FORMATION OF VISUAL IMAGES

FORMIROVANIE ZRITEL'NOGO OBRAZA

ФОРМИРОВАНИЕ ЗРИТЕЛЬНОГО ОБРАЗА

FORMATION OF VISUAL IMAGES

Studies of Stabilized Retinal Images

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В. П. ЗИНЧЕНКО, Н. Ю. ВЕРГИЛЕС

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PREFACE

Students of the ontogenesis of human behavior have long been aware that in the early stages of the child's development it is impossible to distinguish between perceptual, intellectual, and operative acts. With time, perception becomes relatively independent of practical, operative actions, and thinking becomes independent of both. For this reason, general psychologists tend to forget the genetic link between perceptual, intellectual, and operative processes. As a result, thinking is investigated without behavior and behavior without thinking, or skills are investigated without perception and perception without action.

In the course of development of research into mental activity and behavior, experimental psychology has amassed a vast quantity of material and technical experience. Nevertheless, we must ask ourselves to what extent, at the present stage of development of psychological science, must the traditionally sharp lines be drawn between perceptual, mnemic, intellectual, and operative acts? Admittedly, progress in the obliteration of these artificial boundaries is gradually being made from several directions at once. A few illustrations demonstrating the value of the unification of research in the field of gnostic and practical operative processes, using the same methodology and experimental techniques, can be given.

An essential advance in the analysis of the formation of voluntary movements and skills was achieved only after the gap between the study of the structure of the image and the structure of movement had been bridged. The work of A. V. Zaporozhets showed that the key to the problem of skill formation is the study of investigative and perceptual activity, as the result of which perceptual images, regulating the course of operative actions, are formed. However, the close link between perceptual activity and skill is evident only at the stages of its formation. When skills are formed, perceptual acts do not play a visible part in their realization, and concrete forms of regulation of skills by the corresponding images become increasingly less obvious.

The situation is similar as regards the analysis of relations and connections between external, practical and internal, intellectual activity. The work of P. Ya. Gal'perin has shown that mental action is formed on the basis of external material actions, with real objects. On the basis of contemporary psychological and genetic-epistemological research, A. N. Leont'ev has given convincing proof of the genetic link between external and internal activity. He emphasizes in particular the role of transition and conversion of external, material, practical activity into internal, ideal, intellectual activity, and vice versa. However, in the sphere of thought, the developed intellectual act apparently loses its direct connection with external behavior, and no visible traces of investigative or practical activity can be found in its composition.

Modern investigations of perception have shown that the formation of the perceptual image of the situation and of actions which must be carried out in it not only precedes the formation of motor skills and voluntary movements, but itself takes place of necessity with the participation of movement. An extensive series of investigations into the problem of relations between perception and action has been carried out by A. V. Zaporozhets, V. P. Zinchenko, and their collaborators. This work has demonstrated the validity of the use of the term "perceptual action," although as yet it is applied only to genetically early forms of perception. Meanwhile, other processes, such as those of what is called simultaneous identification, cannot be regarded as actions or as particular skills (however much we talk about perceptual learning) until the motor alphabet on which they are based is discovered and studied.

In these examples, attention is drawn to the fact that it is only in the stages of formation that definite interaction can be observed between investigative, gnostic, and operative processes. In developed forms, even if this interaction exists, it is inapparent. Leont'ev pointed out that the characteristic feature of many complex mental faculties and functions is that during their formation their effector components are reduced, and when their formation is complete, they function from then on as a single entity, with no apparent evidence of their complex nature. These complex mental processes have the character of simple, direct acts.

A. N. Leont'ev claims that complex mental faculties and functions are effected through special functional organs of the brain, formed in the course of life. His use of the term organ in this context is based on A. A. Ukhtomskii's idea of "physiological organs of the nervous system." When discussing the formation of functional organs, Leont'ev points out that their effector components, initially expanded in character, gradually become reduced so that the system finally formed appears as a single, intracentral cerebral process.

However, it can be postulated that even in their final form, complex psychological structures still retain effector components which now appear in a contracted or reduced form. It may be asked what is the function of these reduced components, and how and by what methods can their role in developed forms of perception and thinking be discovered. We know that intracentral cerebral processes cannot yet be investigated by modern scientific techniques (I do not include the simulation of higher mental functions). The question thus arises: can we find other manifestations which would enable us to discover the forms of participation of action in deloped perception, and of perception in developed intellectual activity, and so on? Have the available methods of experimental psychology exhausted all their potential from this point of view? Should we continue the search for adequate methods suitable for resolving integral and developed forms of mental activity into its components? The solution to this last problem would, in particular, improve our understanding of the morphological and physiological structure of these functional organs which carry out higher mental functions.

During my investigations into the problem of image formation I put forward the hypothesis that in the course of the development, perfection, and elaboration of functions of the visual system there is a frequent interchange not only of the operative units of perception or the alphabet of images, but also of the alphabet of the motor components of perception. A detailed account of the historical, theoretical, and experimental grounds for this hypothesis can be found in the book "Perception and Action" by A. V. Zaporozhets, L. A. Venger, V. P. Zinchenko, and A. G. Ruzskaya.

The hypothesis regarding the exchange of perceptual and motor alphabets is connected with Leont'ev's idea of the formation of functional organs. However, the center of gravity of research described in the present book lies neither in the region of formation of these organs nor in the region of intracentral brain processes. My main purpose is to discover the effector components or the motor alphabet of mental processes of differing complexity. I start out from the assumption that a particular system of actions, possessing specific physical and functional characteristics, is equally essential at the stage of formation and at the stage of accomplishment of fully developed forms of perception, identification, recollection, reproduction, and performance of tasks. Reduction of the effector components, as is observed in fully developed mental functions, is never and cannot be complete. This reduction can be regarded as a repeated exchange of the motor alphabet which also participates in the realization of higher mental functions.

The plan of my experimental investigation was based on the hypothesis that before any latent forms of action participation in complex mental structures can be discovered, any idea of a strictly separate, subfunctional investigation of mental activity must be abandoned. It then becomes possible to use the whole range of methods which have been developed, for example, for the study of perception, when studying intellectual activity. The search for functional links, from my point of view, is bound to be of great value to the investigation of individual mental processes, and to help to reveal the structure of developed forms of higher mental functions.

The idea of writing this book arose through the inspiration received from my teachers who developed the system of views put forward by the eminent Soviet psychologist L. S. Vygotskii (1896-1934): A. V. Zaporozhets, who for many years directed my scientific research, P. Ya. Gal'perin, P. I. Zinchenko (1903-1969), A. N. Leont'ev, A. R. Luria, and D. B. El'konin. I take this opportunity of expressing to them my deep gratitude.

The fact that this idea has come to fruition was largely due to the ingenuity of N. Yu. Vergiles, who has developed new techniques of investigation and who has exhibited to the full the perseverance

and the skill of the experimental worker.

Much of the experimental work described in the second and third chapters of the book was carried out with the assistance of M. P. Mashkova. The fourth chapter of the book was written jointly with E. A. Retanova. The advice and critical comments given to the authors in the course of their work by D. Yu. Panov, who has shown great interest in it for many years, proved very useful. For their support and help with the investigations, the authors are grateful to V. D. Nebylitsyn, V. S. Semenikhin, A. A. Smirnov, and F. V. Sorkin, as well as to A. I. Nazarov, the editor of the book, who spared no effort in improving the manuscript.

V. P. Zinchenko

CONTENTS

CHAPTER 1

METHODS OF INVESTIGATING ACTIVITY OF THE VISUAL SYSTEM USING STABILIZED IMAGES AND FREE EXAMINATION

1.1. Characteristics of Methods of Stabilizing Images Relative to the Retina

Several methods of stabilizing images relative to the retina are now known. One of the first methods to be used was that in which a small mirror was fixed to a contact lens, and a beam of light reflected from this mirror passed through a system of mirrors and was projected on a screen. The movement of the spot of light over the screen follows precisely the movement of the subject's eye in both angle and direction. The spot of light, or simple image, thus remained stationary relative to the retina (Ratliff and Riggs, 1953; Clowes and Ditchburn, 1959).

The second method was to stop the eyes from moving. Curare blocks motor nerve endings, so that the muscles cease to work, and the eye is immobilized. In this case, all that is necessary is to fix the object in front of the eyes, and the image will be stabilized (Hechenmuller, 1965). In the third method, used by Yarbus (1956) and Pritchard (1961), the image is located on the eye itself, and thus moves together with it.

The first two methods proved to be unsuitable for the investigation of perception of complex images. With the first method it is very difficult to obtain a sufficiently bright image on the screen with angles greater than 5°; in addition, to stabilize the image in two dimensions, the reflecting mirror must actually be placed on the cornea perpendicular to the optic axis, or if the mirror is fixed to the sclera, a complex correcting optical system must be used. The second method also is unsuitable for systematic investigations, because artificial respiration must be maintained during the experiment. In addition, there is no evidence to show that curare completely abolishes eye movements.

The third method is the most suitable for investigation of perception with stabilized images. In this case, the optical system is secured to the eye by means of a contact lens or suction device. The test object is illuminated either by an external source of scattered light, or the light source itself is secured to the same suction device or contact lens. If the contact lens is used, the possibility of its slipping relative to the original position must be taken into consideration, because it may lead to artefacts. Slipping can take place because the contact lens is secured to the eye only by the molecular forces of the fluid between the eye and the lens. The need for individual matching of the inner surface of the lens and the eye also limits the field of application of this method.

The suction device, known as a cap, is either a truncated cone or hollow hemisphere, held against the eye by the pressure difference between its interior and the surrounding air, and it is less liable to slip. Various types of caps have been introduced by Yarbus (1965) for use in stabilizing images. Their design prevents the possibility of relative displacements of object and retina. By the use of these caps, perception can be investigated under stabilized conditions by means of a comparatively simple technique, and the brightness and angular dimensions of the test object can be varied widely.

A disadvantage of the method is that the duration of the experiment is limited to a few minutes. However, for most experiments (after preliminary adaptation) this time is quite adequate.

Investigations of the perception of images stabilized on the retina have shown that the stationary image, if remaining unchanged in brightness and color, is no longer perceived 1-3 sec after the beginning of its presentation. Hence, if light acting on the receptor remains unchanged in time, information about it ceases to be transmitted to the central zones. This conclusion is also confirmed by electrophysiological investigations (Adrian, 1928; Granit, 1957; Jung, 1952). Meanwhile, in order to investigate many problems in the psychology of perception, it is very important, while preserving the advantages of the cap method, to obtain a longer period of perception of the stabilized image. This is a problem with which investigators have been faced time and time again.

1.2. A Method of Increasing the Time of Perception of Images Stabilized on the Retina

Disappearance of the image during stabilization suggests that involuntary movements of the eye create conditions producing modulation of the light falling on the retina. Some workers have therefore attempted to determine the optimal frequencies of interruption of the light to enable a stabilized image to be obtained and observed for a long time. At low flicker frequencies, when the visual system is functioning under boundary conditions, there are pauses during which no information reaches the observer. These pauses significantly affect the course of the experiment: the subject loses the thread of his visual task, and so on. If the frequency of the flicker is increased, so that the apparent flicker disappears, the image also ceases to be visible because, at frequencies above critical, the intensity of illumination of the flickering light becomes equivalent to that of constant illumination. Not by chance, therefore many investigators have expressed doubts about the applicability of this method for prolonged observation of the stabilized image.

Yarbus (1965) obtained relationships connecting the rate of change of brightness of light with the brightness of the test field at which the image just appeared. These experiments could have been used by Yarbus as evidence that a nondisappearing image can be obtained under stabilization conditions. However, Yarbus (1965) categorically asserts that "the provision of optimal working conditions for the human eye requires some degree of constant (interrupted or continuous) movement of the retinal image" (p. 55; English edition, p. 59).

Adopting the contrary point of view, however, the present writers attempted to discover conditions under which the image is stationary and visible, and to discover whether under these conditions the visual system can work satisfactorily. It can be concluded from Yarbus's experiments that for the image to become visible, a change in brightness is required, yet at the same time, a subjectively perceptible change does not correspond to the conditions of normal perception, when the period of increase in brightness is followed by a period of its decrease. The search was therefore made for a method of increasing the period of perception of a stabilized image, by proceeding in a different direction. The time taken for the afterimage to die away is roughly the same for different colors (including for white light); the critical frequencies of flicker fusion are also similar for these conditions, and for this reason the phenomena taking place during presentation of white light must also apply for presentation of its constituent colors.

Let us first consider the following experiment. A colored object, transmitting only color of a certain wavelength, placed against a uniformly white background, is placed on the cap. After the object ceases to be visible, i.e., after the appearance of an "empty field," let it be displaced slightly to one side. On the part of the retina where the image of the object had previously been, an afterimage of it, of the complementary color, will appear. Meanwhile, on the part of the retina which is not uncovered during displacement of the object, the empty field remains. At the beginning of the experiment, therefore, only certain of the retinal elements sensitive to that particular color were working. When the image was moved, white light began to fall on this area, but only the elements which previously had not been working were able to respond to it, since no changes had evidently taken place for the previously-working elements. This experiment provides evidence for the existence of elements, each of which responds to its own particular color.

The alternate use of sources of light of different colors can thus provide an image stabilized on the retina which will be continuously observed without any interruptions in lighting. We have used this method to study the perception of images stabilized on the retina.

A more detailed description of the mechanism of prolonged perception of the stabilized image will be given in Chapter 5.

1.3. Experimental Methods of Stabilizing Images for Use in Research

1.3.1. Stabilizing Images with an External Source of Light. Stabilization of the objects relative to the eye has been achieved by means of caps. The body of the cap is made of duralumin, which gives it the necessary rigidity yet lightness of construction. Small indentations cut in the lower edge in contact with the sclera prevent rotatory movements of the cap. The axis of the optical system lies at an angle of 4.5° to the axis of the body of the cap, and when the cap is placed centrally it coincides with the optical axis of the eye. The focal lengths of the lenses used in this particular cap are 9 and 4.5 mm. In the first case the angle of the visual field is 30 × 30°, and in the second case 60 × 60°. The lenses are cemented achromats 4 mm in diameter. To increase the depth of sharpness, diaphragms with apertures from 0.8 to 1.5 mm in diameter were used. Black and white or colored photographic negatives were mainly used as the objects. A rotating mirror, at an angle of 45° to the optical axis, was fixed to the tube between the mat screen and the negative. This additional detail was necessary to prevent light from outside from falling on the eye. The apparatus consisted of an external source of light, illuminating the mat screen on the cap through a collecting lens. An obturator was placed between the objective of the light source and the collecting lens so that the intensity of illumination of the mat screen or its color could be changed in the course of the experiment. The obturator consists of a hollow, transparent cylinder, with film light filters cemented to its surface. The density of the colored filters was chosen so that all colors would be perceived as equally bright. The transmission bands of the filters were chosen in the orange, green, and blue regions of the spectrum. A mirror reflecting the beam of light onto the collecting lens was placed in the center of the rotating cylinder at an angle of 45° to its axis. During the experiment the system was adjusted so that the illuminated screen of the cap was slightly below the focus of the lens. In this position, slipping of the beam from the screen was prevented during rotations of the eye.

The number of rotations of the cylinder with the filters could be varied from 0.3 to 1.5 per second, thus permitting from 1 to 5 changes of color per second. In our experiments the rate of change of colors varied slightly from one experiment to another, deviating very slightly from one rotation per second.

During the observation, each color is mixed with the color of the afterimage of the preceding color, i.e., the color perceived depends on the intensity of both components and on the direction of rotation of the colored obturator. Since the brightness of the afterimage is less than the brightness of the direct image, and it rapidly reaches the threshold level, the color of the image changes continuously, the effect being dependent on the differences in the rates of extinction of the afterimages of different colors. An increase in the speed of rotation of the obturator leads to disappearance of the image, because at speeds close to the speed of fusion of the flashes, the sequence of different colors is perceived as a continuous, integral (near-white) color.

This method of increasing the duration of observation of the stabilized image has been used by the writers to investigate the various processes of visual perception: structure of the image, identification, visual search for assigned objects, passage through a maze, and so on.

1.3.2. Stabilization Permitting Alternation of Presented Images. Investigation of visual perception using stabilized images must yield data comparable with the largest possible number of facts obtained by investigation under free examination conditions. In particular, the possibility of alternating images, applied to either the same or to different points of the retina, the possibility of presentation of three-dimensional test objects, the possibility of tachystoscopic presentation of images, and so on, are of considerable interest. These requirements can be satisfied to some extent by the No. 3 cap, the design of which incorporates inertia-free electroluminescent (EL) sources.

The No. 3 cap is illustrated in Fig. 1.1. The EL plates are placed on the tube, perpendicularly to each other, and at the point of intersection of their normals there is a semitransparent mirror with coefficient of reflection of about 50%. The surface of the mirror makes an angle of 45° with the optical axis of the cap.

When the central EL source is switched on, some of the light from it passes through the semitransparent mirror and falls into the objective, while the rest is reflected through 90°. The same

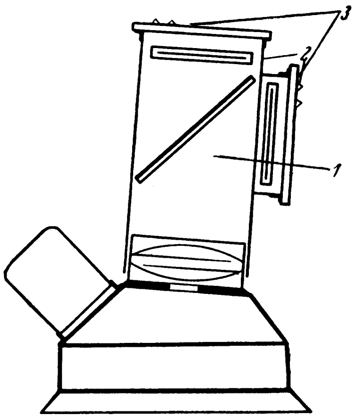

Fig. 1.1 Diagram of the No. 3 cap: Semitransparent mirror; 2) cassette with negatives; 3) electroluminescent plates.

result occurs when the side EL-source is switched on, but in this case, the reflected beam falls into the objective. For experiments not requiring superposition of images, one of the sources is removed and is replaced by a shutter. An external light source can be used instead of one of the EL-plates. Combinations of EL-sources of different colors, as well as the possibility of controlling the brightness of individual areas of the course, make this technique sufficiently flexible.

The advantages of EL-sources over other types of light sources are, not only freedom from inertia and constancy of brightness over the whole field, but also the possibility of switching over from one part of the test field to another, and the ease of control over the operating conditions. The detailed characteristics of the EL-sources and the method of their use in order to study perception will be given below.

1.4. Recording Eye Movements Used in Research

In the course of investigating perception of complex images presented by the stabilization methods described above, in order to compare the process of free examination with that of examination under stabilization conditions it was necessary to be able to record the movements of the observer's eyes. The methods by which these movements were recorded are described below.

1.4.1. Optical Recording of Macromovements of the Eyes under Stabilization Conditions and during Free Examination. Macromovements were recorded optically as shown in Fig. 1.2. For recording eye movements with stabilization of the object, the mirror was placed perpendicularly to the optical axis of the system, on the same cap as the test object.

Macromovements of the eyes under stabilization conditions were recorded in experiments with caps Nos. 1, 2, and 3.

During free examination of the object, a cap with a mirror was placed on the other eye, the movements of which were recorded. This method is possible because macromovements of the eyes are concerted. In this case, just as with stabilization, the work was done by one eye. The trajectory of movement of the beam of light reflected from the mirror was recorded by a camera placed behind a parchment screen. The exposure was equal to the time taken to complete the task.

1.4.2. Recording Eye Movements by Means of an Electromagnetic Detector. The method of recording eye movements by means of a reflected beam of light from a mirror fixed to

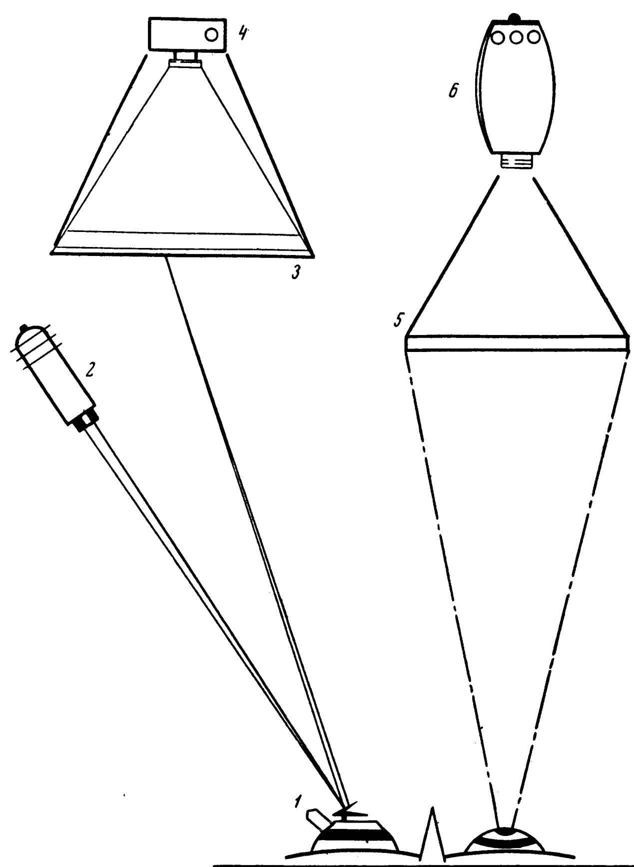

Fig. 1.2. Apparatus for optical macromovements of the eyes: 1) cap with mirror; 2) source of light; 3) recording screen; 4) camera; 5) testing screen; 6) projector.

An important feature is the speed with which the change can be made from one scale of recording to another (e.g., during encephalography) and recordings can be made simultaneously on different scales. The method as described gives an accuracy of recording of 0.5 min of angle. The experimenter has no need to adjust the optical system in each experiment, thereby saving much of the useful time of the experiment, a particularly important aspect for work with caps.

The method as described has been used to study perception both with stabilized images and with free examination.

1.4.3. Recording Micromovements of the Eye under Conditions of Stabilized Images and Free Examination. It has been estimated that tremor has an amplitude of the order of 25 sec of angle and a frequency of up to 150 Hz. In this case, the linear movement of the eye is about 1.5 μ. However, these figures apply only to the ranges of change of the tremor. Detailed analysis is difficult because of the small magnitudes, requiring highly sensitive apparatus for their recording. The optical method (recording the beam of light reflected from the mirror fixed to the cap) cannot be used to record movements less than 1'. Any further increase in sensitivity is limited by the fact that if the distance between the cap and recording instrument is long, a picture of poor quality is obtained because of diffraction, and analysis of the data thus gives results of a low level of accuracy.

By the use of an electron–optical method, in which the beam of light is reflected from a point on the boundary between the sclera and cornea, with a suitable apparatus high sensitivity can be obtained, but the reproducibility of the quantitative measurements of amplitude with this method will depend on the point of the eye on which the beam of light is projected in each experiment.

In conjunction with L. P. Shchedrovitskii we have developed an electromechanical method of recording tremor. Unlike other methods, in which the first temporal derivative of displacement is recorded, it is based on the principle of recording the accelerations of systems connected with the detector. The instrument consists of an accelerometer, fixed to the sclera by means of a cap. The signal is amplified by an ac amplifier with a transmission band of 10–1000 Hz and with a sensitivity of the order of 10^6. Assuming that tremor can be approximated by a linear combination of harmonic waves, the equation for the deviation of the piezocrystal plate, describing forced oscillations in response to a harmonic external action $a \sin \omega t$, is

$$\theta = -\frac{a\omega^2}{\sqrt{(\omega_0^2-\omega^2)^2+4\alpha^2\omega^2}} \sin\left(\omega t - \tan\frac{2\alpha\omega}{\omega_0^2-\omega^2}\right), \quad (1)$$

where ω_0 is the characteristic frequency of oscillation of the detector, and α the attenuation factor of the characteristic oscillations of the system.

Assuming that the characteristic frequency of oscillations of the detector is many times greater than the frequency of the forced oscillations, it can be taken as an approximation that

$$\theta \approx -\frac{a\omega^2}{\omega_0^2} \sin\omega t = -\frac{A}{\omega t} \sin\omega t, \quad (2)$$

where $A = \omega^2 a$ is the amplitude of acceleration of the external agent.

The amplitude and phase of acceleration are recorded with slight distortions only if the ratio ω/ω_0 is small. On the other hand, an increase in the characteristic frequency ω_0 reduces the sensitivity of the accelerometer. In practice, a compromise has to be sought between sensitivity and distortion. In making this compromise it must be remembered that a phase shift is of no significance in frequency–amplitude analysis, while distortions of amplitude are easily allowed for by the calibration of the system.

One type of system in which a barium titanate plate is used as the detector, has as its parameters the characteristic frequency of oscillations

$$f_0 = \frac{\omega_0}{2\pi} \approx 500 \text{ Hz}. \quad (3)$$

and the quality of the system

$$Q = \frac{\omega_0}{2\alpha} \approx 5. \quad (4)$$

By a suitable choice of these parameters the range of frequencies to be tested can be covered and the sensitivity can be increased because of the great rise in the high frequency region.

Analysis of the records obtained by the electromechanical method showed that it possesses high resolving power. For instance, frequencies up to 200 Hz are clearly visible on the records, although according to data in the literature the maximum frequency of tremor is 150 Hz. So far as amplitudes are concerned, this apparatus can record micromovements of the eye with an order of magnitude of 5 seconds of angle.

The sensitivity of the system is increased if crystals of Rochelle salt are used as the detectors, for they give an output signal one order of magnitude higher than barium titanate detectors. These detectors should be used whenever it is required to obtain a general picture of the distribution of amplitudes of the tremor and the lowest degree of frequency-ampltiude dependence of the recording apparatus is desirable within the frequency range to be investigated. The high sensitivity of the detector allows the resonance to be displaced into the high frequency region (about 4000 Hz) and the work can be carried out at low values of ω/ω_0.

Single detectors for recording one component, and also two detectors fixed to the cap so that their planes were perpendicular to one another, were used in the work. In the second case, the vertical and horizontal components of the signal were recorded. A loop oscillograph, a two-channel tape recorder, and an oscilloscope were used to record the results.

The advantages of this method are as follows: independence of the instrument readings of the initial setting of the accelerometer, high sensitivity, and the possibility of processing an extensive series of results by means of a frequency analyzer.

1.5. Electroluminescent Sources in the Investigation of Visual Perception

Electroluminescence arises when an alternating (pulsed) electric field is brought up to phosphorus powder enclosed in an insulating medium. The radiation is also observed during exposure to single pulses of voltage (1-10 μsec or more in duration) of sufficient amplitude, and the inertia of the luminescence process is so small that it can be disregarded in the circumstances of psychophysiological experiments.

It is convenient to use luminophors giving different colors of luminescence for the investigation: green (luminophor EL 510M, λ = 510 nm), yellow (luminophor EL 580M, λ = 580 nm), red (luminophor EL 680M, λ = 680 nm), and blue (luminophor EL 450M, λ = 450 nm). The color of luminescence of the element is determined by the chemical composition of the electroluminophor and the conditions (frequency) of excitation. With an increase in the frequency of the exciting voltage, the spectral characteristics of the radiation move toward the shorter waves, but the color changes are slight. For instance, with a change in the frequency of the sinusoidal supply voltage within the range 50-20,000 Hz, the maximum change in color for luminophors giving green luminescence is 3-4 color thresholds. In the case of luminophors giving blue, yellow, and red luminescence, the changes in color are negligible.

The range of change in the brightness of luminescence of the EL-sources (from 0 to 1000 nit) is determined by the magnitude and frequency of the exciting alternating voltage. The power consumed depends on the area of the excitable surface of the electroluminophore (Sorkin, 1965).

Power units for controlling the working conditions of the EL-sources can be audiofrequency generators working within the range 1-10,000 Hz. Changes in the frequency of supply voltage alter the tint of the color, and this is evidently convenient for many experimental cases. To control the duration of the flashes and their order, besides electronic modulators, relay circuits can be used, although the operating time required for switching over the relay circuit in most cases is between 50 and 500 msec. The use of polarized relays in simple circuits reduces the operating time to 10-20 msec. However, the high electrical capacity between the broken contacts of the relay, mainly because of the short distance between them, does not permit complete extinction of the EL-sources. This is particularly apparent when small sources are used, and the capacitive impedance of the EL-source is comparable with the capacitive impedance of the contact group. This phenomenon can be eliminated to some degree (in time) by including additional contact groups, short-circuiting the nonworking element to itself. For inertia-free control, electronic circuits free from the disadvantages of relays can be used. One type of control of the EL-source is an electronic modulator unit. With this type of unit, not only the duration and the order of the flashes on the screen can be controlled, but also the character of the increase in brightness which, in the case of relay circuits, is extremely difficult to achieve. Generators of periodic or single oscillations as well as programmed instruments have been used as controlling units. The actual circuits of the units can vary very considerably, and there is no point in discussing them further because they have already been described in detail in the radio-engineering literature.

Because of these properties of the EL-sources, they can be used for a number of psychological experiments both under free examination and under image stabilization conditions.

1. To determine the frequency of fusion of flashes and also of flickering shapes consisting of several separately excited lamellae.

2. For tracking purposes, and for equalization of brightness, of flicker frequency, and so on.

3. For tachystoscopic investigations. This can be done by means of a combination of a tape-winding mechanism and an EL-source. Photographic negatives are used as the test pictures. Exposure is timed by an electronic time relay.

4. To investigate apparent movement (phi-movement). Two EL-sources are controlled by an electronic commutator with two outputs. Commutation of a larger number of sources is possible. For instance, for commutation of four fields a mechanical commutator capable of regulating the speed of switching the fields and also the time interval from extinction from one field to triggering of another field, can be used. The brightness of each field can be set differently. In this combination, apparent movement on two pairs of lines can be investigated simultaneously. Photographic negatives are fitted on the EL-sources, so that the length and thickness of the lines and the distance between them can be varied easily. Different colored fields of EL-sources can also be used to study apparent movement.

5. To investigate the formation of orientation and illusions of orientation under stabilization conditions. In these experiments, orienting objects are presented with one source switched on, and control objects with the other source on. This system guarantees projection of the picture only on specific areas of the retina, and two different pictures can be projected simultaneously or in any given order on the same area of the retina.

6. To investigate afterimages formed under stabilization conditions without conscious perception of the direct picture. This can be done in cases in which a gradual increase in brightness of the EL-source is brought about more slowly than the eye adapts itself to the stabilized image.

The methods described above have been used both separately and in various combinations in experiments.

1.6. Artificial Restriction of the Field of Vision

Restriction of the field of vision to 3.5-4° has been achieved by the use of a central cap, with two shutters, each having holes in their center, inside the tube. During the experiments, an electromagnetic recording was made of the eye movements, giving details both of the trajectory of the movements and the duration of the visual fixations. The cap was placed on one eye. A shade was placed in front of the other eye.

This method can be used to determine the characteristic identifying features, to investigate the strategy of familiarization and recognition, and other psychological problems.

The following features of visual perception when the field of vision is artificially restricted make this possible.

Subjectively the field of vision was perceived in the same way as an unrestricted field of vision, i.e., the subject saw the center clearly and the periphery diffusely. This is because of diffraction of light. As a result, there was a smooth transition from a zone of clear vision to an empty field, characteristic of experiments with stabilization of images on the retina.

The recognition of objects smaller than the investigated field of vision took place just as under free examination conditions. The recognition of familiar objects larger than the field of vision required eye movements around their outline, and the search for characteristic identifying features. The eye moves strictly around the outline and does not go outside or inside the figure. The formation of an image of unfamiliar curvilinear figures with the aid of a narrow field was either extremely difficult or impossible, showing the difficulty of recollection of proprioceptive information arriving from the eye muscles. Operations of searching for and counting objects (points, numbers, and so on) outside the narrow visual field are extremely difficult. The observers have difficulty in transferring the eye from one object to another, especially if there is only one object in the field of vision. The amplitude of the searching movements is equal to half the diameter of the narrow field, occasionally reaching the whole diameter, but as a rule never exceeding it.

During fixation of a point, rapid drift and reverse saccades are observed. During the observation of a field without reference points, the rapid drift of the eye takes place in a much larger area than during free examination (5-6° compared with 40'). During the counting of a series of vertical lines the distance between which is greater than the size of the narrow field, the duration of fixation on the lines is 800-1500 msec, and on the spaces between them 200-350 msec.

During presentation of three-dimensional objects at different distances away, they are perceived as flat objects side by side. Perception in a narrow field is inconstant.

1.7. Conclusion

Despite the fact that the stabilization phenomenon and the method of stabilization of images on the retina have been known for about 20 years, no particular importance has been attached to them until recently. Stabilization has been used more as a method of investigation of special psychophysical problems. These include, for example, the possible connection between visual activity and eye movements, for the investigation of which tests were presented stabilized, and the problem of the connection between the critical flash frequency and disappearance of the image. The very numerous investigations carried out under stabilization conditions give the impression of a new phenomenology of vision. The investigators describe the facts which arise under unusual conditions created for the visual system. These facts are concerned with the perception of objects of constant and alternating brightness, the perception of flickering objects, the perception of objects changing in color, and so on (Hechenmuller, 1965; Yarbus, 1965). The importance of the stabilization method for the solution of traditional psychological problems such as the relationship between figure and background, between the whole and the part, the associativeness or "Gestalt"-ness of the image has been assessed by Hebb (1963) and some of his collaborators (Pritchard, 1965). However, these workers used the stabilization phenomenon only as a somewhat exotic method of investigation, and they did not pay particular attention to the refinement and improvement of the experimental technique. Essentially the only object for detailed study was the phenomenon of fragmentation. This is the term used to describe how and at what time the image disappears on stabilization.

The merits and advantages of the stabilization method, which from our point of view make it universal in character, are as follows.

The method allows an image to be presented to the same point of the retina, which cannot be done by any other method.

The method enables movements of the observer's eyes to be eliminated and the principles governing the working of the visual system to be investigated quite apart from any "motor noise" of the eye, and at the same time it can help to define the functions of the oculomotor system.

The method of stabilization of images can be combined successfully with various other methods for recording macro- and micromovements of the eye.

The stabilization method can be combined successfully with the recording of electrophysiological indices of the activity of the visual system.

The stabilization method allows virtually any tests used in psychological investigations of vision to be presented to an observer. The only limitations apply to three-dimensional and moving objects.

The stabilization method allows wide variation of the phototechnical and temporal characteristics of the stimuli, including flashing, variations of color, brightness, and contrast changes in the angular dimensions of the images, and so on.

The stabilization method thus provides much wider opportunities than other known methods of investigation of vision under free examination conditions. Its most important merit is that the oculomotor and sensory functions of the visual system can be separated. It was this type of separation which the tachystoscopic method of investigation attempted to attain. However, tachystoscopy has rightly been regarded as a method of exhaustion of the stimulus because of the short time of its presentation.

CHAPTER 2

NEW DATA ON PERCEPTION UNDER STABILIZATION CONDITIONS

2.1. Perceptual Actions and the Problem of the Successiveness and Simultaneity of Perception

Perception serves the subject's productive activity, is formed together with it, and bares the imprint of this activity. As long ago as the 1930s, B. G. Anan'ev, A. V. Zaporozhets, A. N. Leont'ev, B. M. Teplov, and others began their systematic investigations of the genetic and functional connections between perception and activity. Later, similar investigations were carried out by Piaget and his collaborators. As this cycle of investigations increased in breadth and depth, its authors gradually transferred their attention from establishing the general relationships between perception and activity to a detailed investigation of the effector components of perception, i.e., to the study of movements implicated in the perception process and performed by receptor systems.

An analysis of these movements enabled Leont'ev to postulate that the mechanism of sensory reflection is one of simulation of the properties of the stimulus by the effector components of perception (Leont'ev, 1959). Further investigation of the characteristics and functions of movements of receptor systems led to the conclusion that perception is formed as a result of a suitably organized system of perceptive actions, performing orienting or investigative functions and resulting in the formation of an image and its recognition (Zinchenko, 1961).

The main conclusions of what Piaget called the "praxeological"* concept of perception were described at a special Symposium of the Eighteenth International Psychological Congress (Symposium No. 30. Perception and Action). In his paper, A. V. Zaporozhets, the organizer of the symposium, described an extensive series of investigations of the ontogenesis of human perception. These investigations provide convincing evidence in support of the genetic and functional link between practical and perceptual activity. Perceptual processes are initially formed and develop as organic components of practical activity, and the elucidation of the special features of the perceived situation is the global effect of this activity as a whole. Operations of identification and analysis of the features of the object arise in the course of practical, manipulative activity.

However, as the child's activity increases in complexity, and he is faced with increasingly difficult gnostic problems, the limitations of the purely practical familiarization with an object become apparent, and the need for special orienting and investigative perceptual actions arises. The process of branching of perceptual actions from practical was studied by Podd'yakov (1966), who observed the transformation of practical actions into practical trial-and-error actions, and of these into truly orienting and perceptual actions.

The special perceptual actions formed first were externally similar to manipulative actions.

*I use the term praxeological here as a convenient abbrevation to describe mental formations with practical actions as their genetic basis.

This similarity is observed even in cases involving distant receptors not in direct contact with the objects. It is not by accident that many writers, starting with Euclid, have noted the similarity between movements of the hand and of the eye. Later I shall call these actions external perceptual actions.

The investigation of the formation and development of perception has led to the differentiation of relatively independent processes, differing in the composition of their perceptual actions into processes of image formation and processes of recognition of what is already familiar and known. The formation of these processes in children of preschool age has been investigated experimentally in relation to the visual and tactile perception of form (Zaporozhets and Zinchenko, 1967).

Analysis of the trajectory of hand and eye movements showed that the process of image formation incorporates the following perceptual actions: the search for and finding of the object; the identification of the informative content of the object with specific reference to the task; familiarization with the content thus identified. Depending on the subject's age, these external perceptual actions show different degrees of contraction. For example, children aged 3 years cannot yet distinguish outline as an essential informative feature, but base their assessment on other features of the object, resulting in nonqualitative familiarization and to mistakes of subsequent recognition. Children aged 6 years examine the outlines of objects in detail, and the form of their action becomes isomorphic with the form of the object examined. As a result of the performance of these initially expanded, succsssive processes, an image or perceptual model of the object is created. However, the image does not remain static and unchanged. It is undoubtedly an adequate representation of the object, since the form of activity in which it was embodied resembles the form of the object. However, at the same time this image possesses the quality of subjectivity. In other words, properties and features relevant to the subject's task are embodied in the image.

Not all information received is relevant to these tasks; as a rule it must be transferred and reduced to a form suitable for consideration in behavior. It is only thus that images of perception can enable operative and timely orientation within the situation to be achieved and adaptive behavior to be regulated.

When the image has been formed, identifying and reproductive actions can take place. In the first stages, the process of identification largely resembles the process of familiarization. It includes the same external perceptual actions, such as finding the object and picking out cues adequate to the task. When these cues have been selected, the object presented is compared and identified with a standard recorded in the memory.

If the object contains many essential features, the process of comparison takes place an element at a time, and the more numerous the features in the object and in its model created during familiarization, the longer this process will last. This corresponds to the detailed and apparently repeated examination of the object. However, as the alphabet of objects is learned, the character of the process of identification changes. Comparison is sharply contracted through the discarding of superfluous and unnecessary information, through the distinguishing of critical and supporting features, and through the transformation of groups of individual, special features into structural and integral features.

As a result of this organization of individual features into structures, the observer's analysis of information is speeded up, the identification and reaction times are reduced, the load on the observer's operative memory is diminished, and more favorable conditions are created for anticipation and prediction compared with the action at the preceding level.

Many factors concerned with the acceleration of identification processes were discussed at the Eighteenth International Psychological Congress, at the Symposium dealing with the problem of signal finding and identification (see the paper by B. F. Lomov, organizer of the Sixteenth Symposium, and also the papers by T. P. Zinchenko, M. S. Shekhter, and others).

On the one hand, therefore, perceptual actions become isomorphic with the object in the process of development. Later, with the conversion of perceptual actions into actions of identification, this isomorphism is lost and the latter begin to take place without the external motor accompaniment. The operations of finding the object, picking out the informative cues, and comparing them occupy fractions of a second. The following question, important from both the theoretical and practical points of view, accordingly arises: what is it that enables simultaneous perception and identificiation to take place, what are its mechanisms? However the cues are reorganized and regrouped, this cannot mean that they disappear altogether. However the composition of the identifying actions is contracted, they can never disappear completely.

A unique situation thus arises. Genetic investigations provide weighty evidence in support of the interpretation of perception as an action and they provide a basis for the understanding of qualities of sensory cognition such as activity, subjectivity, and the adequacy of the image as a representation of reality. However, this interpretation cannot be extended to the higher forms of perception until the problem of how simultaneous perceptual processes actually and materially take place has been solved. Unfortunately, this is the most difficult problem in the study of perception and identification. For the most detailed discussion of the arguments relative to this problem the reader is referred to the book by Zaporozhets, Venger, Zinchenko, and Ruzskaya (1967) and that of Shekhter (1967).

To investigate this problem, we have studied the processes of image formation and identification under conditions when the image is stabilized on the retina. Color modulation of the stabilized image, allowing the time of perception to be prolonged virtually without limit, enables the work of the visual system to be investigated under conditions in which the subject is unable to use at least some of his arsenal of perceptual actions. I consider that this artificial subtraction is useful, especially if it is borne in mind that certain elements of preceding forms are reduced in the higher forms of perception. It is generally accepted that the effector components are reduced first, and the change can then be made from successive, expanded perceptual activity to simultaneous, contracted perception. It will be easy to understand that the method of prolonged stabilization can serve as a specific test model of the "natural" process of reduction.

2.2. Comparative Investigation of Perceptual Processes under Free Examination and Stabilization Conditions

2.2.1. Tasks Presented to the Subjects. The methods used in the experiments were described in 1.3.1. The angular dimensions of the field seen by the subject were 30 × 27°. A mirror placed on the cap allowed the eye movements to be recorded during examination of the stabilized image. Photographic negatives were found to be most suitable for use as test pictures.

When choosing optimal conditions for the perception of the stabilized image, the subjects reported fluctuation of the image and its elements. After they had discovered the optimal conditions, the subjects continuously saw a stabilized image throughout the experiment, the duration of which varied depending on the difficulty of the problems, and in some cases lasted as long as several minutes.

Because prolonged examination of the stabilized image was not possible, the subjects could be presented with widely varied and difficult visual tasks, so that the comparative characteristics of perception of ordinary and stabilized images could be obtained.

In the experiments with stabilization of the visual image, the following tasks and objects were used.

1. Familiarization with an object new to the subject. Japanese characters (angular dimension 7-8°) were used as the objects. After the subject had become familiar with one character under stabilization conditions, it was looked for among other characters under ordinary conditions.

2. The search for familiar objects (Arabic or Roman numerals) in tables of figures of different density. The subject looked at a stabilized image of the table and worked under the following conditions: a) naming all the figures in the table line by line; b) searching for the figures using coordinates; c) listing particular numbers together, for example all the two's, all the three's, and so on. The angular dimensions of the tables used were 15 × 15°. This is a convenient task because it has been well studied under free examination conditions (Gould and Schaffer, 1965). These workers describe results characterizing the eye movements of subjects searching for assigned numbers in tables of figures.

3. Familiarization with and search for unfamiliar objects in a table. The subjects were shown a table in the top corner of which the test figure was underlined. A second similar figure had to be found among the other figures in the same table. The angular dimensions of the table were 15 × 15°.

4. The search for the way through mazes differing in their degree of difficulty. To verify their correct passage through the mazes used in the tests, the subject had

no need to draw or to indicate the way which he found out of the maze, but had only to call out the number of circles at the crossroads in the mazes. The rule for finding the way through mazes of this type is to find a path from the lower border to the upper border which has the largest number of circles. The subject must "move" either to the right or to the left, but he must move upward every time, never turning back. For the mazes used, the number could be 3, 4, 6, and 7 circles. The angular dimensions of the mazes were 25 × 30°.

5. Counting similar elements placed close together. Thickness of the lines 30', thickness of the spaces between them 30'.

6. Determination of the position of the gap in Landolt's rings. The subject was shown a chart on which there were three rows of Landolt's rings, and he had to indicate the position of the gap in each ring in a certain order. Angular dimensions of the chart 15 × 15°, thickness of the gap 10'.

Before each experiment, in addition to the instruction to do with the visual problem, the subject was also given instructions limiting eye movements. Individual tasks were investigated under three conditions:

a) Solve the problem by fixing a certain point on the test object;

b) Solve the problem by fixing a control point with the other eye (on which no cap was placed). This method proved useful, because it limited the subject's eye movements;

c) Simply solve the problem without any restriction on eye movements;

During the experiments the following parameters were recorded:

a) the correctness of the subject's reply;

b) the time from the beginning of presentation to the subject's reply;

c) the subject's eye movements during solution of the problem. The movements either of the eye examining the stabilized image, or of the other eye, to which a special cap was secured in these cases, were recorded.

Before describing the results, it should be noted that the large number of tasks presented to the subjects in these experiments is explained by the fact that we could not find a task which could not be solved with the image stabilized relative to the retina. As the subjects solved one problem, they were presented with another which was more difficult and, in particular, which was apparently impossible without eye movements. For this reason, most of the tasks which we used are tasks of visual searching.

Three adult subjects (students) took part systematically in the experiments, and a few other people – psychologists wishing to familiarize themselves with the stabilization method – also took part in them periodically.

All the subjects stated that changing the color of the objects does not disturb perception or the solution of the problems. One female subject drew attention to the changing color only in the second experiment, after she had been asked about colors.

2.2.2. Experimental Results. The chief result obtained in these experiments was that all the problems presented were solved by the subjects. The quality of the solution in individual cases depended on how the cap was placed, on the subjects' individual differences, and so on, but the sufficiently large material (more than 100 experiments in all) proves convincingly that, in principle, the whole series of problems presented to the subjects can be successfully solved with the image stabilized relative to the retina.

All the subjects stated that they had a clear impression that their eye (or attention) moves over the object. This subjective impression was matched by the well-marked and recordable movements of the eyes. The subjects stated that the fixation movement over the stabilized image differs from its movement together with the stabilized image. Moreover, eye movements of large amplitude impaired the fixation movements over the image. Conversely, movements of low amplitude facilitated this movement. If the subjects were prohibited from moving their eyes while solving the problems, no complex searching problems were successfully solved. It did not matter whether the subjects fixed a point on the test object or whether they fixed a control point with the other eye.

Let us now turn to a more detailed description of the performance of individual tests.

Task 1 (familiarization with the Japanese character) gave rise to no difficulty. The subjects carefully examined the outline and stated that it consists of familiar elements, and they determined and memorized their spatial relations. After the cap

TABLE 2.1. Searching Time and Visual Fixations during Image Stabilization

Parameters Measured	Listing assigned numbers	Searching by coordinates
Mean searching time	9.1 sec	3.6 sec
Mean number of fixations	12.6	4.6 sec
Mean duration of one fixation	0.7	0.8 sec
Number of fixations per second	1.4	1.3

had been removed the subjects found the required character without any mistake among the eight other characters of similar shape. The time required for familiarization with and memorization of the character was 8-10 sec.

Task 2 was also solved by the subjects under all conditions. The easiest conditions were searching for the numbers by coordinates. The subjects made more mistakes when searching and counting assigned numbers. They mentioned some difficulty in the successive scanning of the table, especially of its lowest part. Subject M. K. preferred to examine quarters of the table in succession and then to add together the number of figures sought in each quarter. The subjects stated that the presence of a grid facilitates searching, especially searching for Roman numerals by coordinates (Fig. 2.1).

Results showing the mean duration of the search and the mean number of eye movements performed by the subjects during searching are given in Table 2.1.

Comparison of these results with those obtained by Gould and Schaffer (1965) shows that searching on a stabilized test object requires a much longer time than under ordinary conditions. The frequency of the eye movements, on the other hand, is considerably lower (of the order of one per second with the image stabilized compared with three times per second under ordinary conditions). Considering that the number of eye movements under ordinary conditions is about equal to the number of eye movements during stabilization, the slowing of searching in the latter case may be attributed to the lower frequency of these movements. At the same time, the decrease in amplitude of the eye movements compared with the angular dimensions of the tables suggests that work with objects under stabilization conditions takes place with the aid of a larger operative field of vision than under free examination conditions. This picture is outwardly similar to the work of the eye under searching conditions during free examination in the case of trained subjects, and it is in contrast with the test involving listing the numbers (Fig. 2.2), when the eye pauses on each of the cues presented.

Task 3 required familiarization with a figure and its discovery in a test field, in one case among four, and in another case among eight figures. In

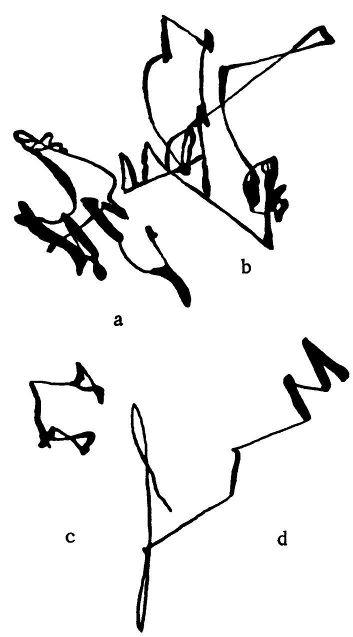

Fig. 2.1. Test table and trajectory of eye movements in different tasks: a) searching for numbers without a control point (duration of search 5 sec); b) the same with a control point (duration of search 9 sec); c) searching for number with coordinates 2, 3, with a control point (duration of search 3 sec), d) the same, with coordinates 2, 5, and without a control point (duration of search 3 sec).

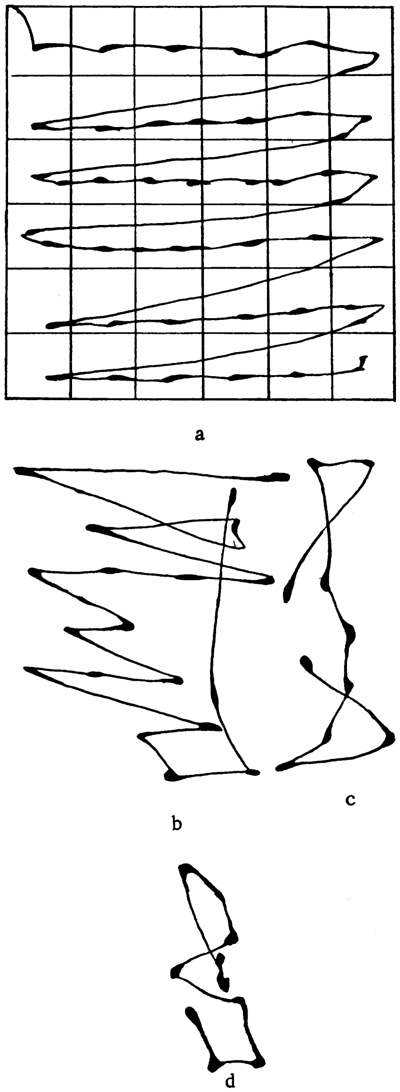

Fig. 2.2. Trajectories of eye movements during solution of problems: a) listing numbers with fixation on each number; b) search for numbers by an untrained subject; c) search for numbers by a trained subject – (d) same, under stabilization conditions.

the first case, the time required to solve the problem was 3-5 sec, and in the second case 18 sec.

Task 4 (seeking a way through a maze) likewise was solved successfully by the subjects. The time required for the solution varied and it did not always correspond to the difficulty of the maze.

Subject M. K. required the following times to solve problems with the specified maximum number of points: 3 points – 33 sec; 4 points – 10 sec; 6 points – 18 sec; 7 points – 43 sec.

It will be recalled that the angular dimensions of the maze were 27 × 30°. Seeking the way through the maze without movements of the eyes (for example, during fixation on a point in the center of the maze) was impossible whether under stabilization or ordinary conditions. When solving the maze problem the subjects reported (as, indeed, they did during other tasks) that the zones most difficult to perceive were the corners at the ends of the diagonals. The fact that the subjects could solve this problem convinced us that it is possible to solve a searching problem of virtually any difficulty under stabilization conditions. The next tasks were therefore somewhat different in character.

Task 5 (counting lines) is a test which has been well investigated recently (Gippenreiter, 1964). The subjects could easily count groups of up to 4 or 5 lines in any part of the field of vision measuring 15 × 15°. When the number of lines was increased to 6-7, they made mistakes. The solution of this problem was thus considerably impaired compared with its solution under ordinary conditions.

Task 6 (determination of the position of the gap in Landolt's rings) was solved correctly and the mean time required for solution was 1.1 sec per ring.

Examples of the trajectories of the subjects' eye movements during these tests are illustrated in Figs. 2.1-2.2. The figures are drawn in such a way that the same scale of magnification of the test objects and trajectories of movement is observed. In its angular dimensions, the zone within which the movements are performed is 2-3 times smaller than the object presented. Attention is drawn to the absence of strict fixation of the eye on these records. Saccades at once change into drift (the thicker lines on the illustrations), and drift changes back into saccades. As a rule, drift was observed in relatively untrained subjects, when tracking movements after an image located a short distance from the fovea developed. From the subjects' reports, it appeared to them as if the image was swimming away, but they did not observe any slipping of the eye toward the same side. The absence of strict fixations was evidently due to the fact that the position of the eye was controlled mainly by the optical input rather than by proprioception. Under stabilization conditions, the subject therefore had no criteria on which to assess the position of his eye, or its fixation in a particular position. Records from the two eyes were indistinguishable. When the subject was given a control point, the drift was less and correcting saccades returning the eye to the control point were observed.

The most interesting phenomenon in these experiments, and the one most difficult to explain, is the movement of fixation over a stabilized image. We postulated that this movement can take place on account of movements of the lens. The possibility of such relatively autonomous movements of the lens was stipulated originally by Helmholtz. S. V. Kravkov, summing up a discussion on this problem, supported Helmholtz' view. To verify this hypothesis, we carried out a controlled experiment with a subject who was given injections of atropine regularly for 3 days to paralyze his ciliary muscle. He was then asked to solve Tasks 4 and 6. He solved both tasks correctly and without difficulty. He noticed no difference between the conditions of perception of the stabilized image before and those after the injection of atropine. The possibility of fixation movements over the test field remained completely intact.

2.3. Discussion

In the experiments described above the subjects were shown unfamiliar geometrical shapes, Japanese characters, complex mazes, tables of numbers, and so on. The subjects solved all the problems presented to them fairly easily, and they remarked on the fact that their eye (or attention) moved over the object. Accordingly, under stabilization conditions, during the solution of difficult visual tasks a mechanism compensating for image stabilization relative to the anatomical fovea comes into operation, and it can be likened to a functional fovea moving over the field of perception. This mechanism enables the subject to perceive successively information falling on different parts of the retina. A phenomenon of "ideal" attention, not directly connected with the position of the eye, was thus obtained in the experiments. When the image was stabilized relative to the retina, attention was directed arbitrarily to different points of the image, and the subjects were not aware of any difference, in principle, between perception during free examination and under stabilization conditions.

A decisive argument was thus apparently obtained, not for the concept of perception as an action, but against it. However, one fact prevents this conclusion from being drawn. The subjects' subjective impression of the movement of attention, or internal fixation, corresponded to well marked eye movements recordable during the stabilization experiments. When, on the other hand, the subjects were instructed not to move their eyes during the experiment, they were unable to solve difficult searching problems or familiarization problems.

A similarity was also found between several characteristics of oculomotor behavior under completely different conditions: both during stabilization and during free examination, the number of eye movements was about the same during the solution of identical problems. Eye movements under stabilization conditions are thus just as necessary for the solution of difficult visual tasks as under the conditions of free examination. This is all the more surprising because eye movements during stabilization apparently cannot perform the function of orienting the eye, the function of choosing the most informative areas of the image, since the test object moves together with the eye. The eye movements were 2-3 times smaller in amplitude than the angular dimensions of the objects presented. According to this feature, the movements during stabilization resemble posttachystoscopic movements of the eyes. We shall discuss this comparison again below.

The principal problem encountered in the discussion of these results was thus to explain the mechanism of movement of internal fixation or attention reported by the subjects and to ascertain the relationship of eye movements to this mechanism. As observation showed, the direction of the eye movements under stabilization conditions was always connected with the location of the assigned object in the visual field. The discovery of objects in various parts of the visual field requires different positions of the eye. The discovery of objects in the same part of the visual field requires similar positions of the eye. This suggests that, with the eye in different positions, the role of different receptive fields of the retina varies, i.e., one field is activated and the others are inhibited. With this approach, the function of the eye movements taking place under stabilization conditions during the solution of difficult visual tasks can be regarded as a mechanism of successive and purposive activation of certain receptive fields of the retina corresponding to the essentially informative parts of the image. E y e m o v e m e n t s t h u s o r g a n i z e t h e m o v e m e n t s o f a t t e n t i o n i n t h e v i s u a l f i e l d e v e n i f t h i s f i e l d i s s t a t i o n a r y r e l a t i v e t o t h e r e t i n a. An additional argument in support of this explanation is provided by the data concerning the afterimage. Perception of a stabilized image is analogous to perception of an afterimage. The stabilized image is projected on the same point of the retina, and its projection remains unchanged despite movements of the eye. The afterimage is also stationary relative to the retina. If the stabilized image and the afterimage were displaced relative to each other, solution of tasks under stabilization conditions would be impossible by our method. Meanwhile, movements of the eyes after tachystoscopic presentation are of the same character as in perception of the stabilized image. In other words, perception of the stabilized image and of the afterimage are two phases of the same process, but the selection of information under stabilization conditions and the taking of information from the afterimage are accomplished by means of the same mechanism. This follows from the actual conditions of the experiment, when the color of the perceived object was a combination of the color of the acting light and the color of the afterimage. Consequently, a detailed investigation of the processes of image formation, of visual search, and identification under stabilization conditions showed that all these processes are based on the use of their own motor alphabet. This alphabet has been called the alphabet of vicarious perceptual actions. The sensitivity of individual areas of the retina is controlled through vicarious perceptual actions. The external form of expression of vicarious actions is the low-amplitude movements of the eyes within the range 3-5°, occurring either as drift or as rapid saccades. Psychologically, this is expressed as ability to shift the attention over the field of the stabilized image. Essentially, vicarious perceptual actions are a mechanism compensating for stabilization of the image relative to the anatomical fovea. By contrast with the external perceptual actions responsible for the obtaining of information from the outside world, the vicarious actions allow the information to be taken from the trace (from the stabilized image or afterimage) collected by the retina. It may be that information is taken from the visualized image, i.e., from the image reaching the retina from the brain, by means of vicarious actions. Experiments have been described in which real objects and mental images lead to identical visual impressions. Sutro cites results to show that 10% of the thick or fast-conducting fibers of the optic nerve transmit information from the brain to the periphery. He also postulates that the three levels of analysis of information in the retina can receive images arriving from the brain and from the external environment and can compare them (Sutro, 1965, p. 11).

Vicarious perceptual actions perform an extensive class of functions in the visual system. Under stabilization conditions, they can perform the successive perception of different areas of the stabilized image as well as of different areas of the afterimage. They are also responsible for the phenomenon of fragmentation, i.e., for the partial disappearance and reappearance of elements of the stabilized image. Vicarious perceptual actions undoubtedly perform important functions also under free examination conditions. In particular, the alternation of external perceptual actions, taking information from the outside world, and vicarious actions ensures the continuity of work of the visual system.

2.3.1. Vicarious Actions and Simultaneous Identification. It has been shown by the use of methods of image stabilization relative to the retina that the perception of the stabilized image and perception of the afterimage are two phases of the same process. It follows from the experimental conditions that the choice of information under stabilization conditions and during identification of the afterimage takes place by the same mechanism. Meanwhile, movements of the eyes after tachystoscopic presentation have the same character as those during perception of the stabilized image. As was mentioned above, perception of the stabilized image takes place through the participation of eye movements transferring the observer's attention from one part of the image to another. The magnitude of these movements is 3-5°, several times less than the size of the test image. Similar eye movements are observed in the postexposure period, when no image is present and all the work must be done with the trace (Zusne and Michels, 1964). The amplitude of the eye movements, just as in the case with stabilization, is within 5° (Leont'ev and Gippenreiter, 1968). Eye movements can evidently organize not only the activation of receptive fields, but also the obtaining of information from those fields which they have gathered. This takes place after brief presentation of the stimulus, when the observer makes eye movements in the absence of an observable object, and examines its afterimage (details Chap. 5 and §5.3.2).

After an examination of these results the question arises: what is meant by simultaneous identification and is it connected with the mechanism of vicarious perceptual actions? Before answering this question, it will be necessary to discover the real significance of that "moment" of time which is sufficient for identification of an object.

Numerous tachystoscopic investigations have repeatedly shown that, provided that test objects are bright enough, the duration of the exposure can be as short as is convenient. In this case the subjects "read" the information from the trace remaining on the retina. If the trace is obliterated by a photic or noise field, presented immediately after the test field (experiments of Sperling, 1960; Glezer, 1966, and others), the length of exposure required for identification is slightly increased. Glezer found that identification with a degree of probability close to unity begins after an exposure of 50-60 msec. Meanwhile, identification with a lower probability can take place during shorter exposures, even down to 10 msec.

Analysis of test objects and a noise field used in the investigations mentioned above, suggested that the noise field could obliterate or mask the presented objects insufficiently effectively. That is why the exposure times necessary for identification appear so short.

In our investigation, the noise field consisted of elements similar to those composing the test objects. The subjects were shown numbers illuminated on a thyratron. One number (measuring 2°) was presented for a measured time (50 msec or more), after which three other numbers chosen at random were exposed. With exposures of 50 msec, the probability of identification was equal to the probability of guessing one of ten numbers. With an exposure of 75 msec the probability of identification was 0.4. It did not reach a level close to unity until the exposure was 90-100 msec. Two numbers presented on two thyratrons side by side, falling in the region of foveal vision, were also identified in 100 msec. If the dimensions of the numbers put them outside the region of the fovea, the identification time exceeded 150 msec.

Identification in a shorter time, as other investigators have reported, may be explained by the irrelevance of the noise to the test image or the unequal brightness of the test and noise images.

The visual system thus requires a certain length of time in order to identify obscurred images, and this time is sharply increased if the angular dimensions of the images presented are increased. The connection discovered between the angular dimensions of the presented image and the identification time, as well as the existence of postexposure eye movements, can be taken as evidence that objects of relatively small angular dimensions (under 5°) can be identified without macromovements of the eyes. This is possible only when familiar objects are presented. Familiar objects of large angular dimensions (under 10°) are also identified in some cases without eye movements. Sometimes such movements are recorded. In our experiments, the presentation of two numbers obscured by a noise field did not increase the identification time. An increase in time was produced only by an increase in the angular dimensions of the presented objects. In Glezer's (1966) experiments, a short identification time could be obtained only after prolonged training of the subjects to identify the presented test material. These results confirm the view that it must not be concluded from the "momentary" presentation of the object that its identification is also momentary (Shekhter, 1967; Leont'ev and Gippenreiter, 1968).

It was shown above that the minimal identification time lies within the region of 100 msec. Can it be asserted categorically on the basis of these findings that objects of small angular dimensions are identified without eye movements? If the identification time is taken as 10 msec (from Glezer's observations mentioned above), such a categorical assertion is evidently justified. However, if the time is 100 msec, it will then have to be asked whether micromovements of the eyes, with a frequency of up to 200 Hz, may not participate in the identification process. Let us consider Platt's (1960) hypothesis from this point of view. Platt considers that identification of simple configurations, such as a straight line, arch, and so on, can take place through a small but definite change in the size or position of the image and establishment of identity between the excited elements of the first presentation and of the second (displaced) presentation. In this case, to identify a straight line, all that is necessary is to displace the sensitive elements along it and to obtain the information: "it is the same set." The function of these displacements of the retina relative to the signal can be taken over by micromovements of the eyes, with a frequency of between 50 and 200 Hz. These movements are highly variable both in amplitude and in frequency (Ditchburn, 1952). Our records also show that besides this, the ratio between the vertical and horizontal components of the tremor varies in different positions of the eyes. Platt thus states that the selection of simple cues takes place through the sorting of a set of directed movements, enabling a new position of the image on the retina to be chosen to give an identical response, while the character of the displacement will serve as a criterion of the simple cue. Platt points out that this system of identification can be used for any mosaic in which the arrangement of the elements is random: some training, i.e., discovery of the correlation between identical responses and the alphabet of the movements, is necessary for this purpose. The alphabet of identifying movements can evidently be changed in the course of training from elementary tracking movements for the identification of straight lines, arches, or parallel lines, to complex movements produced for a given class of objects and enabling comparisons to be drawn with reference to several features simultaneously or from a global feature characteristic of this class.

As an objection to Platt's (and also Hebb's) hypothesis, Glezer cites the observations of Senden (1932) on persons regaining their sight after operations. They see the difference between horizontal and vertical lines, but they cannot state which is vertical and which is horizontal.

From our point of view, this experiment only confirms Platt's hypothesis and tells us nothing about the existence of an inborn mechanism of cue discrimination. The identification of the difference between the lines indicates excitation of different sets of receptors, but it can tell us nothing about the nature of this difference, noticed before training, i.e., before the establishment of the motor alphabet.

The fact that the identifying capacity of the periphery of the eye is lower than the comparable visual acuity for the same parts of the retina, and the possibility of a considerable increase in the limits of identification (by 1.5-2.0 times) of small letters at the periphery of the retina through training (Kravkov, 1952) from our point of view is an argument in support of this hypothesis. Since the periphery and center of the eye have different geometrical displacements, in order to obtain identical shifts of the image the center and periphery must have different alphabets of eye movements. To identify a straight line in the central position, for instance, linear displacement of the eye is necessary, while at the periphery in this case a rotary displacement is necessary, i.e., a new motor alphabet must be developed.

One objection to Platt may be the solution of problems under stabilization conditions, when there is no change in the position of the image. In this case it is only necessary to change the sensitivity of the receptors to correspond to the character of the movement in order to obtain a result analogous to that examined above. I consider that the results of our experiments support such a possibility. Nevertheless, the possibility must be borne in mind that there are configurations displacement relative to which will not provide a reliable criterion of the simple cue (a sinusoid, for example).

I have tried to show in this chapter that the interpretation of perception as an action is equally suitable to genetically early and also to later and more sophisticated forms of visual perception. The higher forms of perception also retain traces of affinity with material actions, on the basis of which the external perceptual actions are formed. This concept is particularly important, because the praxeological interpretation of perception offers a real means for the understanding and investigation of such fundamental qualities of sensory behavior as the activity, subjectivity, and adequacy of the image with respect to reality.

CHAPTER 3

THE MANIPULATIVE ABILITY OF THE VISUAL SYSTEM AND THE PROBLEM OF IMAGE INVARIANCE

3.1. The Problem

Repeated investigations of perception have shown conclusively that the objects with which behavior must be reconciled give completely different informative stimuli under different conditions of observation, so that the subject's task is to decode the object as perceived or to construct a perceptual model on its basis. To construct such a perceptual model, and to compare it with the original, special activity is required. Adequacy of perception, according to some workers, is achieved by the fact that impressions from objects lying considerable distances away, in unusual aspects, or in unusual lighting, are transformed into something normal, just as if the subject had in fact brought the object perceived closer to the distance of optimal vision, had turned its frontal plane perpendicularly to the axis of vision, or transferred it for convenience of examination into more usual and favorable conditions of illumination.

Such transformations of the perceptual situation are seen particularly clearly in cases of "constructive thinking," when the subject anticipates the results of his practical actions, and foresees the solution to the task in hand. Concepts of unconscious reasonings, internal or interiorized actions, ideal transformations of the concrete situation, and so on, have been formulated in order to describe behavior of this type. Usually what are termed processes of internal speech are invoked as the mechanism of these internal actions, and a direct transition from an external practical action with an object to an internal action with a speech mechanism is postulated. However, adequate perception and processes of constructive thinking can also take place in animals. In addition, actions at the speech level do not rule out the possibility of perceptual functions. If, therefore, we adopt a more general point of view, the question of the mechanism of internal actions still remains open. In the process of overcoming distortions, which was mentioned above, depending on the concrete situation practical actions come first, and perception second. The mechanism of these phenomena likewise still remains unexplained.

Many facts suggest that the visual system possesses a repertoire of "manipulative" actions, responsible for normalizing objects perceived. The concept of manipulativeness is introduced by analogy with the actions of the hand. This analogy is also a good one because visual "manipulations" with an object perceived are to some extent similar to the transformations taking place during practical actions. It may be asked: can direct proof of the existence of manipulative ability in the visual system be obtained? In the search for proof of this type, we decided to investigate what would happen if the contrary were true.

Eye movements can form the material basis of the hypothetical manipulative actions. For this reason, to exclude eye movements, we again used the method of stabilizing the image on the retina. The experiments described in Chapter 2 showed that in some cases the subjects can see the presented material in unusually sharp relief. We accordingly selected special tests which would facilitate distortion of the spatial properties of the stimuli.

3.2. Tests Used on Subjects

3.2.1. Reversible Shapes. A flat Necker's cube $15 \times 15°$ was periodically illuminated in different colors by the method described in 1.3.1. The same picture was also presented against the background of EL-sources by the method described in 1.3.3. The time of illumination and the pause were equal, namely 0.5-1.0 sec.

Two types of images were used in the experiments: 1) the density of the lines of the cube was the same, and 2) the density of the individual elements was different. This method was introduced so that in response to one of the colors, with a change in brightness, disappearance of the less dense elements of the image could be obtained.

The other type of reversible shape was Schroeder's staircase; the overall size of the figure was 25 × 25°. This was also presented in two forms: with the aid of an external source of light, as in method 1.3.1, and with EL-sources as described in 1.3.3.

The third type of reversible shapes consisted of concentric circles with the diameter of the outer circumference 10 and 7°. The distance between the circles and their thickness were equal, and were 1° in each case. Presentation was by the methods described in 1.3.1 and 1.3.3.

All the test objects were photographic negatives with a dark background and transparent figure. The object was presented both under stabilization conditions and with free examination, when the cap with the object was placed in front of the eye but not on it.

A three-dimensional variant of Necker's cube also was used in the experiments. A cube with a large square measuring 25 × 25°, a small square measuring 10 × 10°, and a height of 10° (actual measurements 2, 1, and 1 mm respectively), made of thin wire, was placed at the focus of the objective of a No. 1 cap and illuminated by an external source by the method described in **1.3.1.** The plane of the large square was not strictly perpendicular to the optical axis of the cap, so that on free examination, the cube appeared solid.

The last test of this series was combined presentation of the two-dimensional image of Necker's cube measuring 15 × 15°, on which was superimposed a three-dimensional helix, about 5° in thickness. Illumination was as described in 1.3.3.

A combined method proved to be the most suitable for recording eye movements during presentation of reversible shapes; an accelerometer was placed on a cap with an EL-source. This combination was decided upon after it had been found that the method of optical recording of movements is unsuitable because the saccades of the eye are completely masked by drift movements. By the use of the accelerometer method, all the low-frequency components of the movements were abolished, and only saccadic movements were recorded. However, this method did not allow particular positions of the eye at which the movements were reversed, i.e., it showed that saccades were present but did not establish their character.

3.2.2. Tests for Studying Apparent Movement. A special series of experiments was carried out to study the effect of phi-movement under stabilization conditions. The subject was shown one or two pairs of lines, one below the other.

To investigate apparent movement, a modified Link's illusion with two circles at the ends of an arch was used (Fig. 3.1). The modification applied in the test was that the circles were included together with the half-arch.

The last test of this series was a circle divided into four sectors, each containing a small circle. These tests were presented against the background of EL-sources by the method described in 1.3.3.

In all the experiments described in this chapter the subject was instructed to observe the presented tests and to give a detailed report of what he saw. The subjects' reports were written down in the course of the experiments.

3.3. Experimental Results

3.3.1. Observation of Reversible Shapes. All the subjects stated that they observed reversal of the reversible shapes shown to them.

Reversal of the cube, both flat and solid, did not begin at once, but 20-30 sec after the cap had been placed on the eye; during this time it appeared as flat. Reversal then occurred purely automatically with the change in color, i.e., at the rate of 1.5-2.0 times per second. In the case in which the image of the flat cube was of uniform density, reversal passed through three positions: inside – flat – outside, at the rate of 2.0-2.5 times per second. In the course of the experiment there were times when the image assumed an unusual solid shape, for example, a distorted square, in which two diagonals came toward the subject while the other two went away from

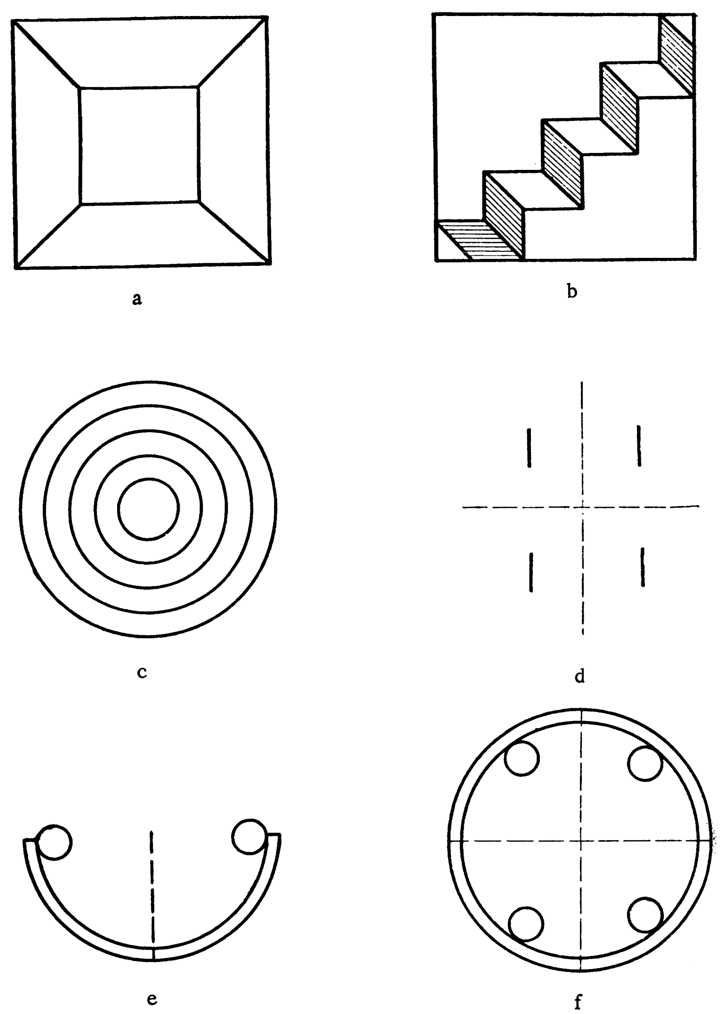

Fig. 3.1. Examples of reversible shapes (a, b, c) and tests to obtain apparent movements (d, e, f).

him, or one came toward the subject and three went away from him, and vice versa. Sometimes the image appeared solid, even if all the diagonals were omitted, or it appeared flat even when all the elements were well preserved. After instillation of atropine into the subject's eye, the picture remained as before: the cube began to reverse involuntarily 25 sec after the beginning of presentation, through two positions: inside – outside, and after 2 min it had passed through three positions. The change in position always coincided with a change in color. Testing this illusion under ordinary conditions showed that reversal takes place also quite automatically with a change in color, but in this case no spatial distortions were observed.

Presentation of Necker's cube against the background of an electroluminescent plate divided into two halves was used in two alternative forms: the whole plate was illuminated simultaneously, or the two halves of the plate were illuminated in turn. In the first case, reversal could at first be controlled at will, but later, after 20-30 sec, automatic reversal of the cube, synchronized with the flash frequency, began to take place. With alternate illumination of the two halves of the cube, an afterimage appeared on the dark side and was perceived as a direct image. This afterimage was combined with a direct image of the second half of the cube, and it reversed together with it. At the same time, the impression was gained of a screen facing the subject, which covered, first one half, then the other half, of the image in time with the flicker. This evoked the additional effect, besides reversal, of swinging of the cube in a plane perpendicular to the plane of the screen. In some cases the impression of rotation of the image of the cube was observed in the plane of rotation of the screen. Under these circumstances it appeared flat.

In response to a combination of a two-dimensional image of the cube and three-dimensional helix, movement of the helix together with the reversing cube was observed, but in such a way that the center of the helix was deflected, but its ends remained in place.

The concentric circles were presented on an electroluminescent plate divided into halves. During simultaneous illumination of the image with a frequency between 4.5 and 9 Hz, the circles rotated around the center in different directions. The whole image appeared solid and was perceived as a cone with its apex toward the subject. During alternate illumination of the different halves of the plate, a screen effect again appeared, with the afterimage on it and moving together with it. The circles continued to rotate in different directions, and sometimes the impression was obtained that they were displaced along their vertical diameter. Sometimes the two halves began to rotate around this diameter, and both the real and the luminescent images rotated in this case. When the light was turned off, the afterimage behaved just like the real image (movement, rotation, and so on).

The surroundings were perceived as a child's pyramid, which reversed like the cube. A decrease in the angular dimensions of the image interfered with this process, demonstrating more adequate perception of an image with small angular dimensions. The subjects performed specified manipulations with the cubes and with the surroundings both in the presence of real objects and in the presence of their afterimages.

A series of psychological tests yielded facts indicating that during perception of double images, such as Rubin's well-known figures, during the perception of Necker's cube or Schroeder's staircase, and other similar objects, eye movements take place. It is postulated that successive replacement of the points of fixation leads to the reversal of such shapes. Investigation of perception of Necker's cube under stabilization conditions and in conjunction with the recording of eye movements showed that reversal of the cube also takes place only with changes in the positions of the eye. These results are additional confirmation of the view that eye movements under stabilization conditions lead to switching of the receptive fields of the retina.

3.3.2. Observation of Apparent Movement. The use of an electroluminescent plate, placed behind the test negative (the tachystoscope on the eye) as the source of light enabled apparent movement to be investigated under stabilization conditions. In this phenomenon, at certain frequencies of flickering of two illuminated lines the lines themselves cease to be perceived. The subject sees the "pure" movement of the line of light from one position to the other.

Wertheimer calls this movement phenomenal, and the phenomenon as a whole he called the phi-phenomenon. It has often been studied under free examination conditions.

To obtain phi-movement, an electroluminescent plate, divided into two halves, was used. Each half of the plate could be controlled separately. During alternating illumination at a frequency of 0.6-1.0 Hz, a clear impression of movement of the line is obtained. The afterimage, which is dark in color, moves to the opposite side. The afterimage of the line appeared to move "closer" to the subject, while the light line moved along a straight line "further" from the subject. The apparent movement and afterimage of this movement are combined into a complete shape which is perceived as a real rectangle rotating around its own axis. On the presentation of two pairs of lines (the electroluminescent plate is divided into four corresponding sectors) the effect of rotating rectangles persisted, but in this case two rectangles rotated around the same axis but in different directions.

Investigation of a modified Link's illusion showed that at frequencies of 1-2 Hz an impression of rotation of the spheres around their own axis was obtained, followed by movement of the spheres along the arch; the spheres together with the arch then began to rotate in the horizontal plane perpendicular to the plane of the image. This created the impression of a rotating goblet, and the afterimage did not participate in the formation of the impression of rotation, but turned as a shining hoop. The afterimage moved along a concave line between the spheres.

When the circle consisting of four sectors, each containing a small circle, was presented at a frequency of 4 Hz the impression of its rotation was created, and the small circles remained in the same position. At high frequencies, the small circles were flung about and jumped from place to place. The impression of movement of the circle around the arc was created in the afterimage. After the light had been switched off the afterimage was stationary.

All these tests were presented to the subjects under free examination conditions also. In this case most of the distortions described above were no longer present, i.e., perception was much more adequate as a result of the participation of eye movements.

3.4. Discussion

Eye movements do more than merely provide the essential physiological conditions for working of the visual system. Their participation is essential for the prevention of distortions introduced into perception by the visual system when working relatively independently of the oculomotor system.

The series of tests described above showed that when working under stabilization conditions the visual system provides the observer with a series of images most of which are inadequate to the actual situation. The most characteristic distortions observed by the subjects may be recalled. Under stabilization conditions the subjects could not distinguish between flat and solid objects. A solid, truncated pyramid and its two-dimensional picture were perceived identically, sometimes as flat, at other times as solid. In another test the subjects reversed these shapes, i.e., a small square was seen sometimes as nearer than a large square, at other times as further away. A three-dimensional helix, intersecting the picture of a cube, was perceived as something drawn against the background of the cube, and it rotated together with it. During the experiment there were times when the image assumed an unusual solid form. For example, the two diagonals joining the large and small squares appeared to be coming toward the subject, while the other two appeared to be going away from him.

Under stabilization conditions, when the illuminated lines flickered at a frequency of 0.6-1.0 Hz, the subjects also had a definite impression of apparent movement of the illuminated line. In addition, a dark afterimage of this line appeared, and this moved in the opposite direction. The afterimage moved nearer to the subject, while the illuminated line moved in a plane away from the subjects. The apparent movement and the afterimage of this movement then joined together to form a complete figure, seemingly a real rectangle rotating around its own axis. On the presentation of two pairs of flickering lines, one above the other, the effect of the rotating rectangle remained, but in this case two rectangles rotated in different directions around the same axis.

The phenomena described above indicate that under stabilization conditions the phenomenal field has apparently more degrees of freedom that the field of the perceived objects. This is evidence, in particular, of the falsity of the assumption made in Gestalt psychology of the isomorphism of the optical, cerebral, and phenomenal fields from the very beginning. The observer under stabilization conditions has difficulty in differentiating the afterimage and the direct image, the stationary and moving object, real and apparent movement, the figure and its background, a flat and a solid object, and so on. These phenomena represent different phases of the observation of an object in the course of a single test. In the light of these facts, a more accurate concept for stabilization conditions would be a variable and not a stabilized image. I suggest that these phenomena are perceptual in nature and not the result of more complex processes of imagination and thought.

Consequently, the methods which we used (blocking movement of the image over the retina), paradoxically as it may seem, were able to reveal the ability of the visual system to perform visual manipulations with images. The conclusion can be drawn that under free examination conditions the ability of the image to move over the retina, even if it does not prevent it, must at least interfere with the study of this manipulative ability. Movements of the eye thus not only participate in the process of image formation (this function of them was examined in Chapter 2), but they also limit the number of degrees of freedom of the images which have been formed.

It is clear that orientation in a situation is impossible with the aid of images arising in subjects under stabilization conditions. The subject's task is to find the adequate image among many inadequate ones and to fix it. There is certainly something in common between the task of forming an image and the task of forming a movement. During movement formation, excessive degrees of freedom of the kinematic chains of the human body have to be overcome (N. A. Bernshtein). During image formation, excessive and inadequate reflections of the same object have to be overcome.* Just as nature

*The authors were extremely glad to learn that a note was found in N. A. Bernshtein's records stating that an image on the retina may have several degrees of freedom. This note, which was kindly made available by V. V. Lebedinskii, is as follows: triangle: 2 × 3 degrees of freedom on the retina (at its apices); a) their connectedness, b) something like straight lines. Perception (and its mechanical model) are possible only through an actively probing and not a passively scanning mechanism (Bernshtein, January 2, 1961).

constructs a reliable system from unreliable elements, so the observer is forced to construct an adequate image from a set of variable and distorted images.

Let us now attempt to reconstruct from the results so far obtained a system of perceptual actions performed by an observer to secure the adequacy of his image of reality. An independently working (without a motor system) visual system can distinguish an object against the background. However, when distinguishing a figure against the background it turns it and constructs a pseudofigure. The impression is obtained that the observer, under stabilization conditions, cannot retain an unchanged image. The image fluctuates all the time, it breathes and varies. With the aid of movements, the visual system fixes the eye in the position which ensures maximum agreement between the optical and phenomenal fields. Motor activity helps not only to find the most adequate position, but also to hold the eye in this position for the required time. However, in order to find the position in which distortions are minimal, criteria of correlation between the optical and phenomenal fields must exist. The results of experimental psychology show that such criteria do in fact exist; they are formed under the influence of the conditions of life and training, and they undergo modifications. This has been convincingly shown by the investigation of sensory learning, sensory distortions (J. Kohler and others), sensory isolation, etc. Other evidence in support of this view is given by results obtained during the study of perception in people blind at birth, during the first days after removal of their cataracts. Their first impressions of the visible world are very close to the responses of subjects observing stabilized images. Postoperative observations made by such subjects are emotionally tinged because of their inability to find their bearings in the outside world.

Criteria of the adequacy of the optical and phenomenal fields are developed not only by the visual system, but also by the living system as a whole. During prolonged sensory isolation, they can be lost to some extent, and under conditions of sensory distortions, they can undergo considerable modification. Not only the motor system of the eye, but also the entire motor apparatus of the living system, participates in the creation, restoration, or modification of the criteria of adequacy. After the formation of these criteria, this participation is used only under difficult circumstances in order to verify the adequacy of the image.

The following perceptual actions, maintaining the adequacy of the image of the outside world, can be distinguished on the basis of the foregoing facts: guiding the eye to the object and centering the image, manipulation of the image in accordance with the developed criteria of adequacy of the optical and phenomenal fields and, finally, fixation of the eye and holding it in position, so as to maintain this correspondance. Under free examination conditions, these actions as a rule are unnoticed by the subject, and the impression is gained that the image corresponds directly with reality.

In order to interpret and discover the mechanisms of distortion, it is advantageous to use the concepts of "centration" and "decentration" adopted by Piaget (1967) in his theory of the ontogenesis of human perception. In the early stages of development of perception, the visual system works predominantly under conditions which can be described as conditions of centration. This is because of the relatively lower mobility of the child's eye, and the longer duration of the child's visual fixations.* Because of the predominance of work under centration conditions, the child's perception is less affected by the properties of the optical field. Predominance of centration conditions may lead, in particular, to the result that the small child cannot see a close link or mutual correspondence between visible elements on the basis of a system of Euclidean rectangular coordinates: for example, in the classical illusion of perception of vertical and horizontal lines. Lines compared in this text evoke independent centrations, and they are not connected by the child into a single configuration. The centrations remain essentially independent, just as if the lines had not even been in the same visual field. In this case, therefore, distorting influences of the field have no effect on perception.

As was stated in Chapter 2, conditions of stabilization of the image relative to the retina lead to an increase in the duration of fixations. Under these conditions the subjects can also perceive the individual elements of a figure as relatively independent and not incorporated into the context of the whole presented field or of a certain complex con-

*This observation has subsequently been confirmed by an unpublished investigation of G. G. Vuchetich, undertaken in V. P. Zinchenko's laboratory. The results of this investigation showed that the mean duration of fixations in children aged 5-6 years when confronted with the task of identifying a shape against a background, is 0.8 sec.

figuration. During stabilization of Necker's cube, the subjects therefore sometimes saw two diagonals receding into the distance and the other two coming closer. Work with stabilization of the image relative to the retina evidently interferes with the decentration program. Decentration, of course, takes place through vicarious actions, but in order to overcome the program of centrations enforced upon the observer completely, considerable practice with working under stabilization conditions is all that is necessary. We have found that if 3 or 4 stabilization experiments are carried out at intervals of a few minutes, perception becomes less liable to fluctuation, and the subject's perception of the test object is more stable.

Arguments similar to those developed by Piaget are expressed by Gibson (1966). Instead of the concept of decentration, Gibson uses the term "investigative turn" around an object or test, providing a series of perspectives. As a result of the stream of continuous transformations arises; the family of these transformations is unique and specific for this particular part of the environment and for this particular turn. The aim of the investigation, as Gibson sees it, is the isolation and identification of the invariants. The general fluctuation of tactile or visual investigation, according to Gibson, is not to obtain variable tactile and visual sensations, but to isolate information contained in the stream of changing tactile and visual sensations.

An important role in the realization of this function is evidently played not only by external perceptual actions, but also by the ability of the visual system to manipulate images, demonstrated by our own investigation, on the basis of a special system of vicarious perceptual actions.

It will be asked why nature has taken this round about path and has not provided for direct correspondence of the optical and phenomenal fields The explanation is evidently that the image, as one of the regulating factors of behavior, must be invariant relative to certain, but relatively numerous, transformations of the stimulus. This invariance can be obtained in various ways: by the accumulation and storage of all possible alternative forms of stimulus transformations in the memory or by the creation and preservation of one or several general standards. In the first case an infinite memory and infinite training would be required. In the second case difficulties of another type would arise. How would the change from general to special be achieved? This ability to manipulate the image is possibly a means of comparing the general standard and a certain concrete variant belonging to a given class. In this case the task of the visual system is to modify the presented specimen until it coincides with the standard or until a negative result is obtained. Invariance must therefore be achieved in each individual act of perception through the transformations of the incoming stimulus. Under our experimental conditions stabilization of the stimulus relative to the retina leads to its variation and distortion. However, under free examination conditions changing stimuli are perceived as stable within certain limits. This is because identification of the stimulus and standard inscribed in the memory does not take place directly. The visual system normalizes the distorted stimulus on the basis of its established criteria of adequacy and its ability to manipulate images, comparing it with the standard inscribed in its memory. Ability to manipulate images, for example, enables relatively stable objects presenting different aspects to the observer to be seen.

In the light of our findings and hypotheses, the formation of the visual system is represented as a continuous struggle with illusions. In the process of analysis of images the visual system overcomes the illusions, selects adequate images, and continually introduces corrections into perception of the visible world. Perception is thus less like a blind coding of the outside world than a creative, gnostic process in which, as in any creative activity, elements of fantasy and of the unconscious also are evidently present.

It can be supposed that during the individual development of perception in different people, slightly different and original criteria of adequacy are developed and sets and positions are formed which it is customary to call the individual vision of the world. Two, three, or more methods of perception may be formed in artists. The ability to choose and fix different positions of observation is evidently an important component of creative artistic ability.

In the psychology of perception much has been written about the orienting function of eye movements. Indeed, many workers have assumed that this is the only function of these movements. The facts described above demonstrate that such a function does in fact exist. At the same time, they show that although this function has been named for a long time, it still requires serious investigation, because it is connected not only with the problem of guiding the eye to the object to be perceived, but also with the problem of adequate reflection of this object. However, if the formation of an image which adequately reflects reality is a task of some difficulty, naturally the task will not always be brought to a successful conclusion. The subject may fix the position and yet not obtain an adequate reflection. It may, perhaps, be this complexity of the construction of an adequate image which is responsible for those distortions of reality which are sometimes characterized as conscious.

The manipulative perceptual actions discovered during these tests are genetically linked with the manipulative actions of the hand. The mechanism of formation and interiorization of this ability requires further investigation. Manipulation of visual images is evidently a psychological mechanism for the transformation of practical, operative actions with objects into internal, ideal actions, the formation of which has been studied by Gal'perin (1965). Practical manipulative actions, like internal actions, are productive actions. It can be postulated that elements of productivity are also present in visual manipulations with an image.

The manipulative ability of the visual system, demonstrated experimentally, is important in the solution of the problem of image adequacy. A further study of this ability will help to overcome many of the difficulties and paradoxes which invariably arise in the traditional optical–geometrical approach to visual perception, including the approach to the problem of image adequacy.

There is yet another field in which the detailed investigation of the manipulative ability of the visual system must be beneficial. I refer to the study of skills and of voluntary movements. From the biomechanical point of view (Bernshtein, 1947), the kinematic chains of the human body have many degrees of freedom. These chains constitute the effector component of skills. The visual system is an essential part of the controlling element of the skill. It is evident that the controlling element cannot have fewer degrees of freedom than the effector component. Otherwise, several of the degrees of freedom of the effector component would be free from control. The manipulative ability of the visual system is the psychological expression of the existence of a large number of degrees of freedom in one of the controlling elements of the skill. As an illustration we can cite the need for manipulative ability of the visual system in order to form the sense of the body schema or the sense of the body schema together with a working tool, and so on.

Before concluding this section on the manipulative ability of the visual system, it must be emphasized once again that the primary function of vicarious perceptual actions is to perform actions with images which replace actions with real objects. This manipulative ability goes beyond the traditional understanding of the functions of perception. It led us to the conclusion that vicarious actions participate in more complex mental functions such as remembering, visualization, and the solution of problems. We shall examine these matters in the next chapter.

CHAPTER 4

INVESTIGATION OF VICARIOUS ACTIONS IN THE CONTEXT OF INTELLECTUAL PROBLEMS

4.1. A Further Contribution to the Simulation Hypothesis

For many years the simulation hypothesis (Leont'ev, 1959) has been developed and confirmed mainly through investigations of image formation. This hypothesis has frequently been questioned, for it is impossible to determine isomorphism between the motor side of perceptual systems and the properties of the perceptual procedures in fully developed processes of perception.* However, this fact can be explained without any contribution to the praxeological interpretation of perception processes. Any living system, at a stage of development other than zero, possesses a developed alphabet of images or operative units of perception. Whereas in the phase of construction of the image of an object, simulation of the properties of the stimulus by the perceptual systems takes place, in the phase of identification of or operation with the resulting image the characteristics and direction of the simulation process are substantially changed. This was clearly observed by A. V. Zaporozhets: "in investigations by my colleagues and myself, regular changes could be seen in the simulating function of perceptual action throughout infancy and at preschool age, and at the same time, they provided a more detailed explanation of some of the special features of the complex and controvertial process of simulation. On the one hand, it consists of the creation of a likeness of the perceived object with the aid of the subject's own movements and actions. On the other hand, it involves the recoding and conversion of the information received into the subject's own language of operative units of perception, which he has already learned, the symbols of which are familiar to him, and which functional significance has been mastered. In this way, simultaneously with simulation of the object by the subject, there is simulation of the subject by the object, and it is only through such a two-way transformation that a proper orthoscopic perceptual image can be formed" (Zaporozhets, 1968, p. 123). When this two-way direction of the simulation process is taken into account, the naivete and hopelessness of attempts to discover isomorphism between, for example, the trajectory of eye movement and the outlines of objects at all stages of the development of perception will be evident. Equally, the mention of absence of this isomorphism as a serious argument against the simulation hypothesis and the praxeological interpretation of perceptual processes (see, for example, Borozdina and Gippenreiter, 1968) also is groundless. The experimental separation of these two opposite processes of simulation, each with its own motor alphabet, is evidently a very difficult problem. The difficulties are particularly great if the investigator is dealing with an integral act of behavior, and not with its isolated operations or actions.

Analysis of an integral act of behavior shows that there is another form of simulation which differs from those examined by Leont'ev and Zaporozhets. The distinguishing feature of this "simulation" is that it takes place not so much for the sake of construction of an adequate image or of identification as for the sake of the solution of practical or intellectual problems. I refer to the processes of reconstruction and transformation of the image in

*We note that Leont'ev did not relate the simulation functions exclusively to movements of the perceptual system, although he did note their extreme significance to the latter.

accordance with the aims and tasks facing the subject. In a real act of behavior there is always a process of simulation of the properties of the stimulus by the receptor systems as well as an, in some respects, opposite process of transformation and simulation of the subject's tasks by the image of the object. Whereas in the first phases of the simulation process the problem of adequacy of the formed or activated image of reality is solved, in the subsequent phases the problem of transformation and reconstruction of the image and its reduction to a form suitable for use in decision making is solved. In other words, in the successive phases of the simulation process, the problem of preparing for changes in reality, the formation of adequate plans and behavioral tasks, is dealt with. Any such change in reality is preceded by transformation of the image.*

We therefore decided to investigate the processes of simulation of the tasks facing the subject by the image of the object. This involves a consideration of the field of regulating and orienting functions of the image or of the field of memory and thinking (at least so far as they are concerned with images). On the basis of the results described in the earlier chapters, we formulated the hypothesis that higher mental functions rest to a very large extent on the system of vicarious perceptual actions.

Despite the fact that the concept of vicarious perceptual actions was introduced earlier, I think it would be more suitable to give a brief historical note on this concept and to define its meaning more precisely in this chapter.

4.2. Orienting and Investigative Activity

The hypothesis that the motor alphabet is frequently changed during the formation of mental faculties was put forward after comparative studies of the processes of tactile sensation and vision (Zaporozhets, Venger, Zinchenko, and Ruzskaya, 1967), and also after analysis of the data relating to vicarious trials and errors and the development of orienting and investigative activity.

In the Soviet psychological literature a brief description of vicarious behavior or vicarious trials and errors (VTE) has been given by Gal'perin (1967). The concept of VTE was introduced by Muenzinger, and it essentially distinguished the stage in the development of behavior in which true operative responses are replaced by orienting reactions. Orienting reactions begin to anticipate the performance of behavioral acts. The VTE have their own motor alphabet, which includes movements of the head, the limbs, and the sense organs. These movements are not aimed toward the attainment of an object, but toward its investigation or the investigation of the situation. After these movements, the usual trials and errors are either diminished or they disappear completely. VTE has been studied by Tolman (1959) and his school. Tolman concluded from his investigations that VTE cannot be interpreted purely as errors, but they are primarily trials and attempts. Under certain conditions, the relative importance of the VTE is increased to such a degree that they apparently constitute an independent form of behavior aimed at familiarization with the situation. According to Tolman, this type of behavior possesses an "identification vector," and it is contrasted with behavior directed by the "pragmatic vector." It is important to note that VTE or, in other words, orienting and investigative behavior, is linked genetically with operative behavior, is formed on the basis of operative behavior, and ultimately replaces it. Similar descriptions and a similar line of argument can be found in the writings of Pavlov's school and also in the latest investigations of the ontogenesis of orienting and investigative activity conducted by Zaporozhets (1960) and his collaborators.

Podd'yakov (1959) has studied the ontogenesis of orienting and investigative activity as it is formed in children, initially on the basis of practical, and later on the basis of practical–investigative activity.

However, there is an important difference between the behavioristic interpretation of orienting and investigative activity and its interpretation by Soviet authorities. This difference has been pointed out by Gal'perin (1967). He states that Soviet investigators regard orienting and investigative activity not merely as a means of distinguishing the objective link between phenomena, but also as a channel reflecting this link in the processes of the brain.

Perceptual actions, simulating the object perceived in its external form and aimed at producing an image, are derivatives of orienting and investigative activity. Perceptual actions are based initially on the motor alphabet of the operative and orienting actions, but later in their development and perfection they have their own motor alphabet. In this respect the development of feeling movements of the hand

*Help with the analysis of the trend of these transformations can be obtained by investigations conducted in the context of D. N. Uznadze's theory of set.

and the development of the familiarizing and identifying movements of the eye are indicative. Perceptual actions are very far removed in their development from operative orienting actions, including from VTE, and they acquire their own specific qualities. Images formed as the result of perceptual actions begin to perform the functions of regulation of operative and orienting–investigative searching behavior.

In the development of behavior, a successive system of replacements can thus be detected. Operative, practical actions are replaced by investigative (VTE or orienting) actions, and these in turn are replaced by perceptual actions. Each new substitution makes behavior increasingly more adaptive and broadens the prospects for training and for anticipating the results of the behavior. To begin with, the motor alphabet of the preceding stage is used to form each new substitution, but later this alphabet is improved and takes on new features. It may also form its own motor alphabet, more suitable for performing the tasks of the new type of action. Each new form of action can be regarded as vicarious or substitutive in relation to its predecessor, although it does not, of course, replace it completely. The appearance of a new motor alphabet provides the basis for the formation of new and improved perceptual models of the external environment and new operative units of perception. In other words, there is a definite dynamics and improvement not only of methods of image formation, but also of the development of images of the same surroundings.

The question arises: is the system of perceptual actions the "final substituent." Investigations of the activity of the visual system described in the preceding chapters give evidence that it is not. Perceptual, mnemic, and intellectual activity are complex in structure, and distinctive vicarious and substituent forms can evidently be identified in them.

4.3. Perceptual Elements of Productive Activity

The important role of perception in intellectual activity has frequently been described by investigators of thinking and also by shrewd scientists and artists describing the true process of creation. The role of perception is evident from the fact that the process of solution of problems, including creative problems, is usually described in terms connected in some way or other with visual perception. Frequently such terms as discernment, discovery, insight, and visualization of a problem situation or problem complex are often used. Special terms are used in constructive and conceptual thinking. Supporters of Gestalt psychology ascribed an important role to the reorganized, recentered phenomenal field or inner pictures of the world. Some of them reduced the whole problem of creativeness to this simple basis. Notwithstanding the role of perception in productive activity ascribed by supporters of Gestalt psychology, the mechanism of this link between them remained unknown. Apart from the very valuable (phenomenologically, of course) and heuristically useful observations obtained during the investigation of productive activity, the results of analysis of individual gnostic processes were put to very little use. The creative act was regarded globally, with no attempt at differentiation, and individual mental processes were expelled from the realm of investigation of creativeness as self-evident and, moreover, as nothing more than preheuristic processes, making preparation for a creative solution or influencing it in some way or other. It was, of course, accepted that processes such as selection, collection, storage, recall, and forgetting of information perform an important function in the realization of a problem situation and in the reduction of information to a form suitable for decision making. At the same time, however, these processes are not usually included in the context of investigation of creativeness, for they have a high time constant and they are not therefore directly associated with such phenomena as insight and enlightenment. Suddenness and instantaneousness are, of course, the most characteristic features of these last phenomena.

Failure to take due consideration of perceptual, mnemic processes and of the functions which they perform in the creative process leads essentially to narrowing of the field of investigation of productive activity. When these processes are put in parentheses the investigator is left with such scanty remains that their analysis is impossible and no meaningful laws of the creative process can be identified. This field is thus dominated either by phenomenology or by logical analysis.

The phenomenological investigation of creative activity also runs up against fundamental difficulties. These difficulties are not connected with the fact that the science of self-observation has not yet reached a high level of sophistication or with the individuality and subjectivity of the creative process. They arise because self-observation does not reveal the processes of creative activity but the states accompanying these processes. Of course, in each new description of the creative act individual fragments of the process itself can be glimpsed, but it is virtually impossible to reconstruct the creative process as a whole from them. This does not mean that such descriptions are useless. On the contrary, they are extremely necessary as the starting point for research.

So far as the logical analysis of productive activity is concerned, the main difficulty here is unreliability. Basically, of course, this is just the same phenomenology, but with the retrospective identification of the logical operations by which the productive activity was evidently carried out.

The diffuseness of representation makes a strict experimental investigation of the genesis and structure of the creative act extremely difficult. I consider that the interpretation of this act as a process of decision making can provide a reference point for the development of experimental research techniques in this field. By the same token we can attempt to include perceptual processes in the context of the problem of decision making not simply in their auxiliary or preparatory capacity. There are elements in perceptual processes which can be called creative. The identification and investigation of these elements would be a useful means of studying the mechanism of creativeness in the strict meaning of the term.

Panov (1968) analyzed many descriptions of the creative process, in which he distinguishes the following stages: a) the genesis of the subject; b) perception of the subject, analysis of the situation, realization of the problem; c) work to solve the problem; d) appearance of an idea of the solution ("insight"); e) testing and investigation of the solution, presentation of the results.

Stages (a) and (e) need not be considered here, but the rest are appropriate for our analysis. Stage (b) ("perception of the subject") is characterized by Panov primarily as a stage of conscious work, similar in many respects to the activity of the human operator in an automatic control system working from an information program (Zinchenko and Panov, 1964). The main problem in this stage, just as in the activity of the ACS operator, is producing a conceptual program adequate to the situation which arises as a result of the choice of subject, and which will act as the "sphere of crystallization" of the problem to be solved.

The stage of production of the conceptual program of the problem situation is undoubtedly the stage preparing for the solution, and as such it has for a long time been distinguished from productive activity proper. This distinction between the preparatory and decisive stages of productive activity is apparent both in Köhler's classical experiments on anthropoid apes and in the many subsequent investigations. Such a distinction, although a true one, has its limitations, for the content of a conceptual program cannot reflect a situation impartially, being intimately connected with the subject or with the problem it is designed to solve. This connection is so important that several investigators studying thinking, especially in recent years, have shown a tendency to erase completely the line between the preparatory and decisive stages. This tendency has been most clearly discernible in the engineering approach to psychological problems. Initially, the preparatory stage of the creation of a conceptual model was regarded as a combination of processes collectively termed the "search for information" (Berezkin and Zinchenko, 1967; Zinchenko, 1968). Later, however, heuristic functions began to be ascribed to this type of activity. For example, in the investigations of Pushkin (1965), Tikhomirov (1968), and others, attempts were made to use movements of the hand and eye as objective indicators of decision processes. They began their investigation of hand and eye movements by the use of various tests based on existing (unfortunately, not the best) recording methods. However, they made no attempt to differentiate between the search for information and the truly heuristic search, but followed the path of generalization and subsequent confirmation of the concepts of heuristics. This is an unjustifiable approach. Even if movements of the hand and eye are ascribed intellectual functions, as these workers considered, sufficiently evident criteria of intellectual and heuristic qualities should have been formulated. One interesting fact was observed in these investigations: in the course of the test a periodic weakening, or even cessation of movements of the receptor structures was observed. The workers call these periods long fixations. According to Zavalishina (1968), the more difficult the test the greater the proportion of long fixations of the eye. It is also a remarkable fact that weakening or cessation of movements is observed in the periods preceding the solution.

In my opinion these results show that it is desirable to distinguish a phase of preparation in the process of solving problems, the basic function of which is the creation of a conceptual model of the problem situation. This model is created by means of external perceptual actions, and it can correspond to a greater or lesser degree to the problem situation. In the latter case the subject must recognize or rebuild his conceptual model. Methods of investigation developed in the course of praxeological interpretation of perceptual processes are very suitable for the investigation of conceptual model construction (Zaporozhets, Venger, Zinchenko, and Ruzskaya, 1967).

It is important to note that in the stage of preparatory building of models of the external surroundings, the physical characteristics of these processes are clearly distinguishable. For example, the trajectories of eye movements during familiarization with a situation depend essentially on the problem facing the observer. Images which the observer creates are not "impartial." They are adequate to the tasks and plans which, in turn, may be very dynamic.

However, it must be asked whether the phase of the solution process is accessible to investigation in the true meaning of the word. By "phase" we mean the phase of recognition of the conceptual model built in the preparatory stage. Before attempting to answer this question, let us consider phenomenological descriptions of the solution process in the true meaning of the term, paying special attention to observations of the role of visualization in problem solving.

4.3.1. Visualization in Problem Solving. At the beginning of this century, the importance of the contribution of the visual system to problem solving was emphasized. Selz introduced the process of visualization of the problem situation or problem complex as an important stage in problem solving. Max Wertheimer, having given a detailed description of the course of solution of a geometrical problem, stated that the new idea had occurred to him not as a hypothetical suggestion or assertion, but as a penetrating view into the structure of the problem, into the nature of its internal connections. Wertheimer's statement that after 6 weeks of sustained work he became able to visualize complex three-dimensional images, and to join them together and compare them in his mind, is extremely interesting. A similar account is given by M. Bunge, who, in one section of his book "Intuition and Science," regards intuition as imagination. Bunge (1967) writes: "One of the most valuable experiences acquired by the writer of this book during his period in prison, when he was given neither paper nor pencil, was the mental representation of the behavior of polynomial integrals very closely dependent on certain parameters. This visualization helped in the solution of problems after many prolonged but unsuccessful attempts" (page 102).

Many more, similar examples could be given. They are not always connected with the problem of solution, but the phenomenon of visualization is always described in them clearly. Nearly all investigators of sensory and perceptual isolation state that this creates favorable conditions for visualization. It was studied intuitively many years ago by Ignatius Loyola, who regarded visualization as one of the most important elements of the spiritual exercises which were compulsory for anyone entering his religious order. The presence of the visualization phenomenon is thus firmly established. The question of its nature, however, still arises. Are visualized images carried out to the periphery of the visual system, or is this an illusion of self-observation? Some arguments in support of the first suggestion will be given.

L. Sutro cites McCulloch's arguments that the animal creates an image of what it expects to see on the retina of each eye. Sutro writes: "There is reason to suppose that when a man reads quickly, his brain supplies his retina with roughly predicted images of each word or group of words. If the reader knows the author's style, he can predict many of the words which follow, and can skip to words which will give him new information. Facts concerning the structure of the human visual system confirm this hypothesis of vision with prediction. . . . . The three levels of analysis of information contained in the retina can evidently receive images coming from the brain and the external environment and can compare them" (Sutro, 1865, pp. 110-111). On the basis of this mechanism of vision with prediction, Sutro explains, in particular, the high speed of the visual response. In my opinion, the facts cited by Sutro as evidence of the existence of this mechanism of vision with prediction are sound, but they cannot be regarded as sufficiently decisive to allow such a conclusion to be drawn.

The facts obtained by Toidze (1968) are more directly connected with the area of problem solving which we are considering. Toidze observed a phenomenon of selective lowering of the threshold of visual perception to relevant information. The subjects in this test were given a mental problem.

Useful and useless items of information were given at the subthreshold level on a screen placed in front of the subjects. At a definite phase of solving the problem the subjects began to perceive the useful information. Toidze interprets these facts as an important argument in support of the existence of a visualization process running counter to the relevant information. This interpretation is very similar to Sutro's idea of vision with prediction.

Finally, in this context we must also mention the series of investigations conducted by Eisenbud (1966) on Ted Serios, in connection with the photographing of visualized images. Phenomena of this type are described from time to time in the literature, usually in connection with the problem of extrasensory perception. Reasonable doubts have been expressed on the reliability of the phenomenon (see, for example, Rushton, 1968). Nevertheless, the process of visualization probably reaches the peripheral levels of the visual system.

Visualization of a conceptual model of the external environment can be regarded as a way of objectivizing it. Action with a visualized picture sometimes (in pathological cases) creates the illusion of action with reality; however, its basic function has to do with the possibility of using methods of action which have been developed for operating with real objects.

Irrespective of the nature of visualization, there is plenty of evidence for the use of this phenomenon as the basis for a hypothetical mechanism of intellectual activity. The essence of the hypothesis is as follows. During problem solving the role of object to be transformed must be played not by the real situation, but by an image of this situation formed either at the stage of trial and error or at the stage of planned orienting–investigative, perceptual activity. In other words, the image of the situation is created through external perceptual actions. The real situation cannot be an object for direct mental transformations. It must be made abstract, it must be temporarily liberated, in a certain sense, or otherwise it may actually prove an obstacle to mental transformation. The fact that the real situation is essential for verifying the purposiveness and adequacy of these transformations is another matter. The object of transformations of this type is the conceptual model, which appears most frequently as a visualized image of the problem situation or of its elements. This image may be incorporated into new relationships, and it may be manipulated by means of vicarious actions, as took place in the investigations of manipulative ability of the visual system under stabilization conditions described above. The advantage of the visualized visual image over motor or auditory images lies in the subjective simultaneity and the width of grasp of the situation. Visual representation, like visual perception, creates the impression of simultaneity, which is very important from a standpoint of simultaneous or instantaneous penetration into the essence of the problem in all its complexity.

At this point it can be objected that we have ignored the functions and role of speech. As a counter-retort we can quote Claparede's observation that "reflection attempts to forbid speech." This remark contains an important truth, for at certain stages of the thinking process the "manipulations" are much more productive if they are performed with visual images, carrying the imprint of reality and thus allowing penetration into the nature of things, and not with symbols, which always carry the imprint of convention. That is why investigators in the past have rejected the theory of imageless thinking.*

If the hypotheses expressed above are valid, the preparatory phase of the solution process, in which an idea is formed of the conditions of the task, must be followed by a phase of "building up" from the situation, a phase of visualization of the image and its transformation. This activity on reconstruction of the visualized image must take place with the aid of a special motor alphabet, which must differ from the alphabet of orienting–investigative or external perceptual actions both in its biomechanical and in its functional features.

In the light of the results concerned with vicarious perceptual actions described above, the next step must be to verify whether or not they participate in the processes of problem solving. Do vicarious actions constitute the motor alphabet of intellectual processes, just as external perceptual actions constitute the motor alphabet of the processes of perception and identification? Intellectual processes, like perceptual, must surely rest on an absolutely definite material basis. In other words, intellectual processes must have their own motor alphabet, as well as a model of the real situation allowing both perceptual and intellectual transformations. If the existence of a motor alphabet of thinking processes

*It is difficult to overestimate the importance of speech, which undoubtedly plays an important role as a method of fixation of the intermediate results of intellectual activity.

is actually discovered by investigation, this will be an extra (admittedly, not decisive) argument in support of the participation of the peripheral levels of the visual system in the visualization of visual images. The function of the motor alphabet participating in intellectual activity can be taken over by vicarious actions, with a low amplitude of movement.* The purpose of the experiments described below was to test these hypotheses.

4.4. Visualization during Problem Solving

The technique of recording eye movements by means of an electromagnetic transducer (see 1.4.2) was used in this investigation. The eye movements were recorded simultaneously on two different scales on two S1-37 oscilloscopes with an electronic storage system. The general pattern of the oculomotor behavior, i.e., macromovements of the eyes, was recorded on the CRT of one oscilloscope while movements of the eyes which are usually (not absolutely correctly) called movements during fixation were recorded on the CRT of the other with much greater magnification. Simultaneous recording was possible of both the CRTs (the trajectories of the movements) and of the components of the movement along a time base. By using oscilloscopes with an electronic "memory" the experimenter could observe the motor behavior of the eye and compare the viewed picture with the subject's verbal response. Depending on the task and the purpose of the experiment, a particular field in which the eye would work could be chosen beforehand for recording, or, by watching the eye, a suitable field could be chosen in the course of the experiment. In the latter case, the experimenter was guided by what he saw on the low-magnification CRT. One of the methods used in these experiments was artificial limitation of the field of vision to 1-6° by means of a cap.

By means of this method it was possible to record and analyze the eye movements both at the stage of receiving information and at times of apparent passivity of the eye.

The following were the principal problems presented to the subjects in these tests: mental visualization of pictures including simple geometrical shapes, mental manipulation of objects (for example, Grey Walter's well-known test of dividing a colored cube, or the mental determination of the possible moves of a knight on a portion of the chess board, and so on; Figs. 4.1-4.3). The behavior of

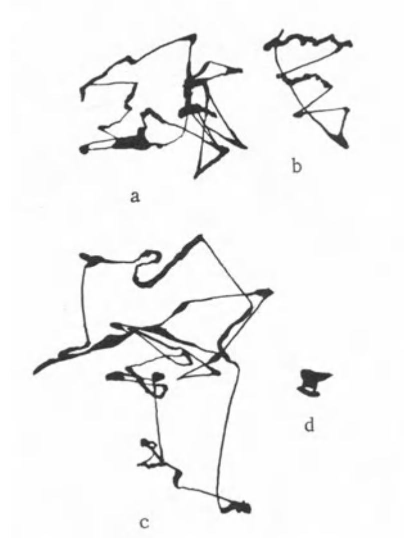

Fig. 4.1. Record of eye movements during solution of various problems requiring visualization and manipulation of images: a) visualization of a dog after presentation of its photograph; b) mental division of a colored cube into parts (Walter's test, 1966); c, d) finding the number of moves of the knight on part of a chess board measuring 5 x 5 squares; scale of recording: a, b, c – 1 deg/cm; d – 5 deg/cm.

the eye was studied in greatest detail during the solution of the problem known as the "5" game, methods of solution of which have been studied fully by Pushkin (1965) and Zavalishina (1968). This test involves a large number of situations and is solved by subjects in a short time (30-60 sec). Movements of the eye were also investigated during the solution of chess problems. The subjects were adults aged between 20 and 30 years.

The eye movements recorded during fixation coincided with results obtained by many other investigators, who found that during fixation of a point with the eye, drift movements are observed around it, together with saccadic return movements toward the point of fixation. The region in which both types of movements occur does not exceed 20-30' during observation of the point for 10-15 sec. In the ab-

*In the investigations of Pushkin (1965) and Tikhomirov (1968), who used a motion picture technique to study the motor components of problem solving, vicarious movements could not be recorded because their amplitude was too small. However, low-amplitude movements of the eyes have frequently been recorded at times other than during problem solving.

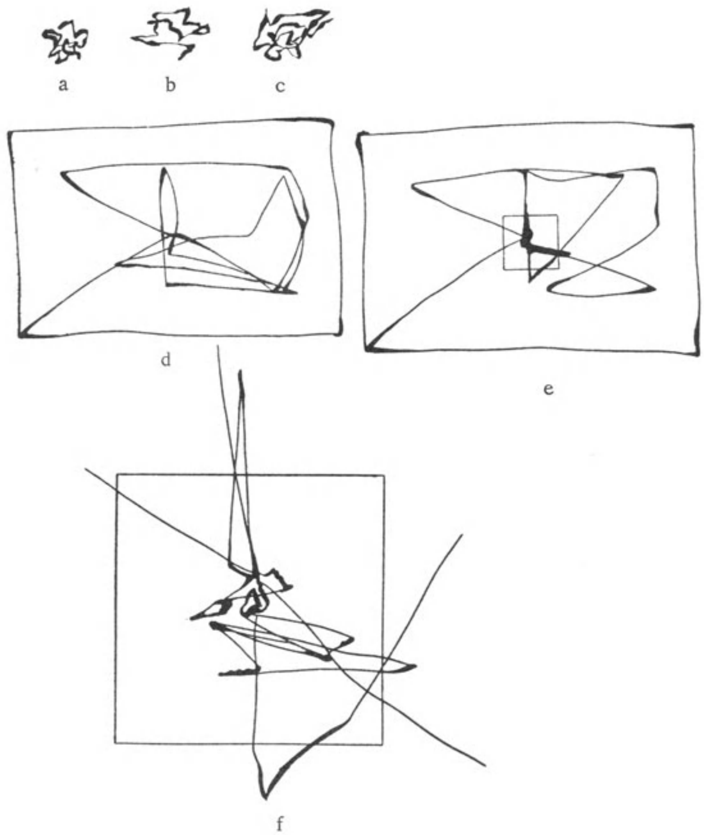

Fig. 4.2. Records of eye movements during visualization of geometrical shapes and solution of the 5 problem: a) visualization of the surroundings; b) visualization of a star; c) visualization of an octagon; d) solution of a simple form of the 5 game during work with a wide field ; e, f) solution of a difficult form of the 5 game during working with a wide field ; scale of records: a, b, c, f – 1 deg/cm; d, e – 5 deg/cm.

sence of a fixation point or of any visual task in general, drift movements of low amplitude also are observed, but they take place within a somewhat larger zone (up to 40-50') during recording for 10-15 sec. Hardly any saccadic movements were observed.

During mental visualization of simple geometrical shapes (in the absence of a fixation point) drift movements are observed and they occur within a much larger area, of the order of 2.5-3.0° or sometimes more.

In tests requiring mental visualization of geometrical shapes and manipulations of them, drift movements within a zone of 2.5-3.0° were observed initially. On the basis of the previous experiment, these movements can be associated with the stage of visualization of the assigned objects. Later, during performance of the main test (for example, counting angles), saccadic movements of low amplitude (of the order of 1°) were observed. The combined area of these movements also was limited to a region of 2.5-3.0°. These movements coincide in amplitude with vicarious perceptual actions recorded during stabilization of images, and also during perception of afterimages. Under these circumstances the drifts coincide with the times of visualization, and the low-amplitude saccadic movements coincide with solution of combinative problems.

Let us analyze in greater detail the eye movements of subjects solving the "5" game. The eye movements were recorded on two different scales. The problem was presented to the subjects in a field of vision measuring 30-45°. While the subject was becoming familiarized with the conditions of the problem, as observations on the low-magnification CRT show, visual fixations differed sharply from

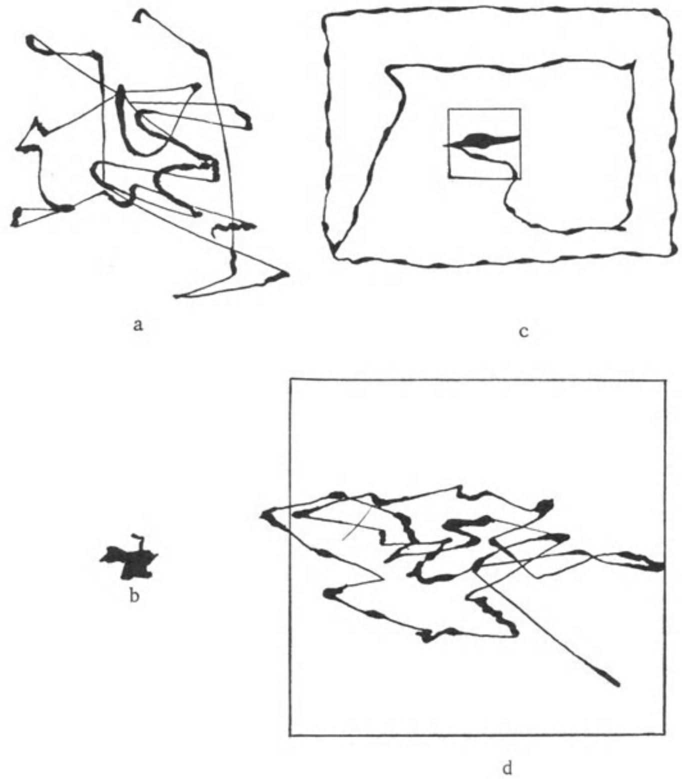

Fig. 4.3. Records of eye movements: a, b) solution of the 5 game presented allowed; c, d) solution of the 5 game during work with a narrow field equal to 6°. Scale of recording: a, d – 1 deg/cm; b, c – 5 deg/cm.

each other by the presence of high-amplitude saccades. Long fixations lasting 1 sec or more appeared as blurred spots on the recording made at this scale. These same fixations, when recorded on the CRO with much greater magnification, were seen as series of low-amplitude saccades (of the order of 1-3°). The zone of action of these movements was limited to 3-5°. The trajectories of the eye movements during long fixations were very similar in character to the trajectories observed in the phase of motor activity of the eye during movements of high amplitude, i.e., in the phase of familiarization with the situation.

Two typical situations in the "5" game, characterized by a certain number of moves to produce the optimum solution, were used as the experimental material. These typical problems differed in their degree of difficulty and also in their structural levels (Zavalishina, 1968). The easier problems are on a higher, and the more difficult problems on a lower structural level. According to Zavalishina's observations, the structural level depends on the structural arrangement of the elements in the situation and, correspondingly, on the required number of rearrangements. Later I shall use the terms easy and difficult situations or problems. The subject was required to reduce the situations presented to him to the normal form:

1	2	3
	4	5

Analysis of the experimental results confirmed the characteristics of the problem solving process obtained by Zavalishina on the basis of motion-picture recording of eye movements. During solving, periods of activity and periods of depression of eye movements were recorded. The periods of activity were characterized by eye movements of high amplitude, of the order of 10-15°, and by the short duration of individual fixations (0.3-0.4 sec). The duration of the depressions depended on the structural level of the problems presented. From the alternation of the periods of activity and depression, Zavalishina was able to distinguish different stages in problem solving.

The present writer's analysis of oculomotor behavior, with analysis of the functions of the low-amplitude movements of the eyes and drifts, led to a new possible interpretation of the principal stages of problem solving. The first stage is characterized by considerable activity: the eye movements are of high amplitude and fixations of short duration. The trajectory of the eye movements at this stage reproduces the pattern of the visual survey of the conditions of the problem. Frequent returns are made to certain numbers. This stage can be regarded as a process of familiarization with the presented situation, as a process of construction of its conceptual model. The frequent returns to the numbers during familiarization can be regarded as attempts by the subjects to find the required link between the elements of the field directly, to reconstruct the visual situation directly, and to reduce it to the normal form. Experienced subjects can solve problems at a high structural level. In the absence of any evident connection, oculomotor activity begins to break down: saccades become infrequent or disappear completely, i.e., the stage of depression, usually characterized as activity in the internal plane, arises. However, on the records made with high magnification, high oculomotor activity is observed at this stage also. In the next stage, oculomotor activity reappears, and just as in the first stage, the amplitude of the saccades is high. The direction and sequences of these saccades show that the subject is returning to the field of the numbers to test the solution he has found, and is "playing back" the alternative links established between the elements.

These stages arise, with different degrees of clarity, during the solution of problems of varying degrees of difficulty. Problems at a high structural level are recognized as such in the initial stage of familiarization with the situation. The subjects do not carry out any complex activity in order to analyze the situation, but they apparently see the solution immediately and jump to the third stage, i.e., to the stage of operative actions. In problems at a high structural level, the sequence of the elements is either unchanged or is sufficiently evident. The subjects have only to perform the necessary displacements and to shift the whole series through a few positions. The pattern of oculomotor behavior during the solution of problems at a high structural level thus corresponds to one of repeated, but not regular, surveying of the field of numbers. As a rule long fixations do not arise in these cases. The total time required to solve the problems is the product of the number of fixations and their mean duration, viz. 0.35–0.5 sec. This program of the work of the eye during the solution of these problems agrees with results obtained in numerous investigations of the work of the eye during the search for information (Berezkin and Zinchenko, 1967).

In more difficult problems, at a low structural level, the subjects find it difficult to identify directly the essential displacements, the connections between the elements, and the necessary changes to be made in these connections. The total time for solution of problems at a low structural level is many times greater than the time for solving problems of the first type, and in individual cases it reached tens of seconds, or even a few minutes. Yet the number of fixations was only slightly increased by comparison with the total time of solution. The number of high-amplitude familiarizing movements remained about the same as during the presentation of problems on a high structural level. Well marked periods of depression, during which drifts and low-amplitude saccades, concentrated in the zone of long fixations, are observed, lead up to a change in motor activity. These saccades cannot be interpreted as a means of forming a connection between the elements of the field, because the movements frequently take place within the limits of the field occupied by a single number. These results show that in the process of problem solving building up in fact takes place periodically from the field in which the conditions of the problem are given, and that subjects attempt to solve the problem "in an internal plane." The accuracy of the method used to record the eye movements enables this conclusion to be drawn with confidence.

Analysis of the solving of problems differing in complexity thus showed that in the solution of structural problems and problems requiring the search for information, the characteristics of the eye movements are identical. In the solution of complex problems at a low structural level, the eye movements are contracted and long periods of depression are observed, during which the eye operates by drifts or by low-amplitude, fast saccades.

Are we justified in interpreting the oculomotor activity observed during these depressions as vicarious perceptual actions, i.e., as a form of activity intimately connected with the process of problem solving? To obtain a definite answer to this question, it is necessary to make sure that the eye activity observed within the confines of a field occupied by a single number (or between two numbers) is not connected with the perception of the whole numerical field. In other words, it is necessary to make sure that the subjects, when solving problems, do not periodically enlarge their operative field of vision (Gippenreiter, 1964) and that under these conditions they do not begin to work with a "wide field."

To test the hypothesis that activity of the eye during depressions is a manifestation, not of external perceptual actions, but of vicarious actions, a special series of tests was carried out in which the subject had his field of vision artificially restricted. The size of the field of vision, limited by means of a cap (see 1.6), was equal to the size of one of the digits. By this method it was possible to see in which cases and to which element of the field the subject turned his attention during problem solving. The narrow field prevented the possibility of the subject's working with several digits during a single fixation. The pattern of the trajectory of the eye movements with restriction of the field of vision was indistinguishable in principle from that found in the previous experiments. Only a decrease in the amplitude of the saccades to half the diameter and a long duration of the intermediate fixations were observed. When the field of vision was restricted, repeated returning to the conditions of the problem was made more difficult, and sometimes led to a sensation of discomfort. Because of the difficulties arising during examination with a narrow field of vision, the relative proportion of drifts, with which the eye operates even when solving problems on a low structural level, is reduced. This is associated with an increase in the time of familiarization with the situation, by comparison with the corresponding time under free examination conditions. The familiarization time under narrow field conditions depends on the size of the field and on the number of surveys of the presented situation.

Artificial restriction of the field of vision showed up even more clearly the distinction between the high-amplitude familiarizing movements and the periods of depression, including drifts and low-amplitude saccades. This means that the character of the movements in the zone of fixation remained the same as when the field of vision was unrestricted. In some cases, however, subjects re-examined the conditions of the problem with the aid of the narrow field, and in a few cases rapid saccades during fixation were replaced by drift which, on the basis of the previous experiments, can be interpreted as a method of assisting recall of the original conditions of the problem. The phase of fast, low-amplitude saccades then began again.

It can be concluded from the results of these experiments that drifts and low-amplitude saccades are unconnected with the enlargement of the operative field of vision and do not perform the functions of external perceptual actions or, in particular, functions of linking together the elements of the problem situation. These experiments provide weighty arguments in support of the interpretation of drifts and low-amplitude saccades as vicarious perceptual actions, as a means of visualization of the problem situation and its structural reorganization.

Finally, in the last series of experiments, the "5" game was presented by ear to the subjects. The results showed that this completely ruled out the possibility of high-amplitude familiarizing and investigative movements, i.e., prevented external perceptual actions. Under these experimental conditions the subject was faced with a neutral, uniformly illuminated field. During the solution of these problems, alternation of drift and low-amplitude movements was observed. It took place several times until the problem was finally solved (or was abandoned). As a control, the subjects were also presented with typical problems of finding numbers in tables or finding the way through a maze. In these cases, high-amplitude searching movements predominated, long fixations and drifts were absent, and hardly any low-amplitude movements occurred.

The results obtained in these series of experiments are given in Table 4.1 and Figs. 4.1-4.3, which show the total time required for solving the problems, the number of eye movements of high and low amplitude, and also the drift time. For comparison, results for finding the way through a maze are also included in the Table. The results given in the Table show that the more difficult the problem, the less the subject returns to the presented situation and the more time he spends operating with vicarious actions. A similar pattern was observed during the solution of chess problems. This agrees with the observations of Tikhomirov (1968) who found that more experienced chess players make fewer returns to the position on the board, and that their eyes spend a much longer time (than those of less experienced chess players) in a state of fixation.

4.5. Conclusion

The results of this investigation show that perceptual processes in fact make a substantial contribution to the process of problem solving. A more

TABLE 4.1. Characteristics of Eye Movements during the Solution of Problems of Different Complexity and by Different Methods*

Problem	Method of presentation	Time of solution (sec)	Number of move-ments A > 4°	Number of move-ments A < 4°	Duration of drift (sec)	Drift in percent of solu-tion time
Finding the way through a maze	Free examination	8.5 / 14,0	16 / 25	0 / 0	0 / 0	0 / 0
5 4 1 Easy 3 2	Free examination	5 / 10	9 / 17	0 / 0	0 / 0	0 / 0
3 2 4 Diffi- 1 5 cult	Free examination	264 / 265	10 / 20	48 / 263	202,5 / 156	76 / 58
5 2 3 Easy 1 4	Narrow field	36 / 74	25 / 39	11 / 46	6 / 15	16,5 / 20
3 1 2 Diffi- 4 5 cult	Narrow field	339 / 128	60 / 47	163 / 72	135 / 38	42 / 21
5 4 1 Easy 3 2	•By ear	18 / 57	0 / 0	10 / 49	11,5 / 36,5	63 / 64
1 5 3 Diffi- 2 4 cult	By ear	121 / 112	0 / 0	20 / 41	114,5 / 93,5	95 / 84

*Results for 2 subjects are given (above the line for one subject, below the line for the other). A denotes amplitude of movement.

detailed analysis of oculomotor behavior during solving indicates the presence of different phases or stages of this behavior. The first phase is one of externally marked and even visually observable perceptual actions, by means of which the subject familiarizes himself with the situation, and forms an image or his own conceptual model of this situation. In this phase the subject operates with vicarious actions. During the process of building up from the situation, drifts coinciding with the mental visualization of the problem situation or its elements are observed. Naturally visualization reaches the degree of distinct afterimages only in rare cases, and of eidetic images more rarely still. In most cases visualization and subsequent manipulation of the visualized image take place at the subliminal level, and the subject is unaware of them. That is why these processes are so difficult to investigate. In the phase of visualization the problem solving usually known as solving "in the internal plane" begins. In the third phase, manipulation of the image or model of the situation takes place by means of low-amplitude eye movements, in order to reconstruct the image in a useful way adequate to the particular problem. The borderline between visualization of the image and its structual reorganization is drawn to some extent conventionally. Before a sharper line can be drawn between these processes, further investigations are necessary.

The purpose of these transformations of the image and their conformity to the problem can be understood not merely as simulation of the properties of the stimulus by the receiving systems (Leont'ev), but also as the subsequent simulation of the problem facing the subject by the image of the object. Simulation of the problem by the object can, of course, also take place directly, by practical actions. However, too many actions, inadequately "lost in the head" would prove fatal. That is why living systems prefer to construct images and to visualize and transform them. This happens, first, because the same elements of the situation may have completely different meanings at different stages of solving the problem. For this reason, the visual situation can have an interfering effect on the solving process, and the need for building up temporarily from it arises. This was sensed very accurately by the supporters of Gestalt psychology, who wrote a great deal about "field effects."

Consequently, structural reorganization of the image by means of vicarious perceptual actions plays an important role in the process of problem solving, specifically in the development of a system of actions which must be carried out in order to find a solution or to put it into effect. In this sense the process of solving in fact is an interiorized activity: an activity in the internal plane or activity with an image of the situation. Enlightenment, insight, discovery – all these are the result of this activity which, like any other, must have its perceptual and its motor alphabet in order to give it the right to be called an activity. The essential components of the interiorized activity, carried out with an image of the situation, are exteriorized in the system of vicarious actions, and they accordingly become accessible to investigation.

It is clear from these results that the investigation of the various motor alphabets used in both simple and more difficult processes of information seeking could prove very promising. A much more difficult matter from the point of view of intellectual problems is the definition of the alphabet of images or operative units of perceptual and intellectual activity. A number of different methods which have been used to tackle this problem have been described by T. P. Zinchenko, Toidze, Shekhter, and others, in their papers to which reference has already been made, but very few results yielding definite information about the content and form of the operative units of perception have yet been obtained.

Further developments in the basic principles underlying experimental investigation of the perceptual and motor alphabet at different functional levels of information systems will, we can hope, help to establish a solid experimental basis for the study of such fundamental problems as the formation of "functional organs" (Leont'ev) or "physiological organs of the nervous system" (Ukhtomskii), or the "formation of schemes" (Oldfield) which were mentioned at the beginning of this book.

In the light of the results described in this chapter, the problem of formation of decision making ability can be expressed in the terms of the praxeological interpretation of perceptual processes which has gained acceptance at the present time. This problem has two aspects. First, the subject's ability to manipulate images must be formed so that he can in fact perceive the different aspects and properties of the object. This enables him to reduce the information received to a form suitable for decision making. Second, the information reduced to its essential form must be converted into something similar to the purpose of the action or the intellectual problem facing the subject. Both these abilities are largely perceptual. If this interpretation is correct, not only the reduction of information to a form suitable for decision making, but also the decision itself is a very important aspect of the problem of image formation.

CHAPTER 5

A FUNCTIONAL MODEL OF THE SENSORY COMPONENT OF THE VISUAL SYSTEM

In the previous chapters we have studied the results of investigations of perceptual and intellectual activity. The authors have attempted to shed light on the links between higher mental functions. The experimental analysis of the participation of perception in other mental processes such as thought and memory has largely rested on the results of intrafunctional investigation, in which the method of prolonged stabilization was used. As was pointed out at the beginning of Chapter 2, this method is a unique test model for studying the reduction of effector components of visual perception, because in it, those elements which, according to the widely held view, are absent in the fully formed functional system, have been artificially excluded. In this chapter we shall turn again to the problem of simulating certain properties of the visual system, bearing in mind the fact that an improvement in the methods of intrafunctional investigation is one of the essential conditions for the future construction of models of interfunctional interactions.

5.1. Characteristics

As a rule models are built and improved in connection with the appearance of new facts. In recent years such facts in the field of psychophysiology have been obtained by the study of visual processes under the conditions of perception of images stabilized relative to the retina (Yarbus, 1966; Pritchard, 1966; Zinchenko, 1966; Vergiles and Mashkova, 1966). Some discussion of these facts themselves is called for. At the same time, they can also shed light on important aspects of the function of the visual system which could usefully be taken into consideration when problems are encountered during the simulation of the elements and functions of the visual system.

A hypothesis to explain a number of phenomena arising during stabilization of the visual image is described below. At the same time, an attempt is made to suggest a more universal model of the process taking place at the periphery of the visual system, and embracing a wide circle of psychophysiological phenomena, including phenomena arising during stabilization of the image. The object of the exercise was to examine the operation of one channel acting on the receptor–optic nerve section of the visual system. The essential objective characteristics of every communication channel, rather than individual effects and phenomena of visual perception, served as the basis for the model. First and foremost among these characteristics is limitation of the spectrum of transmitted frequencies, a property of every physical system. It is evident that limitation of the frequencies in the channel from above will determine its inertia, or the velocity of transmission of information through it. Limitation of the spectrum of transmitted frequencies from below means that at some frequencies the channel virtually ceases to perform its functions, i.e., it ceases to be a channel of communication.

In both cases, limitation from above or from below, some of the original information is lost in the channel, and the information passing through undergoes a number of changes and distortions, the character of which depends both in the characteristics of the channel and on the characteristics of the incoming signal. The essence of the problem is thus to examine the transformations undergone by the signal in the channel of communication functioning at the periphery of the visual system, and their dependence on the characteristics of the signal entering the system.

The character of the transformations taking place in the visual system can be judged, for example,

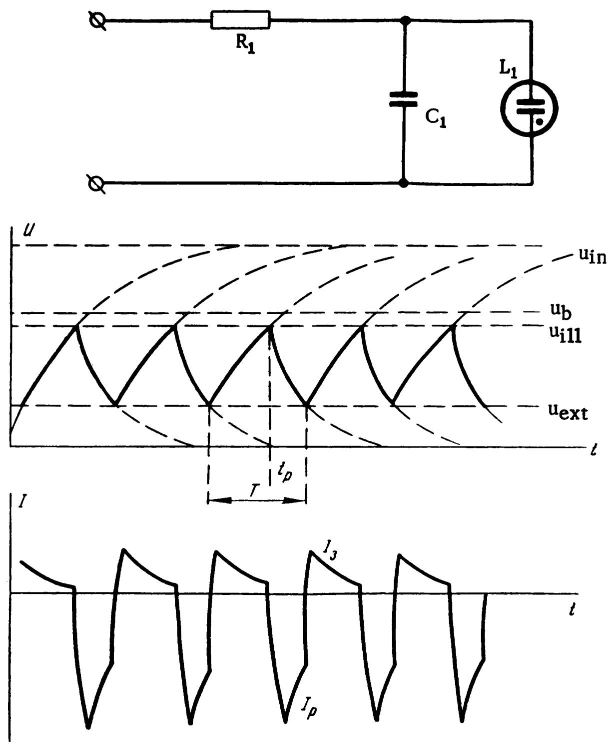

Fig. 5.1. Circuit of a relaxation transducer and curves showing changes in voltage and current.

by comparing the subject's report of what he sees with the stimulus applied to the input. One important relationship established in the course of this comparison was Fecher's law, relating the amplitude of the input signal with the subjective evaluation of brightness. At the same time, the response of the visual system to a photic stimulus is the spike response of the ganglion cell. These two phenomena can be satisfactorily simulated by a transformation expressing the relationship between the amplitudes of the input signals and the frequency of the output spikes as a logarithmic function. Such a converter is known in technology as a relaxation transducer.

The working principle of the circuit is as follows: if an electrical signal is applied to the input through circuit R_1C_1 (Fig. 5.1.) a current starts to flow and charges capacitor C_1. The voltage on the capacitor arises in accordance with an exponential law and the rate of charge will be determined by the magnitude of the resistor and of capacitor C_1. The voltage on the capacitor and, consequently, the voltage on the neon tube at any moment will be determined by the voltage applied and the time constant

$$u_{\text{bulb}} = u_{\text{in}}(1 - e^{-\frac{t}{\tau}}).$$

Tube L_1 lights up, i.e., its resistance falls sharply, at a certain voltage u_{ill}. Hence, when the voltage u_1 on capacitor C_1 becomes equal to the threshold voltage of the tube, the capacitor discharges. The next cycle takes place similarly, i.e., the capacitor is charged through resistor R_1 and discharges through tube L_1 (through its [low] resistance r). The shape of the curve of the current flowing through the tube at the time of discharge will evidently be determined by the internal resistance of the tube and by the capacitance of C_1.

Without going into a more detailed analysis of the operation of the circuit, it can be pointed out that the relationship between the amplitude of the input signal and the period of repetition of the output pulses will be a logarithmic function only at mean values of the amplitude of the input signal. If the signal is weak, close to the bias voltage, i.e., only slightly higher than the threshold of the transducer, the output pulsed response will be a combination of two values: the reaction to the input signal and the spontaneous activity of the system itself. If the signal strength is high, a new deviation from a logarithmic function will take place, and the circuit will continue to respond with an unchanged maximal pulse frequency to any further increase in amplitude of the input signal. The maximal frequency is determined by the duration of each output pulse. The full expression for the relationship between the period of the output pulses and the amplitude of the input signal can be represented as the sum of two logarithms

$$T = R_1C_1\ln\frac{(u_{\text{in}} + u_{\text{b}}) - u_{\text{ext}}}{(u_{\text{in}} + u_{\text{b}}) - u_{\text{ill}}} + rC_1\ln\frac{u_{\text{ill}}}{u_{\text{ext}}}.$$

Since the maximal frequency of the discharges of a ganglionic cell measures several hundred hertz, such a system cannot limit any variable input signal whose changes in frequency are below this threshold. At the same time, however, the cell ceases to respond to much lower frequencies of stimulation than the discharge frequency. This suggests that the signal undergoes definite frequency limitation to a greater degree than at the cell itself before it reaches the level of the ganglionic cell.

This frequency clipper could be an RC circuit connected through a frequency-pulse transducer. This circuit (Fig. 5.2) consists of a high-frequency filter, in which capacitor C_2 has frequency-dependent impedance; consequently, the amplitude of the output signal will be determined by its frequency.

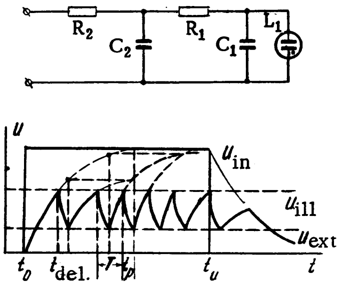

Fig. 5.2. Changes in output voltage with a square input signal.

In the R_2C_2 circuit the square wave applied to the input is converted at the output into a differently shaped signal. This circuit can also be regarded as a storage network for the pulsed signal. The voltage on the capacitor, i.e., the output voltage, is determined by the equation

$$u_{out} = u_{in}(1 - e^{-\frac{t}{\tau_2}}), \tag{1}$$

where τ_2 is the time constant for circuit R_2C_2. This additional circuit produces no changes in the logarithmic character of the process of the frequency-pulse transducer. The voltage on the capacitor C_1 is thus

$$u_{l_1} = u_{in}(1 - k_1 e^{\alpha_1 t} + k_2 e^{\alpha_2 t}) \tag{2}$$

where k_1, k_2, α_1, and α_2 are constants determined by the values of R_1, R_2, C_1, and C_2.

In our case, however, the decisive factor is not the voltage on capacitor C_1, but the difference between the potentials of illumination and extinction of the lamp, but in this case also the character of the process still remains unchanged, and only the constants have different values [a case in which a single pulse of long duration (t_u) was applied to the input of the circuit is illustrated in Fig. 5.2]. It is clear from the graph that the system response to this signal with some delay determined by the time taken to charge capacitors C_1 and C_2 to the threshold voltage. This time is the delay time or inertia of the system. However, it must be remembered that capacitor C_2 need not be a single element, but the sum total of the capacitances of all elements from the input of the system connected in parallel.

The system illustrated in Fig. 5.2 can thus perform the functions of transforming a continuous signal into a discrete signal establishing a logarithmic relationship between the input and output signals, delaying the output signal relative to the input, and limiting the maximum frequency of the input signal which is transmitted to the output.

Many investigators have so far confined their attention to the analysis and simulation of the functions of the visual system we have just examined, so that many psychophysical phenomena have remained unstudied. The investigations of stabilization of the visual image provide evidence of yet another functional component in the visual system.

Experiments on human subjects with stabilization of the image on the retina, in which the test stimulus remains unchanged for a certain time both in brightness and in position, show that the image ceases to be noticed after a certain time, and after removal of the test stimulus, an afterimage appears at the same place on the retina. On the other hand, a change in the brightness of the stimulus at a certain speed leads to the appearance of an image, and the sign of the change is immaterial (Yarbus, 1965). It can be concluded from these observations that the visual system has a low-frequency filter at some point. This filter must evidently be situated functionally below the level of the ganglionic cells, as physiological experiments show. For instance, ganglionic cells functioning under on-conditions cease to respond to an unchanged photic stimulus. On withdrawal of the stimulus, cells functioning under off-conditions begin to respond with a series of spikes (Jung, 1964).

An RC circuit can be used as the simplest low-frequency filter. A similar choice was made by Antakova et al. (1966) to simulate the insect retinogram.

In our case, loop R_3C_3 is used as a differential circuit connected to the input of the existing circuit. If, for instance, a pulse of current is fed into the input of the loop, the capacitor begins to charge by an exponential law up to the value u_{in}. The voltage on resistor R_3 correspondingly falls, and when the source of current is disconnected the process goes in the opposite direction.

To simplify further discussion, the integrating circuit will be left out temporarily. The new circuit then consists of a combination of the transducer on tube L_1 and a differential network (Fig. 5.3). In this case the voltage on the tube when the input signal is fed in will be determined by its shape and amplitude and by the time constant of loop R_3C_3. When the current is first switched on the voltage on the tube is maximal and, consequently, the pulse frequency at the output will also be

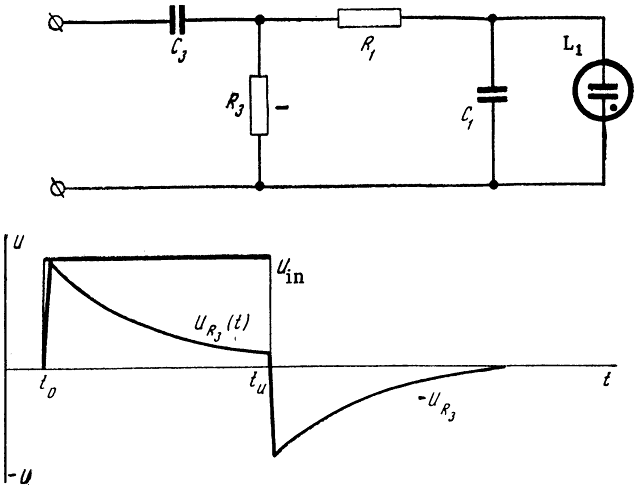

Fig. 5.3. Changes in square wave voltage at low-frequency filter.

maximal. Later, during charging of the capacitor, the tube voltage will fall, as also will the frequency. When the voltage on the tube has dropped below threshold (but not yet reached zero), the flow of pulses ceases. When the source of power is disconnected, the capacitor discharges, the potential differences on the tube is of the opposite sign and it does not evoke a pulsed response because the voltage of the capacitor discharge is compensated by the bias voltage.

In order to obtain a pulsed off-response, yet another transducer must be included in the system, i.e., the circuit must be constructed as shown in Fig. 5.4, in which first tube L_1 gives an on-response and tube L_2 an off-response to the input voltage, i.e., an on–off system is obtained.

In fact, on application of the stimulus, i.e., with a direct image, the on-system operates, and on withdrawal of the stimulus the off-system begins to function, and evidently responds to the afterimage. However, such a rigid distinction can be drawn only when the system was at rest before application of the stimulus, i.e., when there was no charge on the capacitor. In that case, the direct image in fact corresponds to on and the afterimage to off. If, on the other hand, at the moment of application of the stimulus the system was brought from equilibrium (if a strong background source of light was first switched on), the whole process in response to stimulus on–off takes place on one tube only. This variant corresponds to an on– off response, and the afterimage in this case is negative, i.e., its brightness is below the background level.

This circuit thus allows passage of the frequencies of a harmonic signal above a certain level, the creation of an afterimage, and operation of the system under on, off, and on–off conditions.

Another important property of the visual system is its adaptation. The laws governing this process have been fairly widely studied and they represent the change in sensitivity of the eye as a certain function of time. By introducing yet another RC loop with a high time constant (of the order of several minutes) into the circuit a system is obtained in which the ratio between the amplitudes of the input and output signal depends on the initial conditions. This is essentially storage circuit R_4C_4, connected in parallel with the source of the signal. The actual amplitude of the input signal is thus determined by the difference between the levels of the signal applied and the charge on capacitor C_4.

Having examined the working of the schemes separately, we can now go on to use the complete scheme illustrated in Fig. 5.5. This scheme is now adequate to simulate many pyschophysical phenomena, notably: 1) the transformation of a continuous into a discrete signal, 2) absolute thresholds of sensitivity, 3) limitation of the frequencies of signals both from above and from below – CFF (critical flicker frequency), and disappearance of the image on stabilization, and 4) adaptation.

5.2. Illustrations of Properties

A more complete illustration of the properties of the model is given below and its link with known psychophysical laws is demonstrated. The descrip-

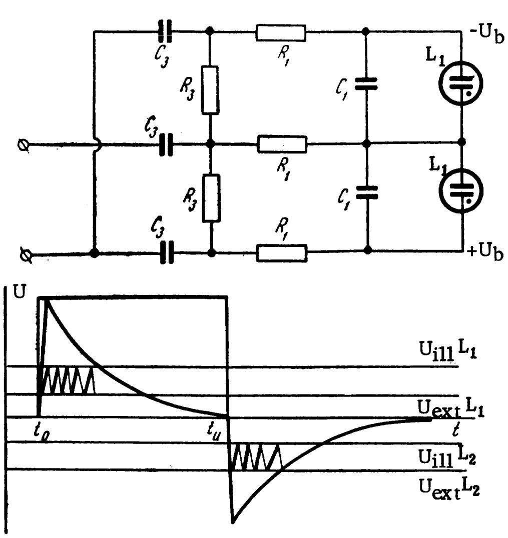

Fig. 5.4. Operation of the circuit under on–off condition.

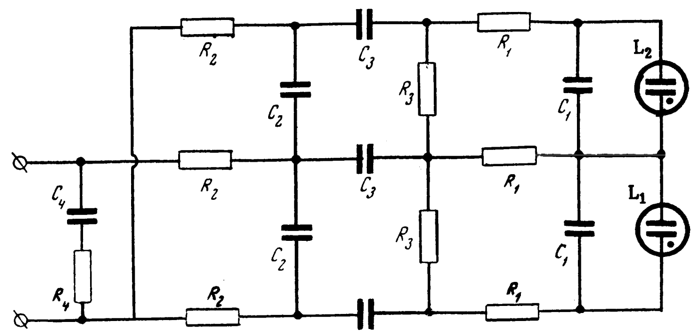

Fig. 5.5. General scheme of the model.

tion of these phenomena must take into account interaction between different parts of the model and the signal.

To prevent undue complication of the examples with irrelevant transformations, we shall examine only the changes undergone by the input signal in two components of the model, i.e., in circuits R_2C_2 and R_3C_3, the filters of high and low frequencies. The conditions of adaptation of the circuit are determined by the presence of a certain residual voltage on capacitors C_2 and C_3 of the circuit. It must be emphasized once again that the model describes only the sensory component of the peripheral part of the visual system. This means that all effects connected with movement of the eyes must be allowed for when results obtained on the model and in classical experiments are compared. Such allowance can be made in two ways: either the characteristics of the eye movements and the related effects must be precisely known, or they must be abolished when the experiments are conducted. The most convenient method is by stabilizing the image relative to the retina, so that differences between the conditions of operation of the model and the experiment can be eliminated. In addition, comparison of known psychophysical results with the results obtained in stabilization experiments enables certain functions of the eye movements applicable to these experiments to be determined.

5.2.1. The Laws of Plateau and Talbot. Let us now examine the well-known laws of Plateau and Talbot, connected with the critical frequency of fusion of flashes.

According to Plateau's law, critical frequencies measured for two complementary discs are equal. On the other hand, according to Talbot's law, during fusion of flashes the sensation of brightness of the fused image is proportional to the light part of the period. At the same time, we know that the critical frequencies are proportional to the brightness of the flashes, i.e., the brighter the flashes the higher the critical frequency of fusion. There is thus a contradiction between the laws of Plateau and Talbot, and on this basis they can be regarded as applying to different classes of phenomena.

Let us now examine these phenomena on the model. The pair of complementary discs, the wide sector of one of which is equal to the black sector of the other, and vice versa (Fig. 5.6), can evidently be replaced by two series of flashes with the same ratios. This variant does not change the character of the experiment but it allows analogous series to be performed on the model.

The first series of flashes with amplitude u is fed into the input of the model. The duration of the input signal is designated T_1, and the length of the pause T_2. Let us consider the transformations taking place in each component of the scheme separately, assuming that the output signal from the first component is the input signal for the second.

When the pulse acts at the input, capacitor C_2 begins to charge through resistor R_2. The rate of charge will be determined by the amplitude of the input signal u_{in} and the time constant $\tau_2 = R_2C_2$ (the time constant defines the time taken to charge the capacitor up to the level of 0.7 of the input voltage). Since in our case the time of action of pulse T_1 is chosen to be smaller than τ_2 (a case of subcritical frequency), the capacitor can be charged only up to a very small value. At the next moment T_2 (the pause), the capacitor begins to discharge, but it will discharge more slowly than in the first case, because the capacitor was not completely charged. It can be shown that the discharge is also incomplete, because T_2 also is smaller than τ_2. As

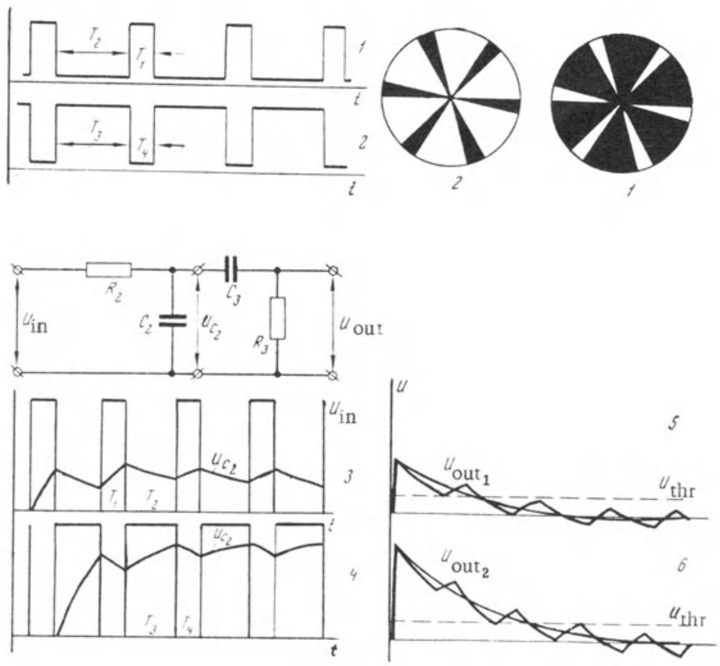

Fig. 5.6. Working of the scheme under conditions of complementary pulse sequences.

a result, the next cycle begins, not at zero, but at a higher level. This continues until a state of equilibrium is reached, when the extra charge on the capacitor is equal to the partial discharge. This potential difference, called the amplitude of the variable component, is established at some distance from the zero line. The level at which the variable component is established is called the constant component. Quantitatively, the magnitude of the constant component is determined by the mean value of the signal over the period and it varies from zero to the amplitude of the input signal—pause ratio is increased.

Let us now turn to the second pulse sequence in which the duration of the flash T_3 is equal to the pause T_2 in the first series. The processes of charge and discharge of capacitor C_2 are similar, but the level at which the process is set, i.e., the magnitude of the constant component, is different (Fig. 5.6, curve 4). These curves are mirror images of each other. Transformed pulse sequences thus act on the input of the second component of the scheme. The differential capacitor of the second component passes only the variable component of the signal, and the constant component changes only the level of charge of capacitor C_3. Since charging of the capacitor does not take place instanteously, but depends on the time constant $\tau_3 = R_3C_3$, the voltage on resistor R_3, which is equal to the constant component, will fall to zero as capacitor C_3 charges. The variable signal, having passed unchanged through capacitor C_3, is superimposed on the curve of the voltage drop. As a result, curves 5 and 6 (Fig. 5.6) are obtained. These curves differ from each other only in the initial time sectors after application of the signal. They later reach a steady zero level. At frequencies above critical the amplitudes of the variable components of these curves are below the threshold of operation of the output transducer, and the whole scheme gives no response, equivalent to the absence of a signal. Since the amplitudes of the variable components of both signals are equal at all frequencies of pulse repetition, frequencies at which the amplitudes are below the threshold are also equal, i.e., their critical frequencies are equal. A difference between the applied sequences can be found only at the actual moments of application.

The analysis thus shows that complementary pulse sequences have identical critical frequencies above which information passes only at the moment of application.

We can postulate that in a stabilization experiment the following effect can be obtained. If two complementary sequences of flashes are applied to the eye, each presented on its own half of the screen, the subject will see two flickering halves on the

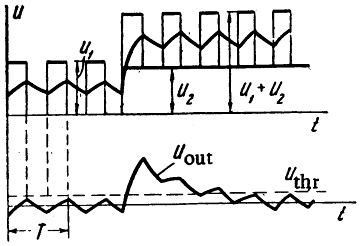

Fig. 5.7. Operation of the circuit under critical flicker frequency (CFF) conditions.

screen, and if the frequency is increased everything will disappear and instead of the screen he will see a black field. On further presentation of the flashes, two halves of different brightness will be seen for 1-3 sec, and these then disappear. The experimental results completely confirmed this hypothesis.

Comparison of the experimental results obtained under free examination conditions and with stabilization of the images shows that in the latter case the eye movements have the function of a modulator of light.

It can thus be concluded, from analysis of Plateau's and Talbot's experiments, with the aid of the model, that they investigated two phases of the same process, and that the contradiction between their laws is imaginary.

5.2.2. Fluctuations of CFF. Experimental investigations have demonstrated fluctuations of the CFF. Some fluctuations are connected with changes in the external conditions of stimulus application (extra illumination, etc.), to which the visual system responds very precisely. Let us consider the following example. A screen is illuminated by a flickering light so that the frequency of the change in brightness of the light is slightly above critical. If an additional source of light with constant brightness is now switched on, so that it illuminates the screen (i.e., the contrast is lowered), for a short time after the extra light has been switched on the subject will notice flickering of the screen, i.e., his critical flicker frequency has been raised. The decrease in contrast ought to lead to a decrease in the CFF, but in fact the opposite is observed. Analysis of this phenomenon on the model shows that it is due to a transitional process developing in the system. It is illustrated graphically in Fig. 5.7, where u_1 is the amplitude of brightness of the source of flickering light, and u_2 the brightness of the source of steady light. The decrease in amplitude of the signal in the circuit compared with the input signal is due to the presence of a filter of the higher frequencies formed by the elements R_2C_2.

Under the conditions of this test the amplitude of the variable component falls below the threshold level of operation of the output element, and there will be no signal at the output of the circuit. On addition of the second source, an extra charge begins to accumulate on capacitor C_3 up to the level of this source, leading to a temporary increase in voltage on resistor R_3. The time of this transitional process is determined by the time constant of the R_3C_3 loop.

However, the operation of the model agrees most closely with the experiments when it takes place under stabilization conditions, when relative displacements of the eye and object are eliminated. In the case just examined, for instance, the model gives no response at any time except when the additional source of light is switched on. A similar phenomenon also takes place with stabilization, when the flickering screen (with a flicker frequency above the critical level) is perceived as an empty field, and the only time when the observer sees the flickering screen is at the moment of the change in brightness of the additional source. This mechanism explains the transient observation of flickering when a source of light with a flicker frequency above the critical level is switched on.

5.2.3. Aftercontrast. The models can also give a response which is known in psychophysics as the phenomenon of aftercontrast. This phenomenon is illustrated by the following example.

Suppose half the retina is illuminated for a certain period of time $t_0 - t_1$ by a source of light of brightness I. At the next moment t_1, both halves of the eye are illuminated by another source of greater brightness: $I_2 > I_1$. The subjective sensation of brightness arising in the course of the experiment will be smaller for the half of the retina illuminated previously than for the other half.

The equivalents of brightness for the model will be the proportional values of voltages u_1 and u_2. In this case the process can be described graphically (Fig. 5.8). The first graph simulates the process taking place on the first half of the retina, the second graph simulates that on the other half. At time t_0 the voltages u_1 fed into the circuit begin to charge capacitors C_2 and C_3; since the charge passes through resistors R_2 and R_3, the charging

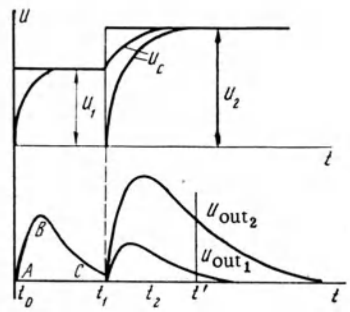

Fig. 5.8. Operation of the circuit under aftercontrast conditions.

process will extend over a period of time, and the greater the product of the capacities and resistances, i.e., the greater time constants of the circuits, the longer this time will be. The segment of curve AB characterizes the charging of capacitor C_2, and segment BC the charging of capacitor C_3. When the next voltage u_2 is fed into the circuit, additional charging of the capacitors begins to take place from the level of their charge at that particular moment up to the level u_2.

Comparison of the graphs for the two situations shows that the voltage at an arbitrary moment t' is smaller in the first case than in the second, a result which corresponds to the differences in the subjective sensation of brightness in the experiment described above.

5.2.4. Afterimage. If a system possesses inertia, the inertia must be manifested both on entry and on exit of the signal. In the latter case the effect of inertia can be regarded as storage of the accumulated information, and the time of this storage must be determined by the magnitude of the input signal and the quantity of energy accumulated. In the psychology of perception, this phenomenon is known as the afterimage. Let us examine how this process can be described by the model.

As was shown above, the afterimage arising after removal of the stimulus is stimulated by the process of charging of capacitors C_2 and C_3 (in particular, C_3). This concept is supported by the work of P. P. Lazarev, who gave a mathematical description of the process of extinction of afterimages. Lazarev concludes that the brightness I of the afterimage is determined by the expression

$$I = A + Be^{-\alpha t},$$

where A and B are constants characterizing the brightness of the image-stimulus and α is the coefficient of the rate of extinction.

The charging of capacitor C_3 in the model can be described by a similar exponential law.

We consider that all the effects predicted by theory should be reproducible by the model. As an

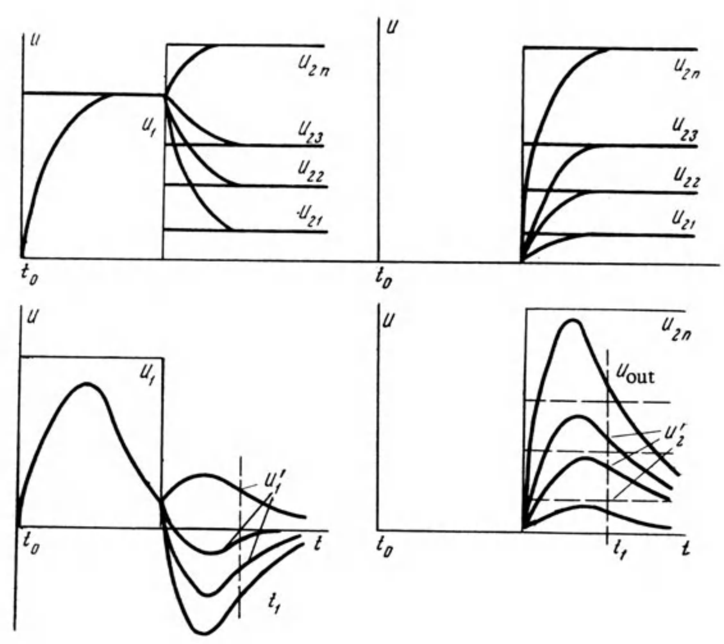

Fig. 5.9. Operation of the scheme under afterimage conditions.

example let us examine the case in which a pulse of light of brightness I_1 acted on a certain point of the retina, after which the whole retina was illuminated with background brightness I_2. According to Lazarev's theory, during the increase in brightness of I_2 from zero to a certain considerable magnitude greater than I_1, the afterimage will change from positive to negative, passing through a value when its brightness will be equal to the brightness of the background. This will correspond for the model to the case shown on the graphs in Fig. 5.9. It is clear from these graphs that the absolute values u of the charge on the capacitors at time t_1 will be determined by the magnitude of the background illumination u_2 and the time when this additional illumination is given relative to the first stimulus of brightness u_1. The sign of the value u_1' is also a function of the background illumination, from which it follows that the difference between the values $u_1' - u_2'$ will also be a function of u_2. The problems examined on the model for white light can also be extended to its individual components and to their combinations. In this case, one channel transmitting white light in the model must be replaced by several channels with different time constants of their circuits, because the rates of extinction, like the rates of increase in visual sensations, are known to differ for different colors (Kravkov, 1950). It is convenient to consider the colors adopted by the classical three-component theory as the basic colors. In that case, the whole system will be formed from three equivalent canals connected in parallel and possessing some degree of interference.

An illustration of the working of the model for different colors is the experiment already examined in Chapter 1. Let a certain part of the retina be illuminated by red light, and in that case when the source of light is removed the observer will see an afterimage of the same color; this is simulated by the discharge of the capacitor C_3. If instead of removing the source of red light, it is replaced by white light, the observer will see an afterimage of the complementary color, i.e., blue-green. This will correspond to charging of the capacitors C_3 in the channels for the blue and green colors, and to an unchanged state of the channel for red. This experiment is best carried out under stabilization conditions in order to eliminate the effect of displacements of the eye relative to the source of light, which could reduce the degree of saturation of the colors through the activation of other areas of the retina not illuminated previously by the red light.

5.3. Experimental Verification

Let us now examine experiments confirming, in my opinion, the validity of the functional model of the sensory component of the visual system I have just described. This model has proved useful not merely for reconciling the contradictory data yielded by classical psychophysics, but also for explaining a number of controversial phenomena known in the psychology of perception, and for predicting new data from the field of perception and short-term memory.

As was mentioned above, the essential elements were included in the model on the basis of results obtained by the study of stabilization. Naturally, when testing the model, we also used the stabilization method, because it enabled more strictly valid results free from "motor noise" of the visual system to be obtained.

5.3.1. Destabilizing Function of Macromovements of the Eyes.

The functions of macromovements of the eyes have been examined in detail in the chapter giving new data confirming the praxeological interpretation of perceptual processes. Here we must examine yet another function of these movements, namely the destabilization of the visual system.

Under free examination conditions the function of changing the intensity of illumination of parts of the retina is performed by movements of the eyes. To provide normal conditions of vision, the period of change in brightness must evidently be shorter than the time taken for the image to disappear, and longer than at the critical frequency of flicker fusion. This interval must thus lie between 0.05 and 1.0 sec. Values of the fixation times during voluntary examination must also lie within the same time interval (100-500 msec). The problem of micromovements of the eye is of particular interest in this connection. Attempts have been made to link optimal conditions of vision with micromovements of the eyes, and the statement has frequently been made that tremor is the mechanism producing destabilization of the image on the retina, and thereby evokes a variable signal on the receptor. It follows from the previous discussions that tremor with frequencies above critical cannot provide the necessary conditions for vision.

To confirm this statement, experiments were carried out to simulate the individual components of tremor. These experiments were as follows.

After disappearance of the image of an object stabilized by means of a cap, a generator causing the test object to oscillate was switched on (for details of the method, see 1.5.1). The object consisted of a negative with vertical and horizontal lines of different colors. The frequency and amplitude of the oscillations were varied at each presentation. The experiments showed that the image appeared only at the moments of starting or stopping the oscillation signal, regardless of the frequency of the oscillations of the object. The only effect of amplitude of the oscillating signal was to determine which part of the image was made visible, i.e., if the amplitude of the signal was greater than the linear dimensions of the object, the whole of the object was seen, but if it was smaller, only part of it equal in size to the amplitude of the oscillating signal was apparent. At frequencies of oscillation below the CFF, the image was observed to move over the field or to oscillate.

These arguments and experiments provide evidence that high-frequency micromovements of the eyes have no direct relationship to the mechanism providing for deadaptation and continuity of perception; the functions of micromovements in the visual process require further detailed investigation. At the same time, it follows from the above account that macromovements of the eyes not only center the image and guide the most sensitive part to the object, but also provide the conditions of normal vision, i.e., they are an automatic mechanism preventing stabilization of the image and ensuring the normal operation of the visual system.

5.3.2. Short-term Visual Memory. The phenomenon of short-term visual memory was chosen as the next test for the suggested model. The logic of operation of the model indicates that short-term storage of information is possible in the visual system.

If a slowly changing voltage, and not a square pulse, is fed into the input of the model, so that the rate of its change is less than or equal to the rate of extinction of the process in loop R_3C_3, the amplitude of the output signal on tube L_1 will be below threshold, and no pulse response will be given. At the same time, on removal of the input signal a negative half-wave of output voltage appears and serves to operate tube L_2.

We consider that a similar result can be obtained in the investigation of short-term visual memory. Moreover, on theoretical grounds there cannot be a limited volume of visual memory or, more precisely, these limitations must be connected entirely with the resolving power of the visual system and the phenomenon of irradiation. The retina must store all presented information, and the storage time must be proportional to the logarithm of brightness. However, practical experience of the investigation of short-term visual memory by the traditional tachystoscopic method indicates that the capacity of the memory is limited to four or five symbols. In investigations by Sperling (1960, 1963), who used a poststimulus instruction method requiring the subject to reproduce some of the presented material, it was found that the capacity of the visual short-term memory is 2-3 times greater than that found by the classical tachystoscopic method. Sperling's findings were confirmed by the investigations of Vuchetich (1968) and others. Immediately after the publication of Sperling's work, Buschke (1963) suggested another method of estimating the capacity of the short-term memory: by determining the absent component in a presented series. This method also yielded higher results than the tachystoscopic investigations.

Analysis of the properties of this model shows that the actual capacity of memory cannot be discovered either by the method of poststimulus instruction or by the method of determining the missing component.

To obtain a more complete estimate of the capacity of short-term visual memory, the method of stabilization of the image relative to the retina was used. This method enabled the process of long subliminal accumulation of information to be simulated completely in the manner in which it takes place in the model.

A central cap with an objective of focal length 9 mm was used in the experiments. Electroluminescent plates were used as the source of light. The brightness of the plates could be varied by adjusting the power supply from 0 to 150 nit. To obtain a negative afterimage, two electroluminescent plates were placed perpendicularly to one another, and at the point of intersection of their normals a semitransparent mirror with coefficient of reflection about 50° was placed. The plane of the mirror lay at an angle of 45° to the optical axis of the objective. This system enabled the test field and a neutral field to be presented alternatively. On the neutral field the subject could see a negative afterimage of the test field.

The subject was shown tables of numbers measuring 15 × 15° with 36 digits. Each digit subtended an angle of about 1°. The subject's eye movements were recorded on the screen of an oscilloscope which recorded the movements of the detector secured to the eye. The records were then photographed.

The cap was placed on the subject's eye, after which the brightness of the electroluminescent plate, on which the test object was placed, was slowly increased. This process continued for about 1 min. Adaptation of the visual system under conditions of stabilization of the test field took place more rapidly than the increase in brightness. For this reason, in the preliminary phase of the experiment the subject saw nothing although brightness of the test field reached 150 nit.

The voltage applied to the test field was then suddenly and simultaneously discharged, and the central field illuminated; against its background the subject saw a negative afterimage of the test table. In response to the experimenter's instruction, the subject counted the numbers on the table. On the average, before disappearance of the afterimage, the subject managed to count between 10 and 12 digits, twice as many as the capacity of the memory revealed by tachystoscopic tests. Just like Sperling, we used the method of partial reproduction and asked the subject to count the digits in different parts of the table. The instruction was given to the subject before the test field was illuminated, i.e., at a moment when the subject could not yet see the table and could not have learned the material required. It was found that it made no difference to the subject from which area of the afterimage the numbers were counted. The volume of material reproduced remained the same. Consequently, by organizing the experiment in this way, an effective impression of the whole test field of the retina was obtained. This impression was more stable than that obtained by tachystoscopic presentation, and this explains the high results of reproduction. In essence, it was shown that within a short time the subjects could imprint the entire test field (36 elements compared with the 17 elements which the subjects remember in the tests with poststimulus instruction), provided that this field is stabilized relative to the retina.

These high results cannot be obtained by tachystoscopic presentation of the information, because during that short time it is impossible for the visual system to accumulate sufficient stimulus energy (it is not by accident that the tachystoscopic method has been called the method of stimulus exhaustion). Under free examination conditions the capacity of the visual memory obtained experimentally is likewise substantially lower than can be explained by obliteration of the afterimage by the new stimuli, which takes place during a change of fixation points.

Analysis of the records of eye movements showed that movements are essential for the removal of information collected by the retina. The eye movements were three times smaller in amplitude than the angular dimensions of the presented test field, they were drift-like in character and they were more reminiscent of wandering fixation than of saccadic search movements. Similar movements have been found during the study of perception of stabilized images and they were called vicarious perceptual actions (see Chapter 2). It can be postulated that by the aid of these movements the useful information collected by the retina can be selected and transmitted into the operative memory.

This investigation and the analysis of the properties of the model I have described suggest that short-term visual memory is largely dependent on the state of the peripheral component of the visual system.

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