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AN OBJECTIVE STUDY OF OCULAR MOVEMENTS AND THEIR CONTROL

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It is impossible to mention the name of a scholar who has made a more important contribution in analysing the structure of some psychophysiological processes - and primarily the processes of perception - than Wolfgang KÖHLER. That is why we take the liberty to present in this volume some data concerning ocular movements which play a considerable role in visual perception. That will be the expression of our high estimation to the eminent scholar to whom this volume is dedicated.

The analysis of ocular movement attracted high interest among psychologists for a long period.

It was nearly a hundred years ago that I. M. SECHENOV, the famous Russian physiologist, anticipated that ocular movements would be found to play an important role in visual perception, "feeling" visual objects just so as the hand feels the tactual ones, and that human eyes are to be considered as a special kind of "tentacles".

During recent time precise study of ocular movements in normal and pathological cases has been used in a number of investigations. These investigations have showed very clearly that an immovable eye is unable to perceive complicated visual objects, that singling out important information from the object perceived includes active scanning movements and that even images of simple visual patterns disappear in 2 - 3 seconds if they are projected to a fixed part of the retina (YARBUSS, 1956, 1961). But not only the role of ocular movements in visual perception can be subjected to analysis. Ocular movements themselves and different modes of their regulation can be studied.

What forms of ocular movements exist and what are the main principles of their regulation? Does the structure of ocular movements change when they are included in distinct regulative systems? Do we have objective methods to study different forms of ocular movements?

It has been shown in a number of studies that at least two kinds of ocular movements can be described: smooth and saccadic motions of the eye (WESTHEIMER, 1954, YARBUSS, 1961).

These two kinds of ocular movements have a different basis, - and what is their relation to reflex (visually afferented) and so-called voluntary movements (regulated by external or internal verbal command)?

Does the structure of ocular movements remain the same when the eye is following a moving object as when the movement of the eye is driven by a verbal command? Does the kind of ocular movement remain unchanged in cases where the velocity of a traced visual object increases? And finally does the structure of these movements change when the subject tries to reproduce identical tracing movements from memory?

All these questions are important for a study of mechanisms regulating eye movements and for the analysis of their dependence upon various forms of afferent systems.

To answer these questions one must make a precise study of very simple ocular movements. We used for this purpose a technique of contactless photoelectrical registration of ocular movements, developed in our laboratory (cf A. D. VLADIMIROV and E. D. HOMSKAYA, 1961). The image of the eye is reflected through frosted glass onto a photocell. The displacement of the eye's image results in a change of amount of light falling on the photocell. Signals from the photocell are amplified and registered in ink on a moving paper. In our device 1° of ocular movement displaces the pen by 1 mm.

Ocular movements in a group of normal subjects were studied. Three series of experiments were carried out.

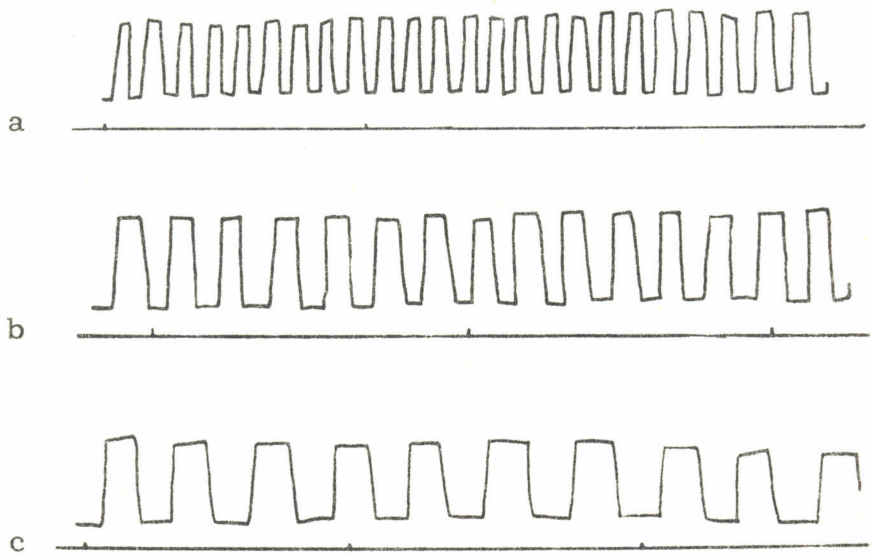

Fig. 1: Ocular movements regulated by verbal command (in the absence of visual afferentation). Upper line = ocular movements; lower line = time (5 sec. intervals); a, b, c = different subjects.

In the first series the subject was instructed to move his eyes back and forth in an angle of 30° as rapidly as possible.

In the second series he had to trace a luminous spot which oscillated smoothly within the same limits. The velocity of the oscillations of the spot gradually increased from 0.3 c.p.s. to 2.0 c.p.s. - up to the limits of the subject's ability to follow.

In the third series the moving spot was absent and the subject was instructed to repeat the same smooth tracing movements from memory.

The results of these experiments showed significant differences in the form of ocular movements under various conditions.

In the first series of experiments the subject produced saccadic movements of the eyes from side to side. No smooth movements i.e. sinusoid curves were registrated (Fig. 1).

The amplitude and form of the curves produced were highly stereotyped with equal periods of fixation on both sides. The maximal speed of different subjects varied from 0.9 to 2.0 c.p.s. with an average of 1.3 c.p.s. They remained relatively steady during the experimental period which lasted 25 seconds.

Ocular movements tracing the oscillation of the luminous

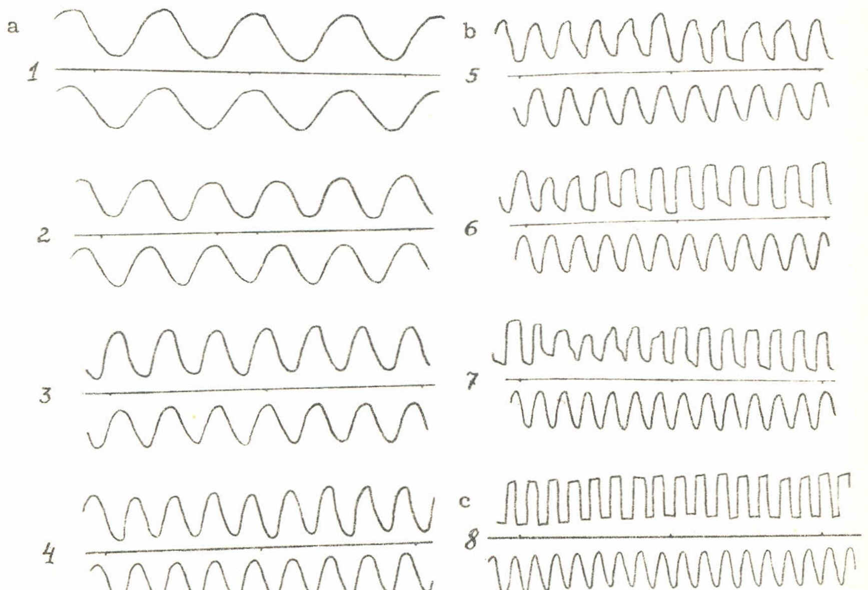

Fig. 2: Ocular movements tracing an oscillating luminous spot. Upper line = ocular movements; middle line = time (5 sec. intervals); lower line = movements of the oscillating luminous spot; a.(1-4) = velocity of oscillations 0.3-0.8 c.p.s.; b.(5-7) = velocity of oscillations 0.8-1,2 c.p.s.; c.(8) = velocity of oscillations 1.5 c.p.s.

spot (second series of experiments) had a different shape. In this case they had a smooth type of movement and were nearly isomorphic to the path of the luminous spot. They were registered as regular sinusoidal waves reflecting the oscillations of the moving object (Fig. 2-a).

This type of ocular movements however did not persist under all conditions of the experiment.

When the velocity of the moving spot was accelerated and the subject had to pursue the oscillations at a rate of 0.8 - 1.2 c.p.s., the smooth structure of the curve of tracing eye movements began to break down and gave way to movements of a saccadic character (Fig. 2-b).

When the oscillation frequency increased to 1.1 - 1.5 c.p.s., smooth movements of the eye disappeared totally, and only quick saccadic movements of the eyes towards the extreme points were observed (Fig. 2-c).

It is significant that the speed of ocular movements which a subject attains is approximately the same as in the first series of experiments where no moving spot was present.

Thus it can be supposed that when the speed of tracing movements increases, their psycho-physiological basis changes and pursuing movements regulated by visual afferentation give way to movements with a totally different form of control.

As the experiments show the tracing movements begin sometimes to anticipate the path of the object, sometimes they drop behind. In either case some corrections shortly follow.

The shift in type of control which occurs at a critical speed has an important psycho-physiological significance and will be the subject of further studies.

A final question deserves consideration. Can the smooth type of ocular movement be reproduced from memory when the moving object is eliminated?

This question was the subject of the third series of our experiments.

The results of this series were unambiguous.

Not one subject was able to reproduce smooth ocular movements when the moving object was not present. All ocular movements reproduced from memory had a saccadic character, which appeared at once when the moving object was eliminated (Fig. 3). It is apparent that the form of the ocular movements in this case was identical with the form of movements following verbal command. All attempts to train the subjects to give smooth ocular movements in the absence of a moving object failed, and the curves registered in this series maintained their saccadic character.

It can be said that the persistence of smooth tracing ocular

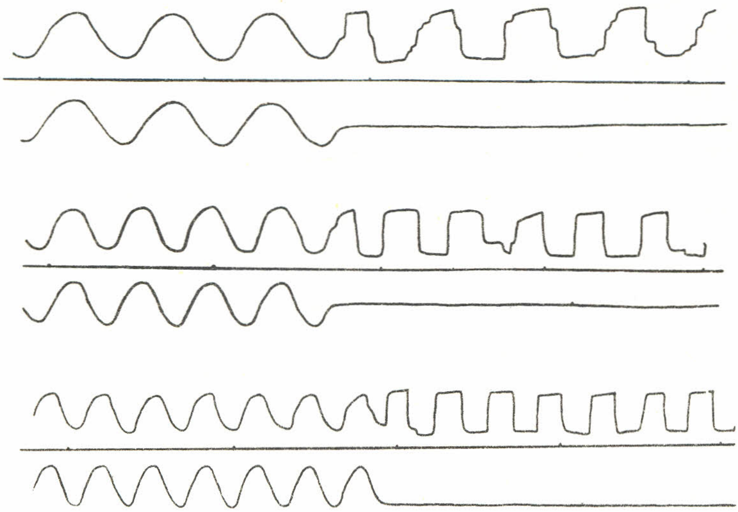

Fig. 3: Imitations of tracing eye movements by memory (elimination of the moving spot results in a change of the structure of ocular movements).

movements is possible only with a real optical afferentation from the moving object, and only within certain velocity limits. An attempt to produce such movements from memory results in transformation of their form which - as far we can judge - is caused by a change of control systems underlying the ocular movements in the two cases.

This change of the form of ocular movements under different conditions opens new vistas in the analysis of their mechanisms.

It is obvious that ocular movements tracing the path of a moving object are closer to visual reflexes whereas ocular movements regulated by verbal command are closer to so-called "voluntary" movements.

The distinction between two kinds of ocular movements was for many years used in neurological clinics. Neurologists tried to describe not only different kinds of ocular movements, but tried to relate them to different neural mechanisms. The "reflex ocular movements" they related to the posterior "oculomotor center" of the cerebral cortex (fields 18, 19) while the "voluntary" movements were related to the frontal "oculomotor center" (field 8).

They observed some disturbances of tracing movements and fixation reflexes when the lesion was located in the parietooccipital zones, and some deterioration of "voluntary" control of ocular movements when frontal "oculomotor centers" were affected (G. HOLMES, 1935 a. al.).

Up to now these data remained at the level of clinical observations, they have never been subjected to experimental analysis.

That is why we attempted to study the question of the roles of the two cortical "oculomotor centers" using an objective technique of registering ocular movements.

The series of experiments remained the same, but this time our subjects were patients with local brain injuries (mostly brain tumors). In some cases the lesion located in the anterior oculomotor zone, in other cases in posterior oculomotor zones. The investigation was carried out on a considerable number of patients at the Neuro-Surgical Institute of the Academy of Medical Sciences of the USSR; the localisation of lesions in all cases was verified by neurosurgical operation.

The data obtained in these experiments (which are not yet completed) allow us to suppose that lesions of the two cortical "oculomotor centers" result in different disturbances of ocular movements.

When a patient with a premotor cortex lesion was told to trace a luminous spot oscillating smoothly from side to side, his ocular movement remained smooth, and a regular sinusoidal curve was registered. This smooth type of ocular movement, isomorphic to the path of the oscillating object, was disturbed only when the lesion of the premotor zone was so severe as to influence subcortical ganglia.

If the moving spot was eliminated however and the patient was instructed to move his eyes from one side to the other as rapidly as possible - the whole picture changed and considerable disturbances of the ocular movements appeared. The ocular movements lost their regularity, they became very slow, uneven, and in a few seconds they died out. It is remarkable that when the luminous spot was reintroduced ocular movements (visually controlled) became regular and their lost speed returned immediately (cf. Fig. 4)

These data support the contention that the anterior "oculomotor center" is important for ocular movements with a complicated form of regulation independent of visual input.

Different results were obtained in cases with parietooccipital lesions, i. e. with disturbance of posterior "oculomotor center".

In these cases visually controlled ocular movements suffered considerably more than the "voluntary" movements of the eyes. As a rule attempts to trace the oscillations of a visual object in these cases were characterised by severe disturbance of the form and amplitude of ocular movements. But when the oscil-

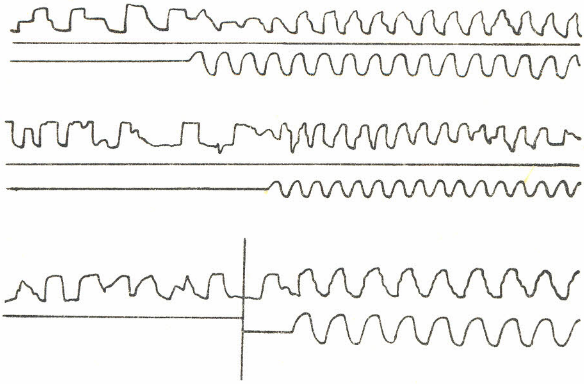

Fig. 4: Ocular movements controlled by verbal command and by visual stimulus in three patients with lesion of the premotor zone. The appearance of an oscillating luminous spot increases the speed of the ocular movements and results in a normalization of their form.

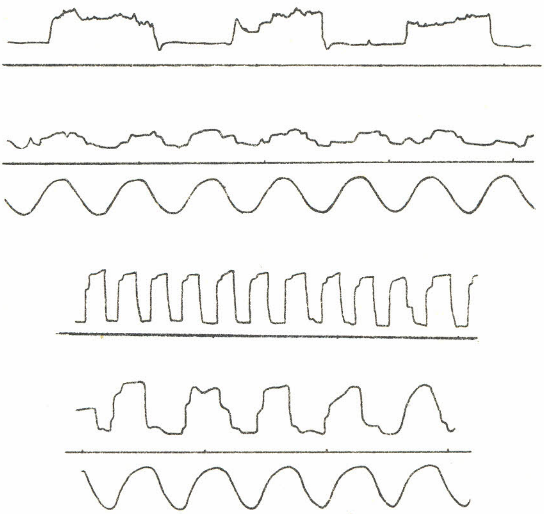

Fig. 5: Ocular movements controlled by verbal command and by visual stimulus in two patients with lesions of parietooccipital zone. Severe disturbances in ocular movements tracing a visual object are seen.

lating luminous spot was removed - a considerable improvement of the ocular movements could be observed (Fig. 5). Observations of disturbances of the tracing movements of the eyes in cases of bilateral parietooccipital lesions (A. R. LURIA, 1959; A. R.

LURIA, E. N. PRAVDINA-VINARSKAYA, A. L. YARBUSS, 1961) give further confirmation of this statement.

All our data open new ways to the analysis of the neurological basis of ocular movements.

We can not only confirm the assumption of different roles of the two "oculomotor centers" in different kinds of oculomotor control, but we receive new reasons to suppose that the anterior oculomotor zone representing the higher level of organisation of eye movements plays an important role in the integration of what we call the "voluntary" ocular movements, which enter in a different, non-visual form of afferentations.

We are sure that the application of precise techniques of registering ocular movements will bring important new data both in the analysis of the psycho-physiological structure and of the neural basis of this most delicate kind of motor activity.

Summary

A photo-electric registration of ocular movements in different forms of control showed that ocular movements regulated by verbal instruction and without visual afferentation had in all cases a saccadic character whereas ocular movements tracing an oscillating luminous spot were smooth and isomorphic to the path of the moving object. When the velocity of these oscillations increased the structure of ocular movements changed and they turned into saccadic movements, similar to movements performed by verbal instruction. All attempts to imitate smooth tracing movements by memory failed, and in the absence of visual afferentation only saccadic movements were possible.

A study of patients with local lesions of the brain showed that a lesion of the anterior oculomotor zones results in a deterioration of "voluntary" eye movements with a persistence of visually afferented tracing movements, whereas a lesion of posterior oculomotor zones had an opposite effect.

An objective registration of ocular movements opens new ways in the analysis of their structure in different forms of control and of their neural mechanisms.

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