investigation of Punktsspringen observed without spectacles.

The subject was instructed to fix his eyes on a spot of light which appeared on a screen in a darkened room and moved up and down with moderate speed. Thus the range of his eye movements was limited. Toward the middle of its path, the spot briefly disappeared, so that the subject was unable to tell whether it continued in the same direction or not (Fig. 4). The subject simply had to rely on his subjective impression. If he thought that the spot had wandered off its course, he asked the experimenter to reset its course until it appeared to move in a straight line again. The discrepancy between the subject’s judgment of the path and its objective straightness provided the measure of the degree of subjective lateral deviation.

Special care had to be taken to insure that the subject kept his head still and that the interrupted portion of the spot’s pathway coincided with the dividing line of the formerly used half-prism spectacles.

Following are the results obtained when the subject wore the spectacles. Where the experimental subject confidently reported an absolutely straight path in all cases when it really was straight, control subjects who also wore the spectacles needed the lower half of the course to be displaced by as much as 15 cm. to the right before the two parts of the path appeared subjectively as a continuous line. At the distance away from the spot of light that these subjects were, 15 cm. are exactly equivalent to the amount of deflection by the prism half of the spectacles.

When the subject did not wear the spectacles, the reverse was observed: now the experimental subject needed the lower half of the spot’s path to be displaced by about 5 cm. to the left in order for the whole path to appear as one continuous straight line, while the control subjects needed no such displacement to achieve subjective continuity.9

Particularly striking was the finding that as soon as the experimental subject moved his head, his judgments of straightness and threshold for perceiving lateral displacement became comparable to the control subjects’. The region of lateral displacement then moved upwards or downwards, and came to a stop precisely where the dividing line would be if the half-prism spectacles had been worn. This accounts for the illusory dividing line reported by the experimental subject.

When the subject was asked to move his eyes up and down in the dark, direct observation of his eye movements revealed jerky lateral motions in the middle range of the movements. When he was asked to accelerate the up-and-down movements, his eyes tended to move diagonally rather than vertically. At no time, how-

9 The question arises why the displacement amounted to only 5 cm. in this case, when the subject was able to compensate for a 15 cm. deviation while wearing spectacles. We have made this observation on several occasions. One way to explain the difference is on the basis of different conditions prevailing in situations where spectacles are worn and where they are not worn. Thus, in the latter, there is no pressure against the nose and ears, no dividing line in the middle of the field, etc. The absence of spectacles therefore may inhibit the appearance of the after-effects. This is suggested by the observation that the wearing of "auxiliary" spectacles, of the kind described earlier, definitely enhances the appearance of after-effects.
ever, was the subject aware of any of this; he always thought that his eyes moved vertically and without sudden deflections.

These results added a good deal to our understanding of the phenomenon. They show what happens when, toward the end of a long experiment, certain habitual eye-movement patterns are no longer associated with the appropriate kinesthetic sensations. Obviously, a subject whose subjective impression is to follow an object with a continuous motion of his eyes will also experience the motion of the object as continuous, even though objectively the movement of the eyes as well as that of the object is discontinuous.

A similar explanation may be offered to account for the adaptation to apparent lateral movements which first appeared whenever the subject approached or drew away from an object. In order to keep the object in focus, the subject learned to move his eyes now to one side, now to the other. In other words, shifting the gaze sideways became a habit which, in that situation, continued automatically even after the spectacles were removed. However, since by kinesthetic adaptation the previously existing coordination of kinesthetic and visual sensations was changed, the subject was no longer aware of the lateral apparent movement as described. Without the spectacles, however, as the result of this habit, a fixation point will move to the right or to the left whenever the subject approaches it or draws away from it (against the formerly used eye motions).

What I have just said does not apply to those instances where the subject reports lateral displacements only in parts of the visual field, as, for example, when riding a bicycle without wearing any spec-

10 This too seems to be a consequence of adaptation, but one which is exclusively kinesthetic. Apparently, automatic movements give rise to increasingly fainter sensations of movement only in those "situations" in which they become automatized in the first place, through repeated practice.

One must be careful, however, not to carry this analysis too far. Perhaps, to be safe, we should express it this way: certain kinesthetic events which, so far, have always coincided with certain pictorial changes on the retina, no longer produce apparent movements at the end of the experiment. We should also add that these "exceptions" apply only to certain total situations (approaching and drawing away from fixation points with the head and body).

These words of caution are particularly important in the following two cases: (1) where certain eye movements (for example, when half-prism spectacles are worn) give rise to changes in spatial values in only half the retina; and (2), which is the reverse of (1), where the absence of eye-movement sensations has a differential effect on standards of optical movement in various retinal areas (see the observations made while the subject was riding a bicycle).

11 Studies on perception of movement are very revealing. I am referring to the odd manner in which people and animals seem to move when seen inverted. Krüger, whom I have already mentioned (p. 30), describes this most impressively.

"I was shocked when I saw what people walking in the inverted picture looked like. Two types of bodily movement stood out: one vertical, and one horizontal. These were not only more prominent than in normal conditions of vision, they were also more pronounced than movements to the sides. Particularly striking were the movements of the legs: with every step, the legs were thrown upwards with enormous vehemence, as if they were protheses attached to the person with elastic bands and not real legs. The effect was similar to that created by mechani-

E X P E R I M E N T S W I T H H A L F - P R I S M S

tacles. Those are special cases involving intricate metakinetie after-
images, a variety of which can be present in the same retinal areas.

(The phenomenon of subjectively colored edges falls into this cate-
gory.) After all, one can hardly expect a subject to move his eyes...

The experience seems analogous with a slow-motion picture. Colors seen in the inverted picture appear to be more varied and fresher: clothes look like new, mailboxes on the street strike the eye, and brightness contrasts are greatly enhanced.

Krüger is of the opinion that all this also occurs in normal conditions of vision, or we are not as aware of it. But is it not a purely "visual" element also involved here? Normally, we "see" all these up-and-down movements in much less accentuated form, even when we pay special attention to them. What normally is little more than the mild acceleration of an object just beginning to fall looks like the acceleration of a rocket shooting up when the picture is inverted. The appearance of one's own face seen through reversing spectacles is a particularly amusing example of a visual aberration induced by unusual conditions. The slightest nasal or ocular asymmetry, hardly visible when viewed in an ordinary mirror, immediately stands out as a prominent feature. Familiar faces, seen in these conditions, give rise to similar experiences.

Up to a point, these phenomena are instances of altered "vision," that is, of vision altered within the context of special "situations." It would behoove us, therefore, to see whether the assumptions necessary for the production of situational aftereffects were met in the above-mentioned cases. That much more is involved in these situations than the position of the eyes (as in the half-prism situation) goes without saying. Nevertheless, the reader will have noted that all the movements just now described (approaching passers-by, trotting horses, falling objects) are in fact characteristic of only certain specific situations. Within the context of these "situations," adaptation could certainly account for a gradual decrease in and deceleration of movement sensations. In the inverted picture, however, those very metakinetie aftereffects which normally decrease subjective impressions of movement do exactly the opposite: they increase them. Therefore, the inverted picture gives rise not only to "unaccustomed" impressions but also to altered visual experiences of movement.

The same is true of the rest of the observations. I think that, besides con-
dency, there is a second area to which the conditioning of aftereffects is relevant. All stimuli are, in many ways, "characteristic" of only specific situations.
in such a way that movements are experienced in only half of the visual field.

B. QUANTITATIVE RESULTS

The preceding section on subjects' day-by-day observations forms only part of our presentation. It will be recalled that we also used more objective procedures in our investigations. With the aid of various devices especially constructed for this purpose, we investigated the perception of straight lines (Fig. 5) and of right angles (Fig. 6), the relationship between the line of vision and direction of reaching (Fig. 7), the extent to which fixation points became subjectively displaced when the subject drew rapidly near to or away from them (Fig. 8), and many other phenomena. Only the most important results of this part of the investigation are presented in Figs. 5-8.

The passage of time is indicated along the abscissa: the first fifty days, during which the spectacles were worn, are plotted first; then come the next forty days, when no spectacles were worn. Magnitudes of "prismatic sensations" are indicated along the positive side of the ordinate, while magnitudes of aftereffects during normal vision are indicated along the negative side of the ordinate.

All results were obtained by the method of subjective comparisons: the subject was required to make adjustments on the apparatus, or have adjustments made, until the desired subjective impression (for example, a "straight" line, or a "right" angle) was obtained. The discrepancy between the subject's setting and the objective value of straightness or angularity was then measured and expressed in unit form. These are the units on the ordinates. The curves are all the daily entries combined. Thus, the greater the deviation of the curve from the zero point of the ordinate, the greater the perceptual distortions induced either by the prism (positive side of the ordinate) or later and in opposite directions by the aftereffects (negative side of the ordinate).

Note that each of the four graphs contains several curves. The reason for this is that each study was undertaken in various conditions of head and eye position. The thick solid line represents the combined values which were obtained while the subject was looking up without spectacles. This line starts out
close to the abscissa, but rapidly curves away from it. (The effect is less pronounced in Figs. 5 and 6 because aftereffects caused by a previous study lingered on.) It shows the presence of aftereffects, that is, visual disturbances which occur without the spectacles and which are the exact opposite of those induced by the prisms.

The dotted line represents those combined values which were obtained while the subject was looking down. (In this case the subject never looked through a prism, even when he was wearing the spectacles.)

If we now compare the thin solid curve with the dotted curve, we see that they pretty much coincide at first but subsequently separate. This can be interpreted as follows. At first, the aftereffects are "localized"; this means that when certain retinal areas have been stimulated, they react differently from the way they did before —regardless of the position of the eyes (in relation to the head). The separation of the two curves indicates that the position of the eyes later did have a facilitating or inhibiting effect. As the shaded area shows, spatial vision becomes increasingly differentiated and the "situational" aftereffects gain increasingly in strength, all in accordance with head and eye position. Details of the procedure follow.

Fig. 5: A number of variously curved lines etched into the coating of a photographic plate were projected on a screen. The lines appeared luminous and were 150 cm. long. The following radii of curvature were used: $r = 00, = 60 m., = 40 m., = 30, = 20, = 16 m., = 13, = 11, = 9$, and so on down as far as 2.40 m. The subject was seated 150 cm. away from the screen. The lines were not exposed all at once, but one at a time, by means of an adjustable opening in front of the photographic plate. The plate could be rotated, so that the lines appeared curved in the opposite direction. Each time a line was exposed, the subject rated it as "markedly curved," "slightly curved," "very slightly curved," or "straight." This procedure made it possible to determine which of the objectively curved lines appeared "straight" to the subject. The size of the error is indicated on the graph.

Fig. 6: Perceptual distortions were studied by means of a frame with four movable sides which the subject adjusted until they subjectively formed a "square." Errors in the judgment of right angles were exactly measured by means of a protractor. The sides of the frame were each 10 cm. long, and the subject's head was 25 cm. away from the apparatus. Two different supports were used to stabilize the subject's head, one for looking up (head down position) and one for looking down (head up position).

Fig. 7: This part of the investigation was carried out in a dark room. The subject was instructed to turn a pointer, which he could not see directly, toward a small, dimly lit bulb whenever it appeared in front of him. Errors in setting the direction were measured in degrees. Again, the head was stabilized for each of the two positions. The initial deviation from zero, noted on the graph, may be attributed to the onset of adaptation (in the realm of visual-motor coordination).

Fig. 8: The selection of a suitable apparatus presented a particularly difficult problem here. At first, I had the idea of compensating for the apparent movements of the fixation point by actually moving it in the opposite direction. However, a better solution presented itself. In approaching a fixation point, one does not necessarily have to move one's head straight up; one can achieve the same result by movements of the head running somewhat obliquely to the fixation point. In normal conditions of vision, this forces the eyes to move to one side when one approaches the fixation point and to the other side when one withdraws from it. The same occurs when the prisms are worn. It should be possible, therefore, to compensate for these lateral eye movements by altering the movements of the head. This was accomplished by means of an adjustable guide rail whose position could be measured at all times. The magnitude of apparent-movement aftereffects could now be determined by measuring that position of the rail which marked the cessation of the movement illusion. The method was applicable to those effects and aftereffects which occurred with or without spectacles as well as to those which occurred while the subject was looking up or down. The maximum distance of the subject from the fixation point was approximately one meter; the closest the subject came to the fixation point was 10 cm. The study was carried out monocularly.

In addition to the studies which have been described above, we undertook measurements of the median of tilt, of contraction and
expansion, of subjective standards of movement, and to some extent of subjective coloration of edges. Since all these phenomena yielded essentially identical curves, it will not be necessary to present these results in any detail.

The point of all these studies was to demonstrate objectively the evidence of a situational aftereffect, that is, the "conditioning" of sensory experiences which, in turn, may be considered to be a special trace of the half-prism training period in the sensorium. What we have observed is a characteristic differentiation of vision. This was found to begin after an initial period of three or four days, a period corresponding to the earlier short-term studies on which existing theories of sensation are based. What happens, apparently, is that the aftereffects of earlier stimuli become bound up with the situations which regularly gave rise to them. Each retinal area

12 The method was as follows: the subject was seated in front of two rotating drums, looking squarely at a fixation point situated between them. The drums were thus not directly in his line of vision. One of the drums turned with a constant speed; the speed of the other drum could be regulated by the subject. A fence-like pattern on the drums helped to indicate the speed of rotation. All the subject had to do was to match the speed of the second drum with that of the standard. He did this by adjusting the speed of the second drum until the two speeds subjectively appeared equal.

Normally, this kind of matching can be done with a high degree of accuracy. However, when prisms are worn, the subject characteristically misjudges the two speeds: when the two drums seem to rotate at subjectively equal speeds, the left drum usually turns out to be rotating faster than the right one. This error occurs because the prisms cause movements in the left portion of the visual field (area of contraction) to appear slowed down and movements in the right portion of the field appear speeded up. In the course of time, this error decreases, only to give way to opposite errors when the spectacles are removed.

The same results are obtained when the subject alternately looks at one or the other drum (keeping his head still). This indicates that subjective standards of movements, just like all other spatial standards, have become differentiated depending on the direction of vision. Direct observations made after the spectacles have been removed confirm this. For example, when the subject takes a walk, the houses on the left side of the street seem to recede at a quicker rate than those on the right side. Thus, looking to the left gives the impression that one is running, while looking to the right leaves one with the feeling that one is stuck to the ground. The illusion is strongest when seen indirectly; however, it does persist on both sides even when seen directly.

13 Since the dispersion aftereffect is subject to the laws of chromatic aberration, it is possible to "compensate" for it by artificially dispersing the colors, using, for instance, a projection apparatus. All that needs to be done is to place a prism in front of the lens of a projector. By rotating the base of the prism, colors of any strength can be made to appear along the edges of the vertical contours. The position of the base of the prism can then be used as an index of the magnitude of the aftereffect.

seems to accumulate detailed traces of its past, and not just average values (as during the first few hours and days of experimentation).

It is also noteworthy that once the spectacles have been removed the peculiarity of being "conditioned" persists much longer than the actual degree of visual disturbance. Apparently, the longer something takes to develop, the longer it will endure after the experiment has ended.

C. THE FADEING OF AFTEREFFECTS

The experimental conditions affected not only vision but also overt behavior. The different eye-movement habits induced by these conditions have already been described. I now wish to add the following material taken from the subject's daily reports.

Immediately after removal of the spectacles, the subject wrote as follows: "My eyes have acquired a peculiar characteristic: they absolutely refuse to look straight ahead, that is, in the direction where double images used to appear. As soon as an object appears in this general area, I automatically raise or lower my head, so that I find myself looking at it in a most unnatural position. My eyes behave most awkwardly, I must confess. . . ."

These as well as other behavioral peculiarities, such as errors inrehension, soon disappear, however. In the evening of the second day after the spectacles were removed, the subject writes: "While immediately after I rose this morning the world still looked as chaotic as it did right after I had taken off the spectacles, a marked improvement has now taken place. The apparent movements I observed when I looked up while walking, and which encompassed the entire visual field, have subsided considerably. . . ."

"If I stoop down abruptly, the ground under me still has a tendency to veer to the right; but only if I look up at it. If I keep my head up and look down at it, it is more likely to veer to the left, in the way of contrast."

"Distortions, curvatures, and colored edges remain unchanged. Also still present are apparent movements when I ride a bicycle; they are the same as those which I observed while walking. If I keep looking at the road for a while, the lateral apparent move-
ments decrease noticeably. If, on the other hand, I keep looking
down for some time while bicycling and then suddenly look up,
they immediately reappear in magnified form. The effect is the same
if I close my eyes for a few seconds (while bicycling).

"At dusk I occasionally had the illusion of a peculiarly heavy
dividing line crossing my field of vision. It did not, however, break
up any objects. It looked more like a swarm of mosquitoes, or some
dirty spot, in my visual field, which kept moving along with my
head."

Eleventh day after removal of the spectacles: "The past ten days
have shown a marked decrease in prismatic aftereffects. Curvatures
have all but disappeared. There is still a small remnant of the earlier
total aftereffect, but it occurs only when I look up. . . . However,
looking in different directions still makes a difference in the shape
of the curvatures. . . .

"Distortions of right angles have also faded considerably. There
hardly remains an aftereffect to speak of, except when I look up.

"Tilting of the ground still occurs, but in a most unique way. As
long as the ground is objectively horizontal, it will appear 'level'
no matter how I look at it; but if I abruptly change the position
of my head and eyes, the ground will appear clearly tilted for a
moment. This shows that while the aftereffect as a whole is now
practically nonexistent, differences in tilt still depend, to some
extent, on eye movements. Thus latent aftereffects can still be
mobilized when the eye changes from one position (downward)
to another (upward).

"Of all the aftereffects, those involving the contraction and
expansion of objects as a function of eye movements to the right
or to the left are the most tenacious. Although after removal of the
spectacles, they occurred only during upward vision (eyes moving
left-right), they have nonetheless retained almost their entire origin-
ally vividness. The aftereffect is totally absent when I look down,
even when I do so through a medium as sensitive as my own spec-
tacles, which normally are capable of picking up all sorts of sub-
threshold aftereffects."

EXPERIMENTS WITH HALF-PRISMS

"The visual median, which formerly became divided as a result
of changes in eye position, is now clearly uniform. I find that I
can safely rely on my visual impressions wherever I am.

"The dispersion aftereffect hardly ever occurs now; never when
I look down. When it does appear, it does so only in places where
the illumination is poor. . . .

"Discontinuities are totally absent. And when I look up and
down, edges hardly seem to tilt or move back and forth any more."

Fortieth day after removal of the spectacles: "I find it difficult to
establish a definite cut-off point marking the cessation of aftereffects
resulting from the continuous wearing of half-prism spectacles.
Even in a single day there are fluctuations in the occurrence of these
aftereffects. For example, they tend to be most pronounced in the
morning, right after rising. I also find that they are more pronounced
on certain days than on others. Of all the aftereffects, those of
apparent movements faded away most quickly. Errors in directional
vision were also relatively short-lived. On the other hand, distor-
tions of shapes lasted longer, and contraction and expansion after-
effects are still noticeable. . . ."

In general, those residuals which still remained were so negligible
that it was impossible to judge whether changes in the direction of
vision made them stronger or weaker. But the dispersion aftereffect
continued to be tenacious. About this, the subject writes:

"When I am outside, in bright daylight, all edges look normal.
Indoors, however, where there are fewer brightness contrasts, faint
remnants are still visible. . . . Changes in head and eye position
also still make a difference, but it is so minute that it borders on
the imaginary."

The dispersion aftereffect was most clearly present when the
subject looked at a picture in which a dark contour in the fore-
ground was set off against a light contour in the background. (I
aftereffects which have been observed by subjects wearing ordinary spectacles
after having been exposed to prismatic stimulation. Ordinarily, for example, dis-
tortions tend to increase equally on all sides. In this case, however, they appear
different on certain sides, while on other sides they decrease or disappear alto-
gther. This happens because the prismatic aftereffects interact with the lens-
induced effects: they intensify those distortions which are opposed to them and
suppress those which are similar to them and to which the subject has become
adapted. Thus when ordinary spectacles are worn, residual aftereffects of the
previous prism experiment manifest themselves in an "unsymmetrical" distribution
distortions."
would like to suggest to any farsighted reader who wears spectacles that he look at Plate 17 (p. 50) and simultaneously turn his head slightly to the right. He will then have the same experience that I had without spectacles: the telephone pole will have a slightly yellowish left border and a bluish right border.

EXPERIMENTS WITH TWO-TONED SPECTACLES

A. Design and Statement of the Problem

The studies which have been described so far, that is, those involving the use of fully prismatic and half-prism spectacles, have all shown not only that the same stimulus can, in the course of time, elicit different retinal reactions, but also that the retinal reactions can vary systematically according to the total situation within which the stimulus occurred. In other words, the process of adaptation became bound up with certain "conditions." With regard to spatial vision, it was the position of head and eyes which occasioned this differentiation of the adaptive process. In the case of color vision (dispersion), it was the direction of brightness contrasts which subsequently gave rise to the appearance of alternating complementary afterimages. Note, however, that in studies with half-prism spectacles it was not only the distribution of brightness contrasts but also the position of the eyes which determined the phenomenon of colored edges.

Would it be possible to demonstrate experimentally a relationship alone between eye position and certain disturbances in color perception? It was this question which prompted us to devise the two-toned spectacles. The idea was simply to arrange the colored sections of the spectacles in such a way that certain colors could be perceived only by turning the head and/or eyes in a certain direction.

In this experiment (Exp. 6, p. 45), each eyepiece consisted of two halves, a blue left half and a yellow right half, separated from each other by a vertical dividing line which cut down the whole
eyepiece. Thus, whenever the eye was turned to the left (or the head relative to the eye was turned to the right), the resulting retinal images were blue; whenever the eye was turned to the right (or the head to the left), the retinal images were yellow. We did not consider it important that the colors be optically pure. We were interested only in selecting colors which would give rise to complementary sensations. This means that looking through one half of the visual field was expected eventually to evoke negative afterimages whose colors would correspond exactly to those of the other half of the visual field. The entire arrangement therefore was one which would guarantee that mutually antagonistic stimulation would impinge on the same retinal area. It should be added that the dividing lines were such that they coincided binocularly at a distance of two to three meters away from the fixation point. The spectacles were protected from peripheral light rays by means of flaps attached to the sides.

After putting on the spectacles, the subject was required to take daily notes on his experiences and observations. In addition, we also carried out objective studies of color vision, again using the matching procedure. All investigations were done in two "conditions": an eyes-left and an eyes-right condition.

Specifically, the subject was required to select from among a graduated series of colors the one which appeared "gray" to him. It is a commonly known fact that when the eyes are under the influence of aftereffects resulting from a disturbance in color perception, a gray object will no longer appear gray but will take on a hue opposite to that of the previous color. Or a colored stimulus may be perceived as "gray." The size of the error thus yields a measure of the extent to which color perception has been disrupted. For example: suppose the subject has been subjected to a prolonged, intense blue stimulus; after cessation of this stimulus, he will perceive light blue as "gray," or gray as "yellow."

Keeping this principle in mind, we decided on "Scheffler's color selector" as the most appropriate instrument. The subject sits in front of a color wheel with a bell button in his hand. Pressing the button causes the wheel gradually to turn blue, while releasing the button causes the wheel gradually to turn yellow. The subject is instructed to keep the wheel from changing to either color; he is to press or release the button as soon as he sees the wheel turn either yellow or blue, respectively. The actual changes in the color of the wheel are automatically recorded. The subject's settings yield a curve oscillating between "just noticeable blue" and "just noticeable yellow," with the middle region corresponding to subjective "gray." The apparatus is also provided with a marker which indicates when the wheel is objectively gray (in accordance with the laws of color mixture). This device makes it possible to evaluate the extent to which the subject's judgments of "gray" deviate from true gray. We expected no deviations to begin with. What about later on?

Separate investigations were carried out for the eyes-left and eyes-right conditions. When the subject wore the spectacles, we found that he had to select heavily saturated colors in order to experience grayness: when he was looking through the blue portion of the spectacles he had to select a deep yellow, and vice versa; the color of the wheel and that of the spectacles neutralized each other and produced sensations of colorlessness. Our instrument thus was a neat device for measuring the progressive adaptation of the eyes to the colored spectacles. If, in the course of the study, another adjustment of the wheel showing less saturated colors were to prove sufficient to compensate for the colors of the spectacles, then we would have evidence of adaptation. If, on the other hand, the adjusting of subjective gray without spectacles were to vary according to eye movements, then we would have evidence for situationally conditioned disturbances in color vision with the magnitude of the variation being an index of the size of the situational aftereffect.

Like all the other experiments, this one was undertaken in order to obtain a clear and simple understanding of the nature of the situational aftereffect. This time, however, it was prolonged and

---

1 A description of this apparatus can be found in the Austrian journal, Die Pyramide, 1951, No. 4. Basically, it is a color mixer by means of which all colors and their intermediate hues can be obtained. Its advantage lies in the fact that it is completely automatic: the subject has only to push a button in order to obtain the required colors and intermediate hues (at the desired rate of rotation).

2 Perhaps even more important is the question whether the subject's initial judgments of "gray" will correspond with his later judgments. A certain amount of disparity between true gray and subjective gray always exists. Thus, in the daytime, light blue is often taken for gray, while in the evening yellow tends to be judged as gray. This variability is due to differences in illumination: during the day we normally have natural light, at night artificial light. These differences must affect our color sensitivity. In this type of experiment, therefore, time of day must always be held constant.
frequent complementary color stimuli which impinged on the same retinal area. As before, the "conditions" in which those stimuli appeared were determined by changes in the position of the eyes in relation to the spectacles. We had to make sure, of course, that no single position of the eyes was given priority. We now asked ourselves: what will be the results of an experiment carried out in the above fashion over a period of weeks and months? Will retinal sensitivity change in favor of blue or yellow?

Once again, the immediate temptation is to predict no results whatever. After all, has not every simple experiment on afterimages shown that yellow and blue are complementary colors which, according to Hering, are based on antagonistic physiological processes (dissimilation-assimilation)? And if this is so, why assume that one of these processes should gain the upper hand, even in the course of prolonged experimentation? Both certainly cannot prevail, for yellow and blue are mutually exclusive. The argument is the same as the one which was raised earlier in connection with spatial vision; it was even thought then that our hypothesis conflicted with the laws of logic, for how was it possible to predict opposite aftereffects to appear simultaneously?

Let us now see how this paradox can be resolved in the case of color vision.

B. Procedure and Results

At first, the results were negative: the aftereffects of the yellow and blue stimuli neutralized each other, just as would be predicted on the basis of Hering's theory. The subject reported as follows:

First day: "It is the evening of the first day. The spectacles have been very annoying and a constant source of distraction. Again and again I have had to ask myself why the windows on the left side of the auditorium pictured a thunderstorm while those on the right side made everything appear bathed in bright sunlight; and why my left hand looked darker than my right hand. When I lit a cigarette, I was quite shocked to find that the smoke coming from it looked like a black cloud when present in the left half and like some white mist when seen in the right half of the visual field. Strange how one and the same 'thing' can appear colored this way at one time, that way at another time. . . ."

Second day: "... close to the dividing line, the colors appear to be particularly intense; near the periphery, however, they seem much fainter. . . . When the eyes remain fixed, even for a short time, all color contrasts rapidly disappear; even the dividing line vanishes after a while. However, as soon as the eyes move just a little bit, I am once more quite conscious of the differences in color between the two halves of the spectacles."

The observation that the peripheral areas of the retina were the first to be affected by prolonged stimulation and to show changes in color sensitivity is understandable in view of the fact that it was primarily the fovea which was affected by the "symmetrical" alternation of stimuli, while the peripheral areas were only rarely affected by the opposite stimulation. When the fovea was stimulated, no changes in color sensitivity were noted at first, except a quicker adaptation when the eyes happened to remain fixed to the left or to the right for a few seconds at a time.

Sixth day: "... I have begun to notice localized changes in color sensitivity depending on which half of my retina is stimulated. I am sitting in front of a window covered on both sides by white curtains. If I now lift off my spectacles for a moment and look straight ahead, the right curtain, indirectly seen at an angle, seems to be moonlight colored, while the left curtain appears to be lemon colored. However, if I look straight at either side, the phenomenon disappears."

The subject had similar experiences in the morning, immediately after rising, before he even put on the spectacles. This indicates that what the subject had observed was an "aftereffect," and not a mere afterimage; for if it had been the latter, it would have disappeared soon after cessation of the stimulus. In all other respects, however, this aftereffect, that is, the "localized change in sensitivity" in the periphery of the retina, was exactly like Hering's negative afterimage.

A clearly situational aftereffect was not noted until the tenth day of experimentation; even then, however, it first appeared in a strangely disguised form. Basically it was still an afterimage of the Hering type; but certain situations regularly "facilitated" or "inhibited" it in some mysterious fashion.

Tenth day: "Earlier I reported that the effects of moving the eyes
in relation to the spectacles are not the same as the effects of moving the spectacles in relation to the eyes. This may sound like quibbling, but the fact remains that there is a great difference between these two types of movement. The proof lies in the observation that only the former causes the two colors of the spectacles to appear faint, while the latter causes the colors to remain as bright as they were the first day. This difference becomes increasingly noticeable, and gives one food for thought.

"Why should it be that colors look bright when I move my head (and thus the spectacles) in relation to my (fixating) eyes, and faint when I move my eyes in relation to my spectacles? As far as the retina is concerned, is not the stimulus the same in each case: a change in coloration from yellow to blue and back to yellow? Furthermore, is it not the same change in the relative position of eyes and head which in each case causes the stimulus to change?

"It will be necessary to examine the stimulus situation more carefully if we are to arrive at an understanding of this peculiar variation in color sensitivity despite constant optical conditions. There are two ways in which the relative position of head and eyes can be altered: either the eyes move while the head remains still, or the head moves while the eyes remain fixating. If, in the past, the subject consistently preferred one to the other mode, then we may well expect that his adaptation to the spectacles will proceed more rapidly in the preferred mode than in the nonpreferred one..."

The assumption proved to be correct. The subject did in fact move his eyes in relation to the spectacles (while reading and writing for many hours every day) much more often than he moved his head in relation to his eyes. We were obviously dealing here with a special situation characterized by a type of eye movement especially suitable for reading or writing activities. This insight gave us our first major clue to an understanding of the alternating adaptation to blue (looking to the left) and to yellow (looking to the right). Similar findings were obtained when the subject wore no spectacles, as indicated below.

Fifteenth day: When the subject lifted off his spectacles for a moment, he saw "a yellowish field to the left and a bluish field to the right of a vertical dividing line. The illusion was most striking when I looked straight ahead, but I could also notice it even when I was looking to either side.

"If I move my eyes, the dividing line remains where it was, and I am looking only into the yellow or the blue illusory field.... Without my wearing any spectacles, without even having put them on before, the left rim of the washbowl looks yellow and the right rim blue in the morning, and they remain that way no matter which way I look at them (that is, they do not move with the eyes). As soon as I move my head, however, the entire illusion is gone...."

From this observation we may conclude that if the subject fixates an object for some time without wearing spectacles, then the region to the left of the object turns yellow and the region to the right of it blue. This takes place even when the object is seen at an angle, although not as noticeably. If the eyes now move back and forth in relation to the head, a line appears in the median plane of the head which separates the yellow from the blue region. Movements of the head, on the other hand, make the illusion disappear.

Twenty-first day: "I am more and more impressed by the extent to which objects to my left are tinged yellow and to my right blue whenever I remove my spectacles for a short time. The illusion is there whether I move my eyes or not. In other words, I am able to 'look into' my own afterimages...."

It was at about this stage of the experiment that any relative position of head and eyes began to have an effect:

Twenty-sixth day: "My earlier observations are consistently confirmed in the most varied conditions. With the spectacles off, my eyes regularly perceive yellow and red coloring to my left and blue coloring to my right, depending on their position in relation to my head."

Thirty-first day: "Even though a great variety of yellow and blue stimuli are transmitted by my spectacles and keep impinging on my fovea, I no longer experience the corresponding color sensations. This complex adaptive achievement of the organism, however, is immediately undone as soon as I take the spectacles off. Then everything to my left is tinged yellow and to my right blue, and always in those situations which originally gave rise to opposite color experiences. Obviously I cannot blame my spectacles for these peculiar impressions, since I am not wearing them."

Forty-sixth day: "If I look first at the blue part and then at the
yellow part of the visual field, the latter does not increase in intensity no matter how long I have looked at the former. The same holds true when I first look at the yellow and then at the blue part of the field.

"The situational aftereffect has gained in intensity. Depending on my line of vision, paper looks either dirty white or pure white; furthermore, it turns slightly yellow-red when seen on the left side and blue when seen on the right.

"The aftereffect is so pervasive now that it can be directly observed at any time. Recently I had a strange experience. While I was looking at a picture without the spectacles, I happened to shift my weight from my right leg to my left leg. To my great surprise, a certain white area in the picture suddenly turned blue; as soon as I shifted my position again and put my weight on the right leg, the same white area turned yellowish. What possible bearing could the position of my body have on color perception? Simply this: when I changed the position of my body I also changed that of my head; thus, when I shifted my weight to the left, my line of vision was displaced to the right, and the resulting change in the position of the eyes gave rise to the blue afterimage."

Sixtieth (last) day: For two whole months now, the subject has been limited to two color sensations. He has had only two choices: he could experience at will either blue or yellow hues. How did his visual apparatus cope with this stimulus situation?

No simple answer can be given to this question. At no time were all parts of the retina equally affected by these stimuli. The fovea and the areas immediately adjacent to it were subjected to the most frequent variations in stimulation, whereas the areas which are more peripherally located tended to be subjected to a more uniform kind of stimulation: those on the right side by blue, those on the left side by yellow stimulation. This explains why, now that we have reached the final stage of the experiment, it is on the periphery that the aftereffects are most intense. But what about those retinal areas which have been subjected to a variety of color stimuli? How do they react now? The following excerpt provides an indirect answer to this question.

"If I take off the spectacles, turn them around, and put them on inside out, a most surprising thing happens. Whereas before all colors seemed faint and watery, they now appear deeply saturated."

One may assume that the fovea has acquired a "yellow tendency" as a result of eye position to the left, and a "blue tendency" as a result of eye position to the right. The former acts to reduce sensations of blue, the latter to reduce sensations of yellow. Hence the intensification of color experiences when the spectacles are worn inside out.

Continuing his description of his visual experiences at that time, the subject writes: "I find it easier to describe my present visual experiences than those which I had a month ago. At that time, it seemed as if my eyes tended to 'drag' afterimages along with them whenever they moved from one color field to the other. This always caused the complementary color to appear in intensified form. This no longer happens. While it is true that the two parts of the visual field are not entirely without color, what little color does remain does not vary any more." (Simultaneous and successive contrasts no longer enter the picture.)

"Expectancy" proved to be another factor involved in the process of adaptation to the spectacles.

"The distracting effect which the spectacles had in the beginning is completely gone now. Now I actually feel comforted by the sight of a table which looks blue on one side and yellow on the other. I am so used to it that I would get upset if it were otherwise. . . ."

Expectancies such as this one had already begun to develop during the first few days of the experiment. It is quite evident that they were adaptive in character from the very start, since they kept the subject from being distracted when, for example, something which had just looked blue suddenly turned yellow. It was after these expectancies had been built up that the sensations themselves began to change. At first, these changes were contingent upon avoidance of all but the slightest eye movements; when this condition was not met, the color sensations immediately regained their former intensity. Only gradually, and after some time, did foveal sensitivity come under the influence of head movements (with the eyes remaining fixed).

On top of all this, the gradually emerging situational aftereffect also had to outlast the more short-lived afterimages of Hering type. These always remained as residues of previous moments of stimulation and were "carried along," so to speak, by the eye
movements. By suppressing or enhancing these afterimages, depending on the situation, the situational aftereffect was able to prevail in the end. Thus, in a sense, the aftereffect began to exert its influence backstage, concealing its presence behind familiar and expected phenomena, and did not make its début until about the fifteenth day.

The results of the investigations with the Scheffler apparatus confirmed that adaptation had progressed considerably. A blue of one half its initial intensity on the color wheel was sufficient to compensate for the yellow of the spectacles, and the blue of the spectacles was judged to be completely equal to gray—in other words, the subject no longer perceived it as color.

Investigations carried out without spectacles showed that there were two different kinds of foveal color sensitivity (i.e., two different grays). The same subjective gray was matched with two different colors: objective blue when the subject was looking to the left, and objective yellow when the subject was looking to the right. It is not surprising therefore that both the blue and the yellow of the spectacles looked faded. For each of these two colors, the subject now had a special “standard.” This became operative whenever the particular situation appropriate to it arose.

Following permanent removal of the spectacles, the situational aftereffect was occasionally noted to have an intensity never observed when the subject had been without spectacles for only short periods of time. He writes:

“I was looking at a book lying open in the sun; its blue-violet cover had white strips of paper attached to both sides of it. Those on the left side turned such a deep yellow that they looked like old newspapers; those on my right, on the other hand, remained pure white. The more light-adapted my eyes became, the more pronounced was the effect. In fact, the aftereffect was so strong that even the dividing line was clearly visible (without spectacles), and this in spite of the bright illumination. When I moved my head the dividing line moved too. . . .” (This did not in the least prevent the eyes from continuing to fixate the yellow and bluish-white looking strips.)

“The grass and flowers on one side of the road were entirely different colors from those on the other side. On the left side, the colors were richer, and the green was tinged with a warm yellow.

On the right side, the green was a more bluish shade. The phenomenon was most clearly visible when I looked straight ahead (that is, when it was seen indirectly). However, I was also able to observe it when I kept looking alternately to my left and to my right and tried to make successive (foveal) comparisons. . . .

“This morning I had a real scare. I was looking to some ironing when I suddenly noticed puffs of blue smoke rising from the fabric. My immediate thought was: the iron had gotten overheated and burned the cloth. However, the disquieting apparition vanished as soon as I turned my head to the right, and the steam once more looked the way it usually does. . . .

“Whenever I open up a book, I am amazed to find that the left page looks yellow, and that it looks white with a bluish tinge as soon as I turn it over to the right. As long as I only move my eyes, these afterimages remain perfectly stable; but when I move my head the color fields move with me. . . .

“When I take a walk, I am always conscious of a peculiar glare on my left, as if someone carrying a lighted candle were accompanying me; on my right, nothing of this kind occurs.”

Twentieth day after removal of spectacles: “I have become totally immune to the distracting influence of all these novel impressions. I can now work for hours on end without being the least bit inconvenienced by this great variety of discolorations. However, I am still aware that they are there. If I happen to move my head while I am reading, for example, a yellowish mist seems to descend on the printed page, only to disappear as soon as I turn my head to the other side . . . .”

Only after a whole month of vision without spectacles did the above sensory disturbances diminish to subthreshold intensity.
THEORETICAL CONSIDERATIONS

I now wish to keep my earlier promise to take up where we left off in the introductory chapter and to consider the implications of the experimental results in greater depth.

I shall first discuss the theoretical difficulties confronting us. Then I shall propose a possible solution of these difficulties, make some criticisms of Hering’s theory, and suggest some ways of supplementing it. I shall conclude this work by indicating ways in which the results may be applied to other fields of interest.

A. THE THEORETICAL PROBLEM

As we have seen, there are all kinds of aftereffects. Some always depend on stimulation of certain retinal areas, in Hering’s sense. Others are peculiarly autonomous: sometimes they occur, sometimes they do not, and sometimes it is only their complements that we observe; yet—as can easily be verified—we find that it is always the same stimulus which impinges on the same retinal area.

As long as we focus our attention exclusively on isolated retinal areas and their functions, these “variable” or “intermittent” sensory reactions to one and the same stimulus make no sense at all. This limited point of view gives rise to obstacles which can be surmounted only with a great deal of difficulty.

Only if we broaden our horizon and consider the total stimulus situation (which, after all, is the setting for every sensation) will we be able to discover that these fluctuations in sensory experiences and in the subjective spatial standards are not random. Only then do we find that their occurrence or nonoccurrence is governed by very specific environmental factors. To repeat: only by considering the total (including the nonoptical) stimulus situation is it possible to conceive of these varying sensory reactions to constant stimuli impinging on the same retinal area as being not random but lawful.

Even if we accept this position, however, we may still find ourselves on the wrong track. I am referring here to the common mistake of attributing a cause-and-effect relationship to events which have been found to correlate, for example, kinesthetic and color sensations.

The paradox of different afterimages arising from one retinal area, which we have mentioned so many times, is a case in point. We have repeatedly stated that opposite aftereffects are kept from “clashing” on a retinal area by “situational” factors. But this is only a descriptive, not an explanatory, statement. We are still faced with the enigma of how these situational factors succeed in altering visual experiences instantly. What needs to be concretely demonstrated is the relationship between the total situation and the individual sensation. Not until this has been done will it be possible to understand the peculiar sensory fluctuations accompanying changes in situational factors.

Gestalt psychology, which never tires of emphasizing this relationship, can never provide us with an answer to the question: “How does the contraction of a neck muscle influence retinal sensitivity to color?” To keep asserting that every reaction of an organism to a stimulus is a “total response” is not answering the question at all. On the contrary, it is misleading. As our findings have shown, a total response is not a given; it gradually evolves. Concomitant conditions, which at first have nothing to do with optical sensations, end up being “conditioned stimuli.” Since it is only in the end that the sensations “take into account” previously unrelated aspects of the environment, it obviously must have taken them some time to develop into total responses. The solution must therefore take a different form.

To put this problem in proper perspective, let us, for the sake of argument, hand over our experimental subject to a hypothetical naïve or neutral examiner, and let us do this at the very moment the subject takes off his experimental spectacles. Let us pretend that this subject has just removed yellow-blue spectacles, after having worn them for a long time, and that he is now being examined by an ophthalmologist or a psychophysicist. After examining
the subject, the examiner is forced to come to the astonishing conclusion that certain head and eye positions exert an apparently direct influence on sensations of color. Empirically, however, he knows that retinal sensitivity to color depends on the condition of the underlying sensory substances (in this case yellow and blue substances), and that these, in turn, can only be activated or modified by corresponding color stimuli. How then account for the additional variations induced by contractions of neck or eye muscles? Traditional color theory does not tell him a word about this. The same may be said about the dispersion aftereffect. How explain the fact that the different color experiences resulting from brightness contrasts vary systematically according to whether a dark shade is to the left of a light shade or to the right of it?

Our hypothetical examiner would find himself just as confused if we now presented him with a subject who had been wearing distorting spectacles for months and had just taken them off. True, it would be easier for him to conceive of kinesthetic influences in a situation such as this one which involves spatial localization. This does not mean, however, that it would now be any easier for him to attribute optical phenomena to nonoptical variables.

Problems such as that of “absolute” or “egocentric” localization will never be solved as long as positions of the body are excluded from consideration. The exact location in space of a perceived object cannot be determined on the basis of retinal conditions alone. How could we tell whether it was seen medially or laterally? The same holds true for movements of the entire visual image. As far as the retina is concerned, the effect is the same regardless of whether it is the observer or his surroundings that move. The fact that we are able to distinguish perceptually between these two types of movement clearly indicates that nonoptical variables, for example, kinesthetic sensations while walking, influence perception.

Yet, somehow, even this answer is not entirely satisfactory. Why make this careful distinction between optical and kinesthetic sensations (belonging to two different sensory modalities and therefore not comparable) if, as in the above case, they are only going to become “fused” again in the end? In these circumstances it is easy to understand why one would feel reluctant to formulate working hypotheses and would stubbornly continue to search for optical explanations.

THEORETICAL CONSIDERATIONS

This does not mean, however, that such illusions as tilted visual images or apparent movements of objects accompanying changes in head and body position cannot be explained at all. It only means that the explanation must be based on the recognition that the relationship between the two sets of sensory data is variable and not static. This much we can safely infer from the observation that kinesthetic factors are always involved in the perception of directionality and impressions of movement of the entire visual field relative to the observer's body. Somehow we must revise the so-called “compensatory equation” between certain movements of the image and of the head (which were formerly thought to “neutralize” each other, so that the resulting percept was motionless). Otherwise we will never be able to account for the apparent movements after removal of the spectacles. The same holds true for the other anomalies of the total visual field.

An even more difficult problem is posed by the peculiar alterations in position within the visual field. The problem is similar to that involved in color perception. How can we explain the rubbery transformations of the internal proportions of the visual image that accompany changes in the position of head and eyes?

As far as the retina is concerned, the stimulation is the same whether the head moves in a horizontal or in a vertical direction, as long as the eyes keep focusing on the object in question. Nevertheless, distances will subjectively increase and decrease in these circumstances, angles will contract and expand, parallel lines will converge and diverge, and so on.

If we ascribe size and form perception to the reactivity of retinal elements, and their spatial values to light and color stimuli, then the results of the prism experiments suggest that the coordination between these retinal elements and their spatial values is a variable and not a static one. There is the possibility that in certain circumstances spatial values may be transferred from one retinal element to one adjacent to it. In this case, the realignment has to be such that stimulation of the same retinal element can variously give rise to percepts of acute and obtuse angles, of lines converging left, right, up, and down, of squares, rectangles, rhombuses, and rhomboids, and of straight and diversely curved lines.

These seemingly farfetched assumptions can be supported by clinical observation of certain cases in which the relative position of
retinal elements is altered by a disease. Such patients report corresponding distortions in certain parts of the visual field, for example, the parts of a network which fall within the diseased portion of the retina will appear no longer symmetrical and square but enlarged, reduced, or somehow twisted out of shape. We know this phenomenon by the name of "metamorphopsia." It is one which has frequently been studied. Wundt, for example, investigated the process in one of his eyes.

Let us assume that every retinal element is endowed with a certain spatial value and that, as a consequence, every stimulus maintains its place in the visual field. If we assume this, it follows that shifting retinal elements must take their spatial values along with them and that, consequently, a mix-up in subjective standards must ensue in the diseased area. The process would be analogous to taking measurements with a yardstick of which a portion is wrongly calibrated. Measurements taken with this portion of the yardstick would obviously be incongruent with measurements taken with the accurate part of the yardstick.

So far, everything is clear. But now comes a complication. It has been observed that the vision of patients cured of metamorphopsia gradually becomes normal again, even though no concomitant realignment of retinal elements has taken place. This clearly suggests that spatial values need not necessarily be tied to particular retinal elements. They can be relocated in their relationship to one another. Whether such a relocation is interpreted on an empirical or a nativistic basis is irrelevant.

We could probably approach the problem of relocation of spatial values with even greater flexibility if we applied Hering's theory to space perception. We do not apprehend the dimensions of objects any more directly than we do wave lengths. We must bear in mind that the physiology of the visual apparatus always intervenes between a wave length and the corresponding color sensation. In other words, the light rays must first interact with some nervous substance before any sensation can be experienced. The effect of the rays—the intensity and quality of the sensation experienced—is always dependent on the condition of this nervous substance. The same stimulus can give rise to a new sensation if the condition of the nervous substance has changed. The traditional experiments on visual afterimages demonstrate this point in the simplest and most elementary manner.

This state of affairs prevails not only in the case of color vision but also in the case of space perception. Again a physiological element intervenes between the patterning of stimuli on the retina—the actual spatial stimulus—and the perceptual experiences of size and shape. Only now this element is the momentary distribution of spatial values. We may also call it the "subjective standard." Although it cannot be as rapidly transformed as color sensitivity, it can be transformed just as thoroughly. The transformation takes place whenever a certain area of the retina is continuously subjected to certain biases of stimulation; for example, a preponderance of curvatures, distorted angles, unsymmetrical lines, etc. To put it in Hering's words, the perception of space is a product of the visual "substance" just as much as is the perception of color. . . .

The possibility that spatial values may be transformed without necessitating corresponding changes in the position of retinal elements serves us well in interpreting the visual disturbances experienced by the subjects in our prism experiments. Our hypothetical ophthalmologist or psychophysicist can now assert that the distribution of spatial values on the examined parts of these subjects' retinas was abnormal; that it was of such a nature as to cause straight vertical lines to be seen as curved, right angles as acute or obtuse, regular intervals as irregular, etc.

1 This is no way contradicts the equally plausible assumption that spatial values may change as a result of experience. "Native endowments" are not immutable and incompatible with further development. Conversely, the mere fact that spatial values are influenced by experience does not establish experience as the sole determinant. A valid formulation must take into account both the nativists' and the empiricists' point of view.

It is entirely possible for spatial values to change in accordance with definite principles, even though they are constitutionally determined. They may change either because of the action of some other constitutional factor, or because of the effects of external stimuli. No one is going to have any doubt that the ability to perceive colors is inborn just because of adaptational phenomena. Similarly, it would appear unreasonable to doubt that we are born with spatial values, even a particular distribution of spatial values, just because they change as a result of prolonged stimulation of a certain sort.

2 By "substance" I mean neither some kind of chemical substance nor some kind of retinal structure. What I am talking about is the total nervous process which underlies sensations and which extends from the retina all the way to the visual brain center. Changes in the visual substance therefore include peripheral as well as central aftereffects. Lack of clarity on this point may easily lead to misinterpretations.
be inconceivable to us that the position of the arm should have any influence whatever on sensations of touch and temperature on the palm of the hand. And yet this is exactly what we observed in the visual modality. There we found that the contraction of an eye or neck muscle influenced the inner proportions of a perceived object. How is this possible?

**B. The Solution: A Glance at Hering’s Theory of Sensations**

Let us now see how an examiner who is familiar with the subject’s past experiences would find a way out of this seemingly hopeless dilemma. He would first of all note that certain special conditions “enhance” or “suppress” afterimages (colored as well as spatial) which are the natural result of certain stimuli impinging on certain retinal areas. The longer the period of stimulation, the more differentiated become the stimulus traces which accumulate in the retinal area. The retinal area becomes the isomorphic equivalent of mnemonics by sorting all excitations according to the circumstances governing their recurrence, and not by merely summing them unselectively. If it did that, adaptation to alternating complementary stimuli (opposite distortions) would be completely impossible, as I have repeatedly pointed out.

To recapitulate: the link between the original optical data and the situational factors is established not directly but in a roundabout way, via afterimages which are sometimes enhanced, sometimes

---

3 Köhler and Dinerstein (1947) reported just such a phenomenon. They too did a long-term study and found that, after their subjects had been practicing for weeks (an hour or more a day) on tapered wooden bars, a constant interval between thumb and index finger (subjectively) varied in size as soon as the arms moved. Subjectively, the edges of a control bar did not feel parallel but appeared to taper off in the wrong direction. As in our study, the aftereffect was extraordinarily persistent.

4 In the strict sense of the word, these are no longer ordinary afterimages but more far-reaching effects, in other words, “aftereffects” affecting central visual areas. As we have seen in experiments with monocular prisms, visual disturbances spread over the entire optical apparatus after only a few days (even the covered eye reacts abnormally). That the size of the disturbance is clearly central is further evidenced by the stability and duration of these aftereffects, and, in particular, by the “situational” aftereffect itself, which certainly cannot originate in the periphery. We may rightly assume, therefore, that “afterimages” which are influenced by situational factors no longer represent peripheral physiological changes of the sensory substance.
suppressed. Not that this solves the problem; it only puts the problem in a different perspective. The question still remains: how do the eye muscles manage to interfere with the afterimages?

A partial answer may be found in the distinction between peripheral (superficial) and central (far-reaching) aftereffects.

As long as stimuli are of short duration, their effects can only be peripheral, or, at best, restricted to a limited area. No real differentiation is possible between regularly recurring and "accidental" aspects of the total situation coincident with these stimuli, and the traces which are formed in the sensorium remain equivocal. Only prolonged stimulation can bring about such a distinction. That is why, after short periods of stimulation, some deviations of retinal reactivity still remain localized; that is, each retinal area still functions in accordance with its own average past and "disregards" other aspects of the situation. After prolonged stimulation, on the other hand, the reverse takes place: now the situational factors are excluded from consideration only in special cases, that is, when they lack uniqueness.

Thus, in the case of fully prismatic spectacles, curvatures were present regardless of what other factors were present in the situation; consequently, the aftereffect remained localized. But in the case of half-prism spectacles, curvatures appeared with regularity only in very specific conditions (position of head and eyes); as a result, the aftereffects freed themselves from the affected retinal area and thus became dependent on other situational factors. In the light of Hering's theory, those findings indicate not only that the underlying sensory substance had become altered by the end of the experiment, but that the degree of alteration must have been determined by concomitant recurrent features of the total situation. This means that we can no longer speak of the condition of the nervous substratum in static terms. Instead, we must speak of it in terms of a "profile" which varies in accordance with the characteristics of the total given stimulus situation.

This fact, if given its proper place in a theory of sensations, would amplify the results of all our experiments. It is imperative that we distinguish between accidental and regular conditions. The former cannot exert a differential influence on sensory processes because they are equally distributed; the latter, however, can do so. What is applicable to sensations and sensory processes in general is also applicable to particular cases, specifically to all those sensations which occur most frequently in certain situations.

Stated more precisely, in the full-prism case, the situation did not have a chance to make itself felt; it was too indistinct, because the sensation was just as frequently present in other situations. Only a differentiated effect makes it possible for a connection to appear between the sensation and the total situation. Where no such differentiation has developed, no need exists to go beyond classical theories of sensation. The aftereffects in such a case are completely autonomous. The curvature aftereffect (in the fully prismatic study) is an instance of this; its connection with certain stimuli impinging on the retina remains invariant—it is not affected by different movements of the head. Thus, it appears to be a local phenomenon.

Only for this reason was Gibson (1937) able to generalize from color vision to the perception of straight lines on the basis of simple principles of adaptation.

Let me clarify this analysis by applying it to motor behavior. A muscle can react in many different ways. The specific way in which it reacts is always determined by the demands of a particular situation. This does not necessarily have to be accompanied by awareness. Thus, a "situational" reaction gradually becomes differentiated from a "general" reaction.

The following may serve as an illustration. Someone who is used to a certain typewriter will make typing errors as soon as he begins to use another typewriter with a different arrangement of keys. The earlier machine always exerts a disrupting effect on the later one, at least for some time. On the other hand, someone who has been forced to use many different typewriters for a long time will eventually be able to use them all with equal proficiency. His typing habits have become differentiated, that is, machine-specific, with a characteristic "set" for each machine being used. In other words, the situational factor has become interwoven with the state of the muscles at any given time. What were at first generalized aftereffects of typing have become specific to certain situations. To put it differently, the reactions have become "conditioned."

Similarly, the reactions of the sensorium to external stimuli can become conditioned once the state of the sensory apparatus has become differentiated with respect to different situations.

Just as the long period of practice is necessary for any intricate chain of motor reactions to become automatized, so a long period of stimulation is necessary before sensory reactions become associ-
ated with situational factors. In order for a connection to become established between a sensation and a particular situation, after-images must first become central aftereffects. The physiologically plausible solution which I propose for the problem of how muscular contractions are related to color sensations may thus be based on the assumption of mutually facilitating and inhibiting central aftereffects.6

The hypothetical naive examiner was quite accurate when he noticed variable abnormalities of sensitivity in examining our experimental subject; and he was quite correct in attributing these abnormalities to very specific conditions pertaining to the total stimulus situation rather than calling them hallucinatory phenomena. He could not help thinking in terms of “conditioned” sensations. He erred, however, in inferring a direct causal relationship between these conditions and the observed sensory abnormalities. The reason for his mistake is that Hering’s theory, on which he based his thinking, offered no possibility for conceiving of differentiated aftereffects of previous stimulation. Consequently, it did not occur to him to ascribe the fluctuating phenomena to aftereffects. He was confined in a theoretical straitjacket. If he had realized that Hering’s theory was applicable only to special cases, the right answer would immediately have presented itself. When I say special cases I am talking about stimuli of short duration whose occurrence does not invariably depend on the presence of certain concomitant conditions in the total situation. Only in these uniflakelike conditions do the individual “nerve keys”—to use Tschermak’s term—react in isolation from the rest of the situation. We get entirely different results if, coincident with certain optical stimuli, a particular aspect of the total situation has been consistently emphasized. Then the aftereffects become situational aftereffects, and we are suddenly faced with the enigma of an external factor whose influence cannot be explained in purely sensory terms.

Any attempt to generalize to all stimuli and to all stimulus durations is doomed to failure if it is based on isolated theories of sensation which ignore conditioning processes and which have been derived from the observed effects of short-term or nontypical stimulation.

Although Hering’s law of assimilation and dissimilation may be valuable in explaining individual stimulus effects on the sensory substance, it is absolutely useless when applied to complex stimulus effects, such as different or opposite stimuli influencing a single sensory area. In the latter case, assimilation and dissimilation cancel each other out, and what remains is some watered-down average stimulus effect on the sensory substance.

That is why Hering’s theory of sensations never reckons on the kind of long-lasting alterations of the sensory substance which we observed at the conclusion of our experiments and which took weeks and months, not just a few minutes, to become extinguished. An exponent of Hering’s theory would dismiss long-term investigations such as ours as lacking ecological validity. He would say they have no practical value, because they are so far removed from the conditions which normally prevail. Ordinarily, the stimuli which impinge on our retinas are in fact varied and not prolonged. They are not biased and do not eventually give rise to aftereffects. A straight line, for example, no matter how long it is observed, can never cause the subjective standard to change.

It is time that we give extra thought to this whole phenomenon of increasingly veridical perception which always occurs when experimental spectacles of any kind have been worn for some time. What is the advantage when a taut string, for example, begins to look straight to us no matter how curved the corresponding retinal image may be? Or when a rigid substance keeps its rigidity no matter how elastic it has been made to appear with the spectacles?

We are confronted here with a peculiar relationship between optical and physical facts. We always find that it is the physical dimensions of things which have a tendency to become visually correct. This is due to the fact that physical dimensions are among the most frequent and symmetrically distributed stimuli. Consequently, it is with these stimulus qualities that unique perceptual experiences of straightness, right-angularity, and good form tend to become associated. It is always the physically unique stimuli which gradually become the reference standards for our percepts. This is the reason why, in the process of adaptation, it is always
the world with which we are familiar which wins out in the end. It
does so in the interest of simplicity and economy.

It follows that the classical theory of sensations is applicable
only to very simple adaptational phenomena, and not to those
which, as in the case of the half-prism spectacles, involve multiple
alterations of sensory reactivity within a single retinal area.
Otherwise, biased alterations of the sensory apparatus would in-
crease the error, not reduce it; sensory adaptation to the total situa-
tion could never take place.¹

What good is a theory of sensation which is not applicable to
complex situations and which necessitates our formulating ad hoc
hypotheses every time some incidental condition is found to be
present? Yet this is precisely the state that the study of perception
has been in.

C. POSSIBLE APPLICATIONS OF THE RESULTS

As a general principle, we may expect aftereffects to occur when-
ever sensory data have become transformed through the action of
some special added condition. The aftereffects may be related to
specific stimuli in the past history of the current total situation (the
one transformed by the special condition) or in the history of the
one preceding it. Keeping the possibility of situational aftereffects
in mind, it would behoove us to look for "unusual stimulus con-
figurations" operative in the past. This could be done by means of
conventional statistical methods.

These configurations should not be hard to find. They may be
the product of a particular life style or of some natural law operative
in the environment. Even a superficial record of ordinary stimulus
patterns and sequences should convince us that they are lawful
phenomena and not mere chance occurrences.

Such a record would evidence an unmistakable correspondence

¹ A theory of sensations can have heuristic value only if it is able to explain
the aftereffects which are produced by complex stimuli. Such a theory must place
the emphasis not on stimuli in general but on situation-specific stimuli. Distinct
aftereffects may occur even though the sum total of all the stimuli impinging on
a retinal area average out to nothing. This happens whenever there is a preponder-
ance of stimuli whose occurrence is limited exclusively to specific situations. The
existence of such specific "invariances" within the variability of stimulation, and
their sensory aftereffects, makes it possible to predict far-reaching aftereffects
even in real life situations.

between changes in retinal images and certain positions and move-
ments of the body, head, and eyes. Furthermore, this correspond-
ence would be highly systematic, and not random. Even the optical
data themselves would appear in a new light in this sample of every-
day conditions. We take too much for granted that objects remain
motionless while we voluntarily move our eyes (when the eye
movements are involuntary, the "specific past" is not a determining
factor), that object size remains constant while the observer's dis-
tance from the object varies (as in approaching an object). I have
a hunch that our perceptual experiences would be quite different
if the situational factor were removed, that is, if we were in a state
of anesthesia upon approaching an object. It is even possible that
those factors which are supposed to have a "direct effect" on optical
sensations, such as "limits of the visual field," "limits of subjective
clearness," "gradients of subjective clearness," and "attention," may
turn out to have an indirect effect brought about by aftereffects
(in the sensory substance).

The same applies if we compare "habitual" with "nonhabitual"
ways of looking at things. Although there are, for example, many
ways in which we can hold our heads while inspecting a painting,
we usually maintain a standard stance when we do so, that is, we
stand up straight, move our eyes with moderate frequency, etc.
Without realizing it, we thereby insure that the distribution of
excitations on the retina of the observing eye remains approximately
the same each time we look at the picture. If the picture is in color,
the effect will be that certain colors will always stimulate the fovea
when we look upwards, and certain other colors will always stimu-
late it when we look downwards. The same regularities will prevail
when we look to the right or to the left. Our selective perception
of geometric shapes in various parts of the picture will similarly
vary systematically, depending, in each case, on how we hold our
head. The "stability" of the areas surrounding each part of the
picture will further contribute to the constancy of our percepts. But
suppose we looked at the picture under less habitual conditions.
Then we would immediately observe that the colors and shapes
look quite different: the hues would appear more intense, the shapes
less symmetrical, and slight "errors," which ordinarily we would
never "see," would now be distinctly noticeable. That is why some
painters use a mirror while working on a painting. The mirror serves
to accentuate incongruities which otherwise would go unnoticed. Without realizing it, they are protecting themselves against "situa-
tional adaptation." Another illustration: while riding a bicycle one
is completely insensitive to the effects of acceleration in normal
conditions of body posture; however, as soon as one takes on an
unusual posture (for example, bending the head backwards or
looking at the rear axle), one immediately becomes aware of the
acceleration.

Our daily lives offer countless instances where the absence of
seemingly "irrelevant" concomitant conditions is found to alter a
situation profoundly. In these circumstances, we somehow feel that
things are not the way they should be; whether we know what is
missing or not, we cannot rationalize this peculiar feeling away.
This strongly suggests that some connection must have been formed
in the deeper layers of the nervous system between isolated aspects
of experience and the "familiar" situation.

Professor Erismann tells us of a peculiarly irritating feeling he
once had while he was taking a walk. He traces it to the fact that
he had left his cane at home that day. Not that he ever used it for
locomotion. But he was in the habit of carrying it on his arm.
Therefore, the missing cane was hardly an "insignificant" object.
It was so "significant," in fact, that, according to him, it spoiled
his whole walk for him. Even the beautiful scenery lost its appeal
that day. And all this because he did not carry a cane on his arm!

We are told that Michelangelo, after completing his work on the
ceiling of the Sistine Chapel, had gotten so used to lying on his
back while painting that he was unable to read a book in any other
position. This too shows that more must have been involved than a
mere change in the position of his head. The related fact that we
all have difficulty reading upside-down print is again not due to any
change in the geometric properties of the letters—but to a change in the "customary relationship" between the
letters and corresponding retinal spatial values. Changes in the
usual pattern of the letters further contribute to our difficulty. Just
compare the upper and lower halves of a "normal" figure 8 with
one that is upside down. In normal conditions, both parts of the
figure look approximately the same, even though they actually are
not. (The experience is like the one reported by subjects wearing
our experimental prisms: to the left, everything looks contracted;
to the right, everything looks expanded.) In abnormal conditions,
however, the difference in size between the two parts will look sur-
prisingly large.

I have often wondered why each half of the retina has different
standards of size. Our prism experiments have shown that these
standards are not invariant. All one needs to do in order to increase
or decrease the standards is to subject one part of the retina to
prolonged stimuli of increased size and another part of the retina
to prolonged stimuli of reduced size. As far as I know, only one
investigator, T. Lipps, has come up with an answer to that. Accord-
ing to Lipps, the disparity in retinal size standards is due to the fact
that most of us are right-handed and tend to give precedence to
objects in the right region of the visual field. Consequently, one
half of the retina is usually exposed to slightly larger images. So
far, little attention has been given to this fact.

A question which has not yet been answered concerns the dif-
ference between empirical and mathematical horopters. The differ-
ence is presumably due to an "unsymmetrical" distribution of
"experiences." Since the floor and objects on it are closer than the
ceiling, the distribution of stimulation on the upper half of the
retina is different from that on the lower half: those on the lower
half tend to be smaller, more distant.

The so-called "moon illusion" is a problem which has occupied
many investigators for thousands of years. Although it has been
known for some time that the perceived size of an object is little
affected by whether it is seen "above" or "straight ahead," it is still
not clear what the "immediate" interaction is like between these
two sensations. In an extremely revealing investigation, von Allesch
(1931) attributes differences in size standards to the life style
which characterizes a human being. This is undoubtedly an im-
portant step in the direction of "situational" aftereffects.

There are other factors, too, which are relevant to the moon
illusion. They are usually referred to as empirical localization mo-
...
itives. But are not these exactly the kinds of "incidental conditions" which, if present, have been shown to have such profound effects on our visual experiences?

There is no end to the examples which can be given to show that the presence or absence of such "conditions" is a major determinant of sensory experiences. And even if we considered all of them, there would still remain those stimuli "characteristics" which are contained in the very nature of things and thereby insure that the incidence of stimuli is not a random one. Consider gravity, for example; gravity not only affects our tactile sense, it also influences specific patterns and sequences of optical stimuli. Thus, since the direction of gravitational pull is downwards, it is "low" stimuli which show the highest probability of occurrence. Horizontally, on the other hand, the distribution is much less skewed. The same applies to movement stimuli. Every object, particularly every animate object, moves in a "characteristic" way. The fact that we have become thoroughly adapted to all this is evident as soon as we look through inverting lenses. The effect is the same as if a dog, for example, suddenly were seen to move like a horse. Only then would we become aware of how "peculiarly" horses really move. Before, we would have thought there was nothing strange about the horse.

9 The results of our experiments have not only theoretical but also practical implications. One of these pertains to the practice of orthomelogy. The physician sometimes worries whether his patient will be able to get used to the disagreeable side effects of powerful spectacles. He need worry no more. In cases of strabismus, for example, where prisms are used to correct the condition, he may find it perfectly safe to prescribe much more powerful spectacles than he has ever prescribed before.

Optometry and the manufacture of optical instruments are further practical areas to which our results may be applied. Those engaged in these fields will want to know about the enormous capacity of the visual organ to compensate for spherical and chromatic aberrations in lenses. They may no longer find it necessary to make exact corrections on the lenses when these are being consistently worn.

Finally, psychologists working in courts and physicians interested in forensic medicine will want to know about the persistent and far-reaching traces which "ordinary" stimuli can leave in the sensorium of the individual. It may well prove to be possible to reconstruct peculiarities of the delinquent's past environment on the basis of minor abnormalities in his current sensory experiences. It should be possible, for example, to prove that someone used to wear spectacles, even though he is currently not wearing them for the purpose of diagnosing himself. His own eyes will give him away, because he will not be able to perceive "straight lines" when he holds his head in a certain position. The kinds of errors he makes should even make it possible to determine the kind of spectacles he used to wear. Furthermore, since aftereffects result from other peculiarities of past optical situations as well as from certain habits of long duration, all sorts of other secrets of his hidden past may be uncovered.

THEORETICAL CONSIDERATIONS

An entirely new world has been opened to us, a world of complex stimuli interacting with a sensitive organism. We have seen that a sensory reaction is a product not only of its predecessors, its neighbors, and of residues in its own region, but of any and all the influences affecting the organism. We have discovered one of the laws by which at first separated, unrelated parts are organized into a whole, and we have done so, not in opposition to, but with the aid of, scientific methods. And this gives us a special feeling of satisfaction.

CONCLUDING REMARKS

This presentation should be regarded primarily as a factual report. It is hoped, however, that it will stimulate further work in an area which, since Stratton's pioneering days, has been largely neglected, and that it will thereby generate further knowledge of basic perceptual processes. The effort, exacting though it may be, should be well worth while. Of all the areas of psychology, this one seems most likely to shed light on our assumptions regarding our experiences and is most closely in line with contemporary natural philosophy.

In conclusion, I wish to extend my sincere thanks to Professor Rohracher for his unfailing efforts to make publication of this manuscript possible and for his many helpful editorial suggestions. I am further grateful to Professor Mayer-Hillebrand for the stimulation she and her writings gave me, particularly her still unpublished article, "Die Tendenz zum Gleichgewicht als psychologisches Grundgesetz." I am particularly indebted to my esteemed teacher, Professor Erismann. It was through his lectures and later through working with him that I gained the background necessary for this work. Let me not neglect to add that he was generous enough to let me have my own way even when he did not completely agree with my particular approach to the experimental task.
Part II

REHABITUATION IN PERCEPTION

Part II is a translation of a three-part article "Umgewöhnung im Wahrnehmungs-
Habits exist in all areas of human personality. Whenever something that is originally fluid becomes fixed or grooved in a particular direction through repetition or training, habit is involved. Habitual behavior is characterized by ease of performance, precision of the individual components, and energy saving, both physical and psychic.

Without considering any particular theoretical position, a distinction may be made between "inner" and "outer" habits. We all look at things, imagine them, connect them with other images, think about them, strive for them, in particular ways. All this occurs in experience and thus "inside" the person. From the "outside" we observe movements, sequences of movements, and actions, which may also be "habitual," as evidenced by uniformity of performance, by the speed and effectiveness of the individual movements, by rigid connection to particular evoking circumstances, etc.

Another quite old classification (Fries, 1828) distinguishes between "active" and "passive" habits. Habits may be started intentionally (actively), as, for instance, in school learning or in the acquisition of skills; or they may be built up by themselves (passively), forced upon the person by recurring uniformities in the life situation in which he exists, often termed "training through milieu."

There is no question that habits are very advantageous, as long as they go in the direction of the goal aspired to. This concept of economy—the energy saving accomplished by habits—was first advanced by Avenarius in his booklet "Philosophy as Thought About the World According to the Principle of Least Energy." If the "soul" is in possession of only a finite amount of energy—and this is undoubtedly the case—then it stands to reason that everything which runs off in a uniform manner should become "automatized," that is, should demand neither attention nor any particular
effort. This leaves all the more energy free for what must be adjusted to changing conditions. After all, things are similar in technology: man can be replaced usefully by the machine wherever the same hand movements are necessary; but he must exist to invent those machines that replace the hand movements. In this case, automatization has reached its limit. The more energy is free for such planning or goal-determining behavior, the more can be accomplished. But this assumes that subordinate acts run off by habit.

But it not infrequently happens that the outer situation changes, or that newer goals are aspired to which are opposed to previous habit patterns. And now we see the obverse side of the just praised economy of habits. Nothing is more burdensome and sapping of energy (and hence affectively unpleasant) than rehabilitation. Then only do we notice what habit is, and to what extent we consist of many and strong habits. All these change into resistance when they are no longer appropriate, and, depending upon their strength, become stronger or weaker resistances. This is particularly noticeable at the beginning of a "rehabilitation experiment," for then the individual automatizations start in motion at the slightest opportunity and run through to their conclusion against our better knowledge. The subject with a pair of reversing spectacles actually becomes frightened by the activities of his own hands and feet and looks on them as "natural phenomena," being helplessly delivered into their power. Thus the frightening quality of habits—the "machine in man," as it were—suddenly becomes clear to us.

In adults the process of automatization has progressed so far that new learning in any real sense hardly occurs any longer. There are always old habits in the way which must first be overpowered before new patterns can prevail.

Experiences of this kind, however unpleasant to the person directly concerned, are nevertheless of inestimable value for the scientific study of habit patterns. Only by studying rehabilitation can the complex interweaving of habits, built up throughout the course of life and almost inextricably "boxed into" one another, be disentangled. Now the individual habits sort themselves out quite on their own. They introduce themselves through the kind and strength of the resistance they pose in the rehabilitation situation. Whatever is rooted the most strongly (or as one might say with some justification, most "deeply") in the person requires the most time to be overcome; the superficially rooted changes more rapidly. On one, more industry and attention must be expended, on the other, less. The rehabilitation experiment thus becomes a kind of "probe," with which one can penetrate more deeply into the structure and mutual interweaving of habits than would be possible in any direct way—for example, by self-analysis. We must not forget that it is precisely the strongest and most important habits that run off with so much energy saving that they hardly enter consciousness at all. All the more mysterious, then, is the resistance they send to the surface when they consider themselves attacked.

It is extremely paradoxical to observe what happens when a few (weaker) habits have been corrected but others (stronger) are still active. Observations of this kind showed us clearly how complex the apparently simple habit can be; how it is built up from a "network" of components of different "depths," and how, therefore, it can never be altered as a whole. Only by wearing theoretical blinders, that is, considering an individual component as representative of the entire behavior, can the rehabilitation experiment be considered as completed when a single component is conquered. This is an error of which behaviorism has been guilty, and in part is still guilty today—to the detriment of full utilization of such experiments.

This should be enough to indicate the basic point of view in the light of which we wish to discuss certain experiments with reversing spectacles, some of which have been presented previously but some of which are new. Here we are dealing only with perceptual rehabilitation and reorientation. This, however, does not mean that the results cannot throw light upon other areas in psychology where habits and their overthrow play a role.

Other experiments with reversing spectacles, such as those of Ewert (1930), Krüger (1939), and Snyder and Pronko (1952), can hardly be considered to have come to grips with the questions posed here, in contrast to those of Stratton (1897), the old master of such experiments, whose descriptions, precisely because of their lack of bias, are still a gold mine. A difficulty that should not be underestimated grew from the fact that the above investigators used optical systems which simultaneously reversed both the up and down and the right and left (reversal of 180°). The increased
difficulty of orientation in these circumstances greatly hinders the observation of subtle details. Furthermore, all the followers of Stratton gave credence to a one-sided behaviorism. They were interested only in the "outer" behavior of the subjects and the correction of their movements, not in their "inner," i.e., perceptual, experiences. This means that the rehabilitation experiment necessarily had to become an experiment in motor readjustment or a simple learning experiment. The reversal experiment thus became just another illustration of such common phenomena as putting a handkerchief in the wrong pocket or moving a cabinet at home, and consisted of counting and plotting how often false movements occurred until the right habit got established.

But mere observable behavior, particularly in the crude form of foot and hand movements, is only a minute part of the total picture to which perceptual experience certainly belongs. This is shown by the fact that at the end of a thoroughly executed experiment there will be not only correct movements (these establish themselves very quickly) but also correct seeing. But no one sees the moved cabinet in its old place after having gotten used to finding it correctly in its new location. In perception we are dealing with a particular emergence of both experience and behavior, which cannot be emphasized enough in contrast to the simple learning experiment. This is the justification for paying particular attention to perceptual habits, and to the process of perceptual rehabilitation—which now will be attempted by means of several examples.

Because of space limitations, most of the evidence will be taken from two new experiments, performed in 1951 under the direction of Professor Erismann. The first subject (thirty-seven days of uninterrupted wearing of spectacles) was F. Grill, student of philosophy. The second experiment, which took twenty-four days, I carried out myself. The spectacles used—and we were here dealing with a pure reversal of right and left—were constructed according to the model of a Wheatstone Pseudoscope. Each eye has a totally reflecting prism attached to it which creates a vertically correct image. To achieve corresponding images and to avoid double images, one of the two prisms can be rotated around the vertical axis, and thus adjusted to "near" or "far" by means of a lever. Height and width of the visual field were 33° and 25° respectively.

Even the first impressions after putting on the spectacles are very informative. The new picture immediately splits into various degrees of "normality," depending upon whether previous perceptual habits correspond with it (the picture) or not. Let us consider, for instance, the table and the things upon it, as presented in Fig. 1, with a right-left reversal, and let us do so as a "first impression." Someone who knows the correct original and compares it directly with the prismatic image will immediately realize that everything is reversed and placed incorrectly. More interesting for our purposes, however, is the case in which the observer does not bring any special knowledge concerning the actual situation with him, but still notices some "strangeness" or clear-cut "reversals" in the picture.

Fig. 1

At first glance it is clear that symmetrical line-arrangements are not affected by the lateral reversal. The right and left sides of the picture frame, the handles of the pliers, etc., are reversible without any alteration in the appearance of these objects.

In addition, all objects which ordinarily occur in any position, with no particular position being characteristic, look "normal." To
the extent that the spectacles reverse such objects, no unhabituated, only another habituated picture results. Thus the "prismatic world" contains not only reversed places but also reversed positions of individual objects (for example, cup handles, the positions of the pointers on the scale and the clock, the radio and tuning knobs, the rock in the background), but nothing here is disturbing, inasmuch as these things are mobile: sometimes they are in one position, sometimes in another; in other words, it is common for their positions to be reversed. The impression becomes "strange" only when we are accustomed to a particular constant orientation which is now reversed.

While, for example, the cup handle may face equally often to right or left, the capital "B" has always shown its rounded side to the right of the vertical line. Hence the disturbing and senseless impression of a mirror B. The same holds for all letters and numerals recognizable in the picture: for the scales, where the zero is usually to the left; and for the face of the clock. The positions of the hands are not in themselves disturbing, for the hands are movable, but the inscription is wrong and the individual numerals are obviously reversed. Similarly with the books in the foreground, and the newspaper. The titles of the former seem to appear on the wrong side of the cover, while the latter apparently can only be leafed through by moving the pages from left to right. Other things require special habits from the past in order to appear strange: mechanics would wonder about objects evidently designed for left-handed use; art experts would find the content of the framed picture suspicious, quite apart from the fact that reversals of works of art in themselves disturb the harmony of the lines. The same is true for well-known faces, the fine asymmetries of which (for example, in position of the nose, wrinkles around the mouth, facial expression, etc.) immediately show up in the mirror position. Even the reversal of the hairline changes the entire facial expression in a manner which is very difficult to describe.

The shoe in the foreground belongs in a particular category of objects. True enough, it is not symmetrical, nor can it become symmetrical through any change of position, but it usually has a symmetrical twin, and thus it simply changes its individuality and becomes the "right shoe," though in reality it is the "left." Analogous results will occur with letters which possess meaningful symmetrical opposites, that is, "d" becomes "b," "q" becomes "p." The prism wearer will inevitably read "d" as "b." In context this may be embarrassing, for instance, when one wants to change all die to bei, or when one finds oneself trying to figure out what neden could possibly mean.

Finally, there are objects which, seen through the spectacles, will be neither "normal" nor "abnormal," namely, those whose exact meaning is unknown, regarding which there is no particular experience from the past—though associative suggestions cannot be avoided. In the picture the best illustration of this is the instrument next to the amplifier.

It follows that reversal of right and left is not always evidenced in a correspondingly reversed appearance of the objects observed. Attention should be directed particularly to two groups of objects, the later separation of which turned out to be highly paradoxical: on the one hand, letters, numerals, and so forth; on the other, objects that normally appear in any position. If these are lumped together, one would expect that as the general perception of right and left is corrected, the letters will no longer appear in mirror fashion. But that is not what happens. A right-left which is strengthened by a customary configuration of lines shows a greater resistance to rehabilitation than the other. One can exasperate a subject by pointing out "inconsistencies" which necessarily result from this. Imagine an object whose two sides are correctly localized with respect to right and left, but whose inscriptions are reversed. (Examples of this sort are given in the second part of this essay.)

If further develops—which should indicate the complexity of the problem—that the prisms may also be used as a pseudoscope: that is, they reverse (in binocular vision) not only direction but also near and far. Since this effect also depends upon the optical interchange of right and left for each eye, one might suppose that with the correction of visual orientation the reversed depth impressions will also disappear. But this is not the case: an object may be seen in the correct place (vis-à-vis the position of the subject), it may be seen correctly in itself and thus no longer laterally reversed, but its spatial depth impression nevertheless remains incorrect. This suggests that the right and left we normally take for granted may reach into strange depths, perhaps into the area of innate mechanisms which are not related to habit formation.
Similar results are obtained with respect to the overt behavior and movements of the subject. Inasmuch as the spectacles are worn without interruption (except during sleep) it is not merely a matter of seeing, movements too are involved: movements of the head and eyes turning to a particular object, movements of the feet approaching a given spot, movements of the hands reaching for seen objects, etc. And once more there appears a particular splitting in the difficulty or ease of correct mastery of these movements. If there were no “habits” (and there is nothing else behind the resistance), then it would be enough for the subject to know that the spectacles reverse right and left, and that in consequence he has to react correspondingly in reversed fashion. But the character of habits as opposed to the more flexible thought processes is shown precisely by the fact that habits run in their old grooves for a long time, whereas it is enough for “knowledge” for one to have learned just once what kind of spectacles are involved.

Thus the subject at the beginning of the experiment finds himself in the strange state of being delivered into the power of his own habits, against his own better knowledge. Fortunately, however, not all behavioral patterns are unmodifiable to equal extents. Closer observation can differentiate three separate groups.

There are those movements which are not at all disturbed by the spectacles, for example, eye movements. When the subject wants to fixate a peripherally appearing object he succeeds as before—as long as the head is still. (Head movements are “not right any longer” and continue to be incorrect with exceptional persistence.)

A further consoling observation for the subject is the discovery that there exist movements for which “seeing is a luxury.” A hand moving quickly to a particular part of the body carries this motion to its conclusion without disturbance, even when the image of the hand somewhere crosses the visual field and thus appears to run in reversed fashion. Food on a spoon (that is, once it is there already) is brought to the correct part of the face with certainty, even though the eye sees hand and spoon disappear in an incorrect direction in front of the head. Vision is not strong enough to disturb the automatization of such movements; that is why they run off correctly. Observations on writing are very interesting and belong in this context. With regard to this, we note the comments of Stratton (1897, pp. 344-345): “In order to write my notes, the formation of the letters and words had to be left to automatic muscular sequence, using sight only as a guide to the general position and direction on my paper...there was no resort...when the movement was once under way, [but to] control it visually as little as possible.” A subject trying to write in these conditions has the impression of an ego-separated life in his individual limbs. The fingers run off like a mechanism wound up by someone else, and every attempt to affect them volitionally (after all, the hand writes letters and words which appear to be mirror writing) leads hopelessly to complete inhibition. Inhibitions of a similar sort occur even in later stages of the experiment when the subject is asked to observe critically. Apparently even the “intention to observe” reawakens old patterns which have already been conquered in the process of everyday living. About this we will later report more extensively.

While movements of the sort already mentioned may thus run off independently of vision, the opposite is true of the following group, whose entire progress is controlled by vision. We generally tend to use this procedure when the situation is complicated or dangerous. If, for instance, one walks through a thickly planted garden, one simultaneously watches one’s feet and directs them visually to unplanted locations. While manipulating running machinery, it is well to direct the hand to the desired point under the sustained control of vision, instead of merely letting the eye govern the initiation of the movement, which is what we usually do in reaching movements. By doing so, the performing movements are at all times substantially slowed down to ensure control, and the possibility of correction by vision. This procedure of optical guidance of hand toward visually perceived goal would also be the safest one for the wearer of spectacles, but it does not succeed equally well in all cases. When one analyzes the situations in which it succeeds easily and those in which it does not, the power of previous habits is again demonstrated. In situations where it has become “second nature” to refer the first impulse of an otherwise self-continuing movement pattern to vision, errors mount up. Thus, for instance, in ordinary walking, rapid reaching movements, head movements (to fixate a peripheral object), and so forth, the subject’s intention to work according to the procedure of optical guidance does not quite come off. On the other hand, activities in which
the eye completely governs the hand succeed quite well, despite the
spectacles. Figure 2 sketches subject K. in the process of construct-
ing an electronic measuring device, as an example of one such
visually guided movement pattern (eighth day of the experiment).
Even then many errors resulted from rapid reaching for tools; but
once the soldering iron was in the visual field it could be easily
moved to any desired point. Thus it was possible to work with
machines, to bore holes, to file, and to saw—while the simpler
movements to doorknobs, to hat and stick, always failed.

The first days, even weeks, of the experiment are filled with the
task of breaking the resistance of this dangerous third group of
movements. The danger lies in the fact that the eye only initiates
the immediately succeeding pattern of movements which, once
started, run off without requiring further control. A notable ex-
ample of this is the first “walking attempt.” While walking, we are
only from time to time concerned with the visual aspects of the
situation, to mark out the direction of walking. Once that has hap-
pened, one may happily permit one’s feet to take a few steps on
their own, and may close one’s eyes; one still gets very close to the
desired position. This habit continues despite the spectacles, but
now to the disadvantage of the subject. Subject G. describes his
impressions as follows: “My feet don’t go where I want them to . . .
but I have the feeling that I’m walking straight ahead; only now
and then I get grass under my feet, which I’m quite sorry for . . . .”
His path, taken with the intention of “staying in the middle,”
appears as a zigzag line. No wonder: the first little deviation was
“spontaneously corrected,” but since the visual field was reversed,
the “correction” was incorrect—until finally the error was obvious
and the game (after reorientation) began once more.

Hundreds of times during the day false movements and turns are
taken by the subject in this manner. He puts forth the wrong foot
to get on the pavement; he gets lost at every crossroads; he half
opens doors and then closes them again because the opening ap-
pears where in actuality the hinges are, etc.

It is understandable that the subject seeks methods to control
movements of this type. The attempt to carry back the third group
into the second (even though it has probably developed out of it in
the course of life) succeeds only in exceptional situations and
requires an unusually high degree of attention. But a different
procedure has a chance of success. The subject tries to influence his
initial impulse by saying to himself at every opportunity: “Always
do the opposite, head into danger, walk in the direction that you
want to turn away from. . . .” By doing this he instinctively chooses
the path of least resistance; for now he does not have to influence
the automatic running off of these movements as such, but only
their initial point of departure.

These few examples indicate that behavior too is not unitary,
but is under the domination of vision in many different ways.
Recoordination should no more be expected to occur as a whole
than correction of right and left in visual experience. And, in addi-
tion, we note that behavior and visual experience are not separated,
but are intermingled to the most intimate degree in every action of
the subject. How will this interwoven tapestry dissolve itself in the
conditions of wearing these spectacles? What will give in first, and
what will keep on resisting to the end? Will this resistance continue
in particular situations when it is already conquered in others? These are questions which cannot be answered patly and in a general way. On the contrary: the path to "correct seeing" winds over strange stages of development which can only be understood against the background of a theory of habits and their interweaving.

II

Habits may be studied by the procedure of building them up, by creating new ones artificially. This method (in the manner of classical conditioning) is often used nowadays, for instance, in reflex psychology and behaviorism. This procedure indubitably has advantages when the purpose is to study habits as such: the conditions of their creation, reinforcement, inhibition, and so forth. But for this the exact point of departure must be precisely known. There is no value in it when what is to be learned in the course of the experiment is known and has been practiced previously, or when from the beginning other conditions are present which cannot be assessed. Hence the recourse to animals, in fact to their actual rearing in the laboratory.

Conversely, the procedure of tearing down or altering habits yields advantages in complex situations which are rather difficult to analyze. One can start with something completely formed and then restructure it by forcing it to change and adapt itself to opposite circumstances. The primary factors of prior experience, practice, and habit, as well as their interrelationship, will then manifest themselves in the resistances that are encountered in such a procedure. Much that has been built up in the course of life can only be discovered and disentangled in the context of the rehabilitation experiment.

To make this clear, we started with an example from perceptual psychology: visual experience of right and left. With the aid of experimental spectacles the normal conditions are reversed (what appears as right through the spectacles is actually left, and vice versa). The first impressions and their effect upon behavior show differences that point to the existence of underlying (stronger or weaker) habit patterns. What happens in the later course of such an experiment?

As a first result, it can be shown that the overcoming of the disturbance does not begin with vision but rather with touch. Walking, avoiding obstacles, reaching, etc., become better and finally almost faultless after two or three weeks, while visual experience—in other words, perception—still remains reversed. In these conditions, one cannot yet speak of perceptual adaptation, but only of a correction of behavior. But it is of greatest interest that the latter becomes a steppingstone for the former. This demonstrates that they are related in some fundamental way. The "how" of this relationship was indeed the primary question of the entire experiment, and the participants always waited expectantly for that moment in the experiment when "correct seeing" occurred for the first time. And this climax always takes place. But a peculiar route, one might almost say a "detour," is taken to get there.

How simple it would be—one thinks—if retinal reactivity were all that changed; if every retinal location which formerly reacted as "right" now responded with "left," and vice versa. The disturbance caused by the laterally reversing spectacles would then be overcome immediately, just as if one had superimposed another laterally reversing pair of spectacles over the first. Instead, however, the misdirected motor system wins out and must first be corrected in relation to vision before the first signs of visual readjustment become noticeable; and even this occurs in the most intimate connection with tactile experience, of which we will hear more later.

The notion of an immediate optical readjustment stems from erroneous conceptions about the nature of perceptual experience. We must never forget the weight of previous experience, connected since earliest childhood with retinal stimulation, which still exerts its influence despite our better knowledge. The subject of the experiment brings with him a fully formed and finely differentiated system of coordinations between visual directions and motor reactions of the most varied sort. The required readjustment must occur against the background of this experience. Herein lies the resistance which opposes the reversal of spatial values.

But even when this has been accomplished, it does not necessarily follow that seeing is now "correct" in the pre-experimental sense. The error is too easily made of analyzing visual perception on the basis of optical models. This does not work. The photographer of course can do it. If he reverses the negative, then he obtains mirror-prints. It would be absurd for him to check whether
all parts of the picture have really been reversed. Matters are different in perception, where we find in-between phases. An object may be in the correct place but nevertheless be reversed; the same point may have two directions, or none, and so forth. Such contradictions are particularly informative because they indicate that the final percept is but the end product of an extended process. Physical or physiological optics alone cannot explain it.

In fact, one may justifiably raise the question whether visual perception can be isolated from behavior at all. If so, then the association schema between visual contents and other experience can only be considered as a tentative model. A “bridge” makes sense only when the two areas to be connected are already in existence; it is meaningless when one stems from the other. Whether such a “reduction” is possible in all areas must eventually be decided.

But let us glance at the facts again. It is clear that the goal of the subjects is to learn in some manner how to make correct movements. False pictures can be endured, but false movements (collisions, falls, stumbling, misgrasping, etc.) cannot be endured for long. Hence the immediate necessity to correct behavior. It is therefore interesting to see how this happens, and to trace the transition from behavior to “seeing.”

The first step is undoubtedly one of conscious reasoning. One starts with the given image, decides what direction the target is in the accustomed way, takes the spectacles into account, and only then gives the appropriate signals to the executive organs. For example: “The doorknob appears left (as seen), hence must be right (in reality); consequently the right hand (according to bodily sensitivity) must be used.” It is hardly necessary to say that this method does not go very far. It demands a degree of concentration that few people can keep up for any length of time. In addition, this kind of reasoning process gets all tangled up the moment some extra factor crops up which has been omitted from the calculation. For instance, the right foot—the one to be moved—when looked at remains rooted to the ground, while the left one starts off. Now you try to figure out how the right foot seen through the spectacles becomes the “left” foot. Meanwhile, however, the beginning of the analysis has been forgotten and the whole business starts anew. Even when the subject, following such rational reasoning, manages to move properly, the concomitant visual images will always lead to doubts: they just do not fit. Occasionally, they even look dangerous, cause alarm, or block every attempt to move in the direction that reasoning has decided upon. Only later in the course of the experiment does the subject acquire the ability to “cancel out vision” while keeping his eyes open.

Of course, one can practice such rethinking. But this method did little to further the progress of the experiment. It was only of theoretical value because the subject learned in this manner to name the proper visual direction of a perceived object (without, however, being able to see it properly). When experiments were conducted where the task was to indicate visual direction only verbally, the positive results obtained might have been spurious.

More important for practical behavior was the method, mentioned above, of commanding oneself to go where one does not want to; to raise the foot which undoubtedly “is wrong”; to run into obstacles head-on rather than avoid them, etc. In contrast to the previously mentioned technique, the point here is not first to decide where objects really are, but always to do exactly the opposite of what the first impulse (on the basis of pre-experimental experience) directs. To determine right and left is unimportant for this.

An important prerequisite for this is the occurrence of a general slowing down of movements—an affective tone of “watch out”—soon after the very first few misgrasplings. This does not stop false reactions but does delay them. From this develops an important area of contact between vision and touch which is the basis of the development of a new experience. If a reaction cannot be at least delayed, it cannot be fought.

Thus, the reversal of the initial impulse is the simplest solution whenever we are dealing with automatic activities which are initially under the domination of vision but thereafter run off on their own. To bring every single step in walking under visual control would be unthinkable. The method of doing the opposite of what one wants to do operates according to the general principle of energy conservation. One does not fight, one “sublimates.”

This method is particularly successful when applied to behavior in larger spatial areas. Walking on the street, even in narrow alleys, finding doors and exits, turning correctly at crossings, climbing steps and hills, even bicycling, are possible at this stage, despite the
reversals caused by the spectacles. But, and this is an important point, just as vision later is never completely correct, though it may be right in some respects, so behavior is never completely correct, though it has been set right in some situations. As before, the subject makes mistakes in nearby spatial areas, especially in quickly grasping for objects.

The last-mentioned errors—the most stubborn of all encountered in the experiment—are left to chance. One does not try to do anything about them, but simply reaches. It is a kind of gamble where one hopes that the hits will accumulate. The only thing of relevance is “correct” or “incorrect,” not “right” or “left.” One either encounters the doorknob or one does not. Eventually there develops a kind of premonition, an expectation about this during the moment of reaching, which predicts the result. It will not always be correct, but it becomes more and more correct the longer the experiment is continued. Similarly, one begins to expect collisions, etc., on the correct part of the body. In the end, false movements are no longer completed. The warning occurs at the beginning of the movement, and its execution is immediately shifted to the opposite direction. But one may observe false beginnings even at the end of the experiment.

What at first was practiced consciously by the method of intentional “rehearsing” has been built up unconsciously as a result of numerous pleasant and unpleasant experiences combining visual image and bodily reaction. When dealing with corrections of expectations, we are nearing the initiation of correct seeing. But that is still backstage, and still escapes the scrutiny of direct attention.

It should be added that simultaneously with the events described there develops a kind of autonomy of vision and touch. One gradually learns to permit the pictures of the world of the spectacles to pass in front of one, just like the pictures on a movie screen, without taking them seriously. In fact, it becomes a kind of game to practice activities which are tied to such alarming pictures. For instance, think of a deep gorge on the “left” (the rushing stream of course being heard on the right) and the safe mountain side on the “right,” with a narrow path ahead—which way do you step now? The subject must expend much will to go intentionally in the direction of the gorge, precisely because he wants to stay out of it (Kohler on the third day). Although not as drastic, the same thing in prin-
threatened from a particular (indicated) direction, he made correct responses. But when he was asked, "Please point this marker in the direction the light is coming from," errors occurred.

"Immediate" or "critical" vision has peculiarities all its own. As a subject, one notices that instructions to report immediate experience lead to the emergence of old (pre-experimental) memories and to the old tendency to bring the visual field into correspondence with the sides of the body. Small wonder then that the world of the spectacles remains stubbornly reversed. The instruction for a critical, visually determined attitude is a kind of last stronghold of old habits. Occasionally such instructions are even unnecessary.

The laboratory situation itself often suffices.

This is hard to understand. We only arrived at this position step by step, by way of the observations themselves. Take for instance the results of the daily "fencing experiment" (see Die Pyramide, 1, #2). After about fourteen days errors disappeared, even though the subject saw the rapier point approach in reversed direction as before, when instructed to have a "critical set toward visual experience." To explain this, a distinction must be made between the role played by vision during the act of parrying and the role played by vision when the subject is asked to name the visual direction he experiences. During movement the only thing of interest is the correct reaction, and with this set, everything fits together. (Image and reaction to image form a unitary whole.) But the question, "Where do you see the rapier point?" disturbs this impression. It forces the subject to isolate what for him cannot really be detached yet—except in so far as one brings to bear the old, still living, pre-experimental background of experience.

The following will clarify this point. Subject Grill (fifteenth day) sits in an automobile waiting for Professor Ehrenmann. When Professor Ehrenmann comes, Grill says: "It seems that everything in vision is the way it really is; the house, for instance, which I see through the right window, really appears to be on the right, and the parts of the car look just as they would feel if I were to touch them." Professor Ehrenmann comments: "Did you experience this visually?"

But this critical question is too much. The subject withdraws: "Please . . . I can't say I saw this correctly, for vision in this case was uncontrolled vision . . . . I sat in the car and didn't think about anything in particular, and suddenly I thought that people walked by on the correct side, and not through me . . . funny things are happening, particularly when I don't think about them . . . ."

A more detailed analysis was made on the eighteenth day. Grill asserted: "When I stand close to the wall the street looks right!" We tried to test this assertion and gave Grill the instruction to stand near the wall. This being done, he walked to the curb and stumbled off the sidewalk. To our astonished query he replied, "I saw the wall there [points left] and thought, well now you go right, since that's the way to be sure to get there. This proves to me that I saw the wall correctly in the first place and that I don't have to make any more corrections!" While walking near walls, the correct situation (mediated via touch or even via expectation of touch) becomes so strongly impressed upon the subject that the visual picture suddenly falls in line . . . but this isn't a sudden reversal; the picture remains the same, but it is experienced differently.

The subject was thus able to maintain for a while the situation of the correct visual experience, and could make further observations: for example, he could note whether everything was really in order. Very paradoxical impressions resulted. Approaching pedestrians were seen on the correct side, but their right shoulders were seen on the subject's right side. Inscriptions on buildings, or advertisements, were still seen in mirror writing, but the objects containing them were seen in the correct location. Vehicles driving on the "right" (and the noise of the motor agreed) carried license numbers in mirror writing. A strange world indeed! It is immediately clear that an optical reproduction of this sort is impossible. Either the sides of the street should be reversed along with the number and everything else, or, if we go to the trouble of reversing the numbers alone, the order of the numbers should not change. But even this does not happen, for the subject is capable of localizing both sides of, say, a "3" correctly (open to the left, the curves to the right) and still see it mirrorwise! What is involved here is a split between, on the one hand, a new right-left emerging from kinesthetic experience and, on the other, the simultaneous continuation of old memories of forms of letters and numbers. And in this state it sometimes happens that such optically nonfitting impressions have a further disturbing effect upon the otherwise correct orientation.

In any case, the new right-left requires a situation with strong tactile components (Kohler, thirteenth day). "Today I tried walk-
ing over inclined meadows and paths [see Fig. 3]. At first the impressions are very contradictory. I feel myself closest to the ground where it appears furthest away. But this impression does not last for long. More and more frequently it alternates with a particularly satisfying feeling that 'everything fits,' especially, it seems, the more dangerous and steep the incline. At such moments of course I have no time to be critical about my images; the tactile impression transmitted by hand and foot wins out every time, and suddenly everything 'fits together.' But when I have reached the foot of the incline, a region of much less danger, then I notice that the optical picture is 'really' reversed, and I wonder why I had not noticed this during the descent itself."

![Fig. 3]

Observations of this kind became more and more frequent, and were tested in all kinds of situations: for example, when subjects walking over a narrow board were pushed off sideways by the experimenter, everything was suddenly in order at the moment of the push; at other times, however, the subject would be in doubt whether the right foot was visually "right." Likewise when descending stairs at an angle, or bicycling when the gaze is directed at the handle bars. No doubt about it: the tactile steering to the right and the visual impression of this procedure harmonize beautifully; but as soon as one begins to probe into this and consider the visual picture "by itself," the visual impression immediately becomes contradictory. Split phenomena also occur: the bicycle bell continues to appear on the unusual side of the handle bar (even though the hand bar, when moved, looks appropriate), and the street as well as the whole traffic situation remain reversed.

Still more information was obtained from the following (Kohler, fifteenth day). The subject was instructed to hold a rod parallel to a diagonal line drawn on a blackboard (line CB in Fig. 4). "If I place the rod directly on the line CB and then remove it, stepping back but still keeping the rod at the same inclination and within my field of vision, the sides of the figure have a strange dual meaning with regard to right-left. The part of the figure upon which my right hand rested a brief moment ago still belongs to the region of my right hand, and in this sense lies to my right; in fact, I see it to my right as long as I refer it to my hand. But at the same time there is a definite leftness in the background of my conscious experience which also refers to this side of the figure. Whether the corner of the figure is seen as right or left therefore depends entirely on whether I take my hand into account!" One should add that it
is not so much a matter of the hand as such but of the whole body feeling connected with it. In fact, it helps in getting the right impression if you first press strongly against the blackboard and then, upon stepping back, think about taking a swing at B. Even so, the letter B remains reversed.

This method of “including behavioral connections” eventually carries over to objects that are not directly accessible to touch. One’s own reflection in the mirror is an interesting precursor here. It does not look “crossed over,” as it did initially, but like any other reflection in a mirror. When one walks on the street at night, not only does one’s shadow (Fig. 5) make the “same” head movements as one’s body, but the side of the street has a definite “right quality” when the head is inclined to the right; the subject sees himself on the correct side of the street for the first time. One is better off here not to think about this too much, but to abandon oneself to the total impression. A critical attitude immediately awakens all the old memories of the way the street formerly looked and ruins the present impression, so that “strictly speaking” the side of the street really looks left. This, however, by no means precludes the possibility that the shadow’s head may still be seen as moving to the right.

To summarize: when objects are brought into a new behavioral relationship with one’s body, they can be seen in correct perspective even though they may still look “unusual,” that is, “reversed,” with respect to their “lineal direction.”

So much for the experiment with spectacles. Peculiar experiences, however, did not cease at this point; they continued after the spectacles were removed. Figure 6 shows a situation about which the following (condensed) report is relevant: “I see the picture to the left of the printed page: my right shoulder faces the text and my left the picture. The runner in the picture itself looks familiar [the subject had seen the picture before but not during the experiment]; he runs toward the right, as before. But the edge toward which he is running is the left one! How is this possible? At the same time I see the page number at the lower left even though the printed page is to my right!” When the experimenter asked the subject to read the number, the subject did so easily. The numerals looked all right too, except that the 4 in 46 was to the right of the 6. When a critical attitude was adopted toward the visual experience, strong inhibition and nausea resulted. This phenomenon was of course tested

in other ways also. The immediate aftereffects lasted several hours; some, however, remained for much longer (up to two weeks; for example, apparent movements upon change of position of the head and body).

Subject Grill (with his longer period of thirty-seven days) went
beyond this stage, and eventually achieved almost completely correct impressions, even where letters and numbers were involved. In reading, for example, the first words to rectify themselves were the common ones, whereas those that had to be looked at attentively remained reversed (even though the line of words as such started on the left and ended on the right). After much practice, "mirror reading" became so well established and previous memories so secondary that even print looked all right, as long as attention was not too critical. Following removal of the spectacles, however, the whole room was seen mirrorwise; p's were seen as q's, b's as d's, and on a clock face 10:30 was read as 1:30. When long texts were employed, a sort of mirror writing appeared between the lines (an observation also made by subject Marte with spectacles reversing up and down). Grill in fact was capable of seeing two points of light when only one was presented (and this happened even monocularly). When the source of light, for example, was slightly to the right of his median line, he reported seeing two lights, a weaker one on the left side symmetrical to the original light, etc. But these are details which space does not allow us to go into.

In the light of our observations, many comments of Stratton's become clearer: for instance, his saying that one aid toward correct seeing is to stamp the foot; or his lack of awareness, when sitting in a rocking chair wearing reversing spectacles, that everything is reversed until he starts to think about it. Always there is the same emphasis upon the effects of movements, of even the mere intention of movements, upon the harmonization of vision and bodily experience. Many paradoxical results that we obtained with up-down reversing spectacles can be similarly explained: for instance, the falling downward of snow from trees that are seen as upside down; or the impression that the floor is where it should be but that people are standing upside down on it. Dr. M. was often at a complete loss about the determination of up and down, and said: "If I don't influence visual experiences with my sense of touch, the seen world remains foreign to me... I must enter the picture myself."

In this fashion the rehabilitation experiment is capable of bringing to light relationships which, in our accustomed environment, have long since become undifferentiated units. By the manner in which these connections are first disturbed and later built up anew, some basic lines of the original development of "directional vision" may manifest themselves. The alteration shows how the creation was accomplished. Examples from the realm of perception are only special cases within the realm of all those psychological readjustments involving resistance to change.

III

In modern psychology the so-called Gestalt approach is very familiar. It asserts that, psychologically speaking, everything is related to everything else and thus no part can be studied in isolation. And when the latter is done, one must be careful not to gen-
eralize from the results of such an "atomistic" investigation to the actual situation.

There is much to be said for this approach. But to make any progress one must be able to validate postulated relationships, and to do this one is forced to deal with partial regions. This is all the more justified by the fact that not all parts of a whole are equally interrelated. There are some regions of considerable independence which may be studied on their own without harm to the whole.

Habits, among other things, form such a "state within a state." This is shown by the fact that they may run off for quite a while without disturbance, even though many important conditions have long been changed. And, conversely, new habits manifest a thoroughgoing unity in their first stage of development. You cannot lift them out by themselves because they grow under cover, in the protection of behavioral interrelationships. Now if one tries to watch this process critically at this stage—that is, if one tries to break it into its component parts (visual part, motoric part, etc.)—the achieved harmony disintegrates, and one gets what was previously strong enough to be isolated by itself: the pre-experimental visual and tactile habits. The same thing happens when one tries to test reactions as such. The laboratory tests remain negative, even though similar hand movements are already successful in everyday life. It is not enough to study the ability as such; one has to bring it into a context that is copied from real life. The manipulation of a ruler turns out correctly when the subject uses this ruler as a "shield" to guard against attack (Fig. 7), but fails when the subject is merely told that tactile reactions to visually experienced points of light must be made. In laboratory testing one often pays a price for errors of this kind.

With this in mind, the investigation of those aspects of psychic life which pertain to habit or experience can be very fruitful. The rehabilitation experiment demonstrates this well. It is particularly suited to demonstrating both the relatively rigid part aspects and the way in which new connections are formed. Furthermore, when we are dealing with perception, rehabilitation comprises both behavior and experience; at least this holds for the examples cited above. A point of view entirely oriented toward behavior will miss the most essential facts; but so will an overcritical introspective orientation. In a sense, our experiment stands midway between "behavior" and "introspection," and shows how they can be unified—provided, of course, that neither subject nor experimenter has a stake in either point of view.

To return to our laterally reversing spectacles, the ultimate result consists of the fact that right and left, in the last analysis, are not rooted in vision but in behavioral relationships. Only through manipulation of objects does the person achieve an orientation in the simultaneously perceived world. No wonder then that visual orientation (so intimately connected with the realm of action) can be compared to tactile-kinesthetic orientation; that it may even be substituted for it. Whatever appears in the neighborhood of objects which can be touched by the right hand or foot will also appear visually to the "right"—even if it is a faraway star. The experiment we have described demonstrates that the reversing spectacles may be conquered, and a new right-left relation be created, as soon as one is able to divide the world into "manipulable regions." We stand in the visual world not only with our eyes but also with our hands, feet, and shoulders. It is for just this reason that anyone who
wants to see correctly must first be able to manipulate correctly. The path to vision by way of behavior is thus no detour at all.

From the right and left thus created there splits off in the course of the experiment another right and left, which are related to the familiar and thus habitual linear form of objects. Objects always seen in a particular way before the experiment retain their pre-experimental right and left for a longer time, and are disturbing even when adaptation is relatively far advanced. Here lies the root of many paradoxical situations that result when the subject faced with an object is forced to relate the new with the old visual order. The familiar content of a picture, for example, evokes the old right and left; on the other hand, the frame of the picture is referred to another point of view and to the new right and left. Thus it happens that the person in the picture is running to the "right," even though the side of the frame toward which he is running is the "left" one.

In addition to all this, there is a cultural right and left, the result of right-handed education. But this seems very weak, inasmuch as it relates only to the ability to name correctly the sides of one's body. This should be enough to illustrate the procedure and results of such rehabilitation experiments. The attentive reader will have noticed that some of the observations described here stand in a peculiarly intimate relation to depth psychology, for example, when we are trying to discover hidden causes without further fixing unwanted aspects by overly direct procedures. The results obtained by critical introspection tempt one to draw this obvious parallel. However, this is a topic that deserves its own investigation.
BIBLIOGRAPHY


Köhler, W., & Dinnstein.—(1947), Figural After-effects in Kinetoscope.


(unpubl. Ms. a), Das Problem des Aufrechtssehens und die Lokalisation von oben und unten.

(unpubl. Ms. b), Experimentelle Beiträge zur Lokalisation von vorn und hinten.


