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THE CEREBRAL INTEGRATION OF THE OCULAR MOVEMENTS *

BY

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It is customary among us to commemorate great men from time to time by a lecture or discourse relating to their work or to some subject in which they were interested. To-day we meet to pay a tribute to the memory of Victor Horsley, almost on the twenty-second anniversary of his death in the service of his country, while striving for those ideals which characterized his life—the relief of suffering and the defence of liberty.

Horsley's name is indelibly inscribed on the records of human achievement. His work as a physiologist is incorporated in the heritage of our knowledge, and he will ever be remembered as a pioneer in the surgery of the nervous system, which since his day has grown as only his faith could have foreseen. But great though his achievements were in the realm of science, it is his personality which keeps his memory most vividly alive to those of us who had the privilege and good fortune to work with him. We recall his amazing energy, his enthusiasm for knowledge, the help he gave so liberally to younger colleagues, his kindness and generosity, and his unswerving devotion to the welfare of his fellows. I accept gratefully this opportunity to add my contribution to his memory.

The subject of this lecture is one to which Horsley's investigations contributed materially; some of his earliest work defined accurately an area of the cortex by stimulation of which ocular movements could be obtained; later he described the anatomical paths connecting the visual cortex with the oculomotor apparatus in the midbrain; and his latest experiments on the cerebellum, which unfortunately have never been published in full, dealt with the movements and postures of the eyes which can be elicited on electrical stimulation of this organ or result from lesions of it.

There are several categories of ocular movements. In the first place we can move our eyes by an act of volition, but few of their ordinary movements are in this sense voluntary or the result of a conscious effort. Any peripheral stimulus, as movement, a flash of light, or a sound, may deviate our eyes involuntarily towards its source, while accurate vision demands accommodation and fusion, which is effected by so arranging the visual axes that the images of the object at which we look fall on corresponding parts of the two retinæ. Finally, there are the compensatory or adjusting movements by which the eyes are kept directed on an object when either it or our heads move. The upper part of the brain stem contains

a complicated mechanism by which all these types of movement are effected and co-ordinated; here we are not concerned with this mechanism, but with the more highly evolved nervous centres at the behest of which it acts.

All our movements, those of our eyes as well as of our limbs and trunk, are directly or indirectly initiated, guided, and controlled by afferent impulses, and in the case of the eyes the most important impulses are those of retinal and labyrinthine origin. The work of Magnus in particular has shown how the labyrinths, either alone or in conjunction with proprioceptive impulses from the muscles of the neck, ensure the correct postural adjustments of the eyes to changes of the head in space; but in the higher animals retinal impulses suffice for the normal control of the movements and postures of the eyes even where the labyrinths or the fibres conducting from them are destroyed.

Differences in Organization of Vision between Man and Animals

Experiments on animals have contributed much of what we know of the physiology of ocular movements, but all conclusions from such experiments are not applicable to man owing to essential differences in the organization of vision. In the first place each human retina contains an area of highly developed sensitivity at the fovea which is employed exclusively for distinct vision, and many of our ocular movements are directed to allow a distinct image of the object which interests us to fall on this part or keep it there; in lower animals which do not possess differentiated foveae such movements are naturally not fully represented. Binocular vision is also more accurately organized in man. Further, though in the phylogenetic scale vision is the first function to acquire cortical representation, the visual cortex is more highly elaborated in the primates, and in man complex associational areas which play a part in the movements of the eyes develop around it. The differences in the organization of cortical vision in various animals are obvious from the effects of destruction of the occipital lobes. All observers agree that in man no perception of light or reaction to retinal impulses, except contraction of the pupils, can be obtained when the occipital lobes are destroyed. In monkeys, closure of the lids occurs on sudden illumination (Klüver); dogs can in addition react to differences in intensity of illumination (Marquis); rodents may recognize the position and distance of objects, and even avoid obstacles (Lashley), while birds from which the forebrain has been removed may react even more normally to retinal

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stimuli. During ascent in the animal scale there has been, therefore, a gradual transference of vision from lower to higher levels of the nervous system, till in man it is exclusively a function of the cortex.

Parallel with this movement of vision corticalwards there is a similar "encephalization," or transference towards the forebrain, of the seat of reactions which may be excited by retinal stimuli till in man no movements in response to light are obtainable without participation of the visual cortex. It is therefore on the study of clinical material that we must mainly rely in any attempt to understand the physiology of the ocular movements in man. But the methods should be the same as those of the experimental physiologist—to study the simpler components of a complicated function by isolating each of them, and then attempting to integrate the separate parts into a normally functioning whole. We must, however, remember that symptoms of dissociation of the ocular movements cannot be simply interpreted as loss of function of the injured part; they are usually the response of the organism to the abnormal situation produced by the lesion, and include, as Hughlings Jackson repeatedly insisted, manifestations of disordered activity of undamaged structures.

Cortical Areas Concerned in Eye Movements

In both man and lower animals movements of the eyes can be obtained by stimulation of certain parts of the cerebral cortex. One of these, which was originally described by Hitzig and Ferrier but was more accurately localized by Beever and Horsley in the ape, lies in the frontal lobe, separated by inexcitable cortex from the motor centres of the precentral gyrus. Cushing, Foerster, Penfield and Boldrey, and others have demonstrated it in man. The function of this oculogyric centre has naturally been compared to that of the precentral motor area, but Sherrington has shown that in the chimpanzee there are such marked differences in the nature of its responses that it is necessary to put it into a separate physiological category. It is interesting that Beever and Horsley, in contrasting the responses from this frontal area in the orang-outang with those they observed in the bonnet monkey, recognized these same features—a slowness in development and in execution of the movements of the eyes. The projection fibres from this frontal centre pass through the anterior portion of the internal capsule, then probably enter the cerebral peduncle and turn dorsalwards into the tegmentum.

The fact that destruction of this frontal centre does not produce a persisting palsy of any of the ocular movements has raised doubt on its significance. It may be that, as Wernicke suggested, all ocular movements are represented in both frontal lobes and consequently, as in other bilaterally innervated movements, the effects of a one-sided lesion may be compensated by the unaffected side. Permanent voluntary palsy in man has, however, been described by Tilling, Lutz, and others as a result of bilateral frontal lesions, but Ferrier and Turner observed no paralysis after removal of both frontal lobes in the monkey.

Ocular movement can be also obtained by electrical stimulation of the visual cortex on the inner aspects of the occipital lobes. This oculomotor area was first described by Schaefer and later studied by Munk and others, including Foerster, in man. According to some it is the cortex immediately around the visual area rather than the area striata which is excitable, but from our point of view this matters little. It was naturally suggested that movements elicited from it are due to subjective visual

impressions excited by the stimulus and that these activate the frontal oculomotor centres, but Munk showed that they could be still evoked after he had isolated the occipital lobe from the rest of the cortex by a deep incision. That there is an apparatus in the occipital lobe from which ocular movements can be excited directly was made more probable by the demonstration by Beever and Horsley of fibres passing from here to the anterior quadrigeminal bodies in the neighbourhood of the oculomotor nuclei. About the same time Probst described these cortico-tectal fibres in the cat. According to later authors, as Minkowski, Biernacki, and Poljack, they take origin in the cortex around, not within, the area striata. They descend through the occipital lobe medial to the optic radiations, and pass through the pulvinar and the anterior brachium to reach the tectum of the midbrain.

There are therefore two widely separated cortical areas concerned in movements of the eyes, and each has its own projection tract to the oculomotor mechanism in the brain stem. A study of the effects of their injury or destruction throws light on their functions and on the part each takes in the normal organization of the ocular movements.

Effect of Disturbances of Frontal Centres

Disturbances of the functions of the frontal centres produce the more obvious symptoms. These usually result from involvement of the frontal projection fibres in the internal capsule or in the neighbourhood of the anterior part of the midbrain rather than of the cortex, and in this respect they are comparable to the loss of voluntary power in the muscles of the lips, tongue, palate, and larynx which characterizes pseudo-bulbar palsy.

The most striking features of a typical case is the inability of the patient to move his eyes to command or, when ordered, to look at an object in one or possibly in any direction. For instance, on command to turn his eyes to the right or to look at an object in the right half of the field of vision no deviation of the eyes occurs, though the effort at movement is obviously great. The attempt is often accompanied by expressions of distress; one patient on being asked to look to the right first turned his head in that direction, then jerked it about and raised it from the pillow, flexed his body forward and rotated it to the right, advanced and flexed his arms, clenched his fingers, and groaned and protested he could not do it, an example of the "catastrophic reaction" which Goldstein has described associated with failure to carry out a task owing to a cerebral lesion. Even when the head is actively turned in the desired direction the eyes often fail to move with it.

This condition at first sight shows all the appearance of loss or paralysis of the movement, but that this is not present becomes obvious when the subject is asked to follow with his eyes a slowly moving object; then, provided the rate of movement is uniform and not too fast, a full range of deviation may be obtained. If, however, the displacement of the object he attempts to follow is too rapid or irregular the eyes move through only a small angle and quickly slide back to their position of rest. When the patient looks at a slowly rotating drum on which lines or figures are displayed the eyes also deviate in the direction in which the figures move, but the optic nystagmus seen in normal persons does not appear. He may also fail to converge on a near object, but can do so when a distant object is slowly approached to his face. We therefore find that though voluntary effort fails to produce movement the eyes follow a moving point the images of which fall on the foveae.

The influence of foveal impulses on the execution of these movements is obvious, but impulses from the imme-

diate neighbourhood of the maculae may be effective too. If there are two marks on a sheet of paper the patient may be unable to turn his eyes from one to the other, but he can often do so when the marks are joined by a line; his eyes then as it were creep along the line from one point to the next, the movement being excited by a series of impulses coming from the confines of the foveae. Similarly the eyes can travel along a series of closely arranged dots, the retinal image of each succeeding dot being an adequate stimulus. Attempts to read reveal the same facts; the eyes travel slowly from letter to letter, but if there is too wide a space between the words the attempt may fail. At the end of the line he is unable to bring his eyes leftwards to the beginning of the next line, but frequently patients surmount this difficulty by moving a finger slowly along the line as they read and by it lead the eyes back to the start of the next line.

Movement of the eyes can be elicited even more easily by either active or passive movement of the head; if, for instance, the subject is unable to look up or to the right his eyes may deviate upwards when his head is bent forwards and to the right when his head is rotated to the left: his eyes move simultaneously with his head and through an equal angle, but in the opposite direction. This compensatory deviation has been by several authors attributed to adjusting reflexes of labyrinthine origin, but though this may be their nature in animals under certain experimental conditions we shall later see reasons why it is not the explanation. Bielschowsky, who originally regarded it as a labyrinthine reaction, later stated that this holds only if the movement of the head is quick and abrupt. Labyrinthine reflexes may, however, play a part, for in some of these pathological cases a compensatory deviation of the eyes occurs even when the lids are closed and all retinal stimuli thus excluded, and in a patient with complete cortical blindness whom I examined the eyes moved to the left when the head was passively rotated to the right, and vice versa. On the other hand, in two patients who were deaf and in whom no vestibular reactions could be excited I found that the eyes moved with the head when the lids were closed; as both retinal and vestibular impulses could be excluded the probable explanation is that the tone of the ocular muscles dependent on their own proprioceptive impulses kept the eyes in their normal relations to the orbits.

When the eyes are deviated from their normal central position either by following a slowly moving object or by rotation of the head, the patient may be unable to move them back, or he may experience much difficulty in doing so, particularly if the eyes remain fixed on the original point; this is one of the arguments against compensatory deviation being essentially of labyrinthine origin, for the stimulus which excites the labyrinths is movement, and reflexes dependent on them cease rapidly at the end of the movement.

Further investigation of these symptoms helps us to understand their nature. All observers have been struck by the fact that the paresis is variable; under certain conditions no voluntary movement can be observed, under others the eyes can move through a modified range at least. Though in a typical case deviation of the eyes to either side on command or towards an object is impossible, the eyes move simultaneously with his head, but in the opposite direction, when his head is rotated. If, however, the lids were closed, or if the experiment is carried out in a dark room, or if a screen is held immediately in front of the eyes, so near to them that no point can be accurately fixed, this compensatory deviation does

not occur. There must therefore be a visual factor concerned in the phenomenon, and this factor seems to be fixation—that is, the tendency to keep the images of the object at which the subject looks on the foveae, either by maintaining the postures of the eyes or by moving them.

The Fixation Factor

Another series of tests emphasizes even more strongly how important this factor is. If in a normal person one ear is irrigated by cold water nystagmus is evoked, the slow phase being towards the ear which is irrigated; the same effect is obtained by passing a galvanic current through the two ears or by rotating the person. In many of these pathological cases, however, no nystagmus develops, but the eyes become strongly and persistently deviated in the direction towards which the slow phase of the nystagmus should occur—that is, towards the irrigated ear, or towards the anode of the galvanic current. This deviation is frequently so strong that it is uncomfortable or distressing to the patient. It varies, however, under different conditions of examination. In one patient who lacked almost all voluntary movements of the eyes it was generally very pronounced, but on other occasions it could not be elicited. Further examination showed that its appearance was influenced mainly by the patient's visual interest in his surroundings; for when his eyes were not fixed on an object, or when his lids were closed or his eyes screened, a strong deviation could always be obtained, but when his eyes were fixed on any point, as on the eyes of the observer who sat in front of him, even the strongest vestibular stimulation often failed to produce any deviation. Fixation, which was the only variable factor in these experiments, is therefore capable of inhibiting the powerful reflex deviations which in its absence can be obtained by stimulation of the labyrinth.

Fixation may influence even volitional movements, for patients in whom the degree of palsy is not great can often move their eyes on command or look towards an object when accurate fixation is made impossible by placing convex lenses or a screen in front of the eyes. In severely affected cases the range of movement possible under these conditions is usually small, and the movements, which obviously need great effort, are jerky and discontinuous, but in milder cases an approximately normal degree of deviation may be observed.

In attempting to follow a moving object the accuracy of fixation also plays a large part; success is possible only when the subject's eyes are accurately directed on the object before it moves, and if its movement is so rapid or so irregular that fixation is for a moment broken—that is, if its images no longer fall on or in the immediate proximity of the foveae—the eyes cease to follow it and recede towards their position of rest.

These observations explain a curious paradox which has often been observed in these patients. Though they fail to move their eyes in one or in all directions on command and to turn them towards an object, the eyes may at times move about in a more or less normal manner. Tiling, in the first recorded case of this type, found that though there was apparent paralysis of vertical deviations and of movement to the right, the eyes sometimes moved involuntarily in these directions; in Bristow's case, recorded a few years later, "the eyes moved independently of her will," though there was no power of voluntary movement; in a similar case Roux reported that "nothing in the hospital ward escaped the patient"; and one of my own cases was regarded by the nursing

attendants as "hysterical," as they observed that his eyes frequently moved about as he lay in bed but failed to do so while being tested. Such spontaneous movements are most often seen when the patient is drowsy or half awake, or when he is in a state of emotional excitement; for instance, one man who was unable to move his eyes voluntarily became excited while being prepared for vestibular tests, and his eyes rolled about in all directions.

It was also repeatedly found that when these patients tried to look towards an object they employed various devices by which to interrupt the fixation of the point on which their eyes were directed: some blinked or closed their eyes momentarily, or jerked their heads abruptly; one man occasionally brought his hands before his eyes. It is therefore obvious that fixation of the eyes on an object tends to impede voluntary ocular movements and can even inhibit the powerful reflex reactions excited by labyrinthine stimuli. It is now necessary to consider the nature of normal fixation.

The Nature of Normal Fixation

Fixation means the maintenance of postures of the eyes by tonic contraction of the ocular muscles so that the retinal images of the object which is fixed fall on the two foveae. These postures can be kept up with remarkable accuracy for long periods. It is true that fixation in this sense is only relative, for the lines of vision constantly oscillate through small angles about the point fixed and consequently the images move over the foveae; this avoids sensory adaptation, and the appearance of after-images which would interfere with the acuity of vision. But fixation does not imply only immobility of the globes in relation to the orbits, for we can fix moving objects and keep our eyes on a point when our heads are in motion; this requires constant adjustment of the eyes by contractions and relaxations of their muscles, for the slightest displacement of the head necessitates a compensatory deviation of the eyes in the opposite direction, so accurate and immediate that the foveal images remain relatively stationary. By voluntary effort alone this accurate adjustment of the eyes would certainly not be possible, and the observations referred to above show that fixation may persist when volitional movement is defective. Fixation must therefore be regarded as, in part at least, a reflex act. But fixation, as all the other visual reflexes, requires perception—that is, the intervention of consciousness—and in this respect the fixation reflex differs from those reactions in which only the lower levels of the nervous system are concerned, to which the term "reflex" is usually applied.

Normally, fixation is under the control of volition, for we can move our eyes from object to object as we will, but when voluntary movement is defective the fixation reflex becomes so dominant that the eyes may remain anchored to an object and can move from it only when the reflex is broken by interruption of the retinal impulses. It is for this purpose that persons affected with this condition blink, jerk their head, or place a hand between their eyes and the object which fixes gaze. We can speak of the pathological condition as "spasmodic fixation." It was first observed and carefully described by Gowers in 1879.

Spasmodic and Reflex Fixation

Spasmodic fixation is comparable to the spastic paresis which results from lesions of the cortico-spinal tracts; in this condition there is, as in the eyes, a defect of voluntary power, but movement is also interfered with by increased

tone of the muscles due to uninhibited reflexes initiated by proprioceptive impulses from the muscles themselves, and it disappears when the muscles are deafferented. The exaggerated tone of the ocular muscles, on the other hand, is dependent on retinal impulses acting on a cortical mechanism no longer under control; when these impulses are interrupted tone decreases, the power of voluntary movement improves, and the responses to other stimuli, either voluntary or labyrinthine, are no longer impeded.

It is impulses of foveal origin which determine reflex fixation. On the other hand, the chief function of the peripheral parts of the retinae is when an image excites them to bring about such movements of the eyes that the images fall on the foveae. James has aptly said that the periphery of the retina acts as a sentinel which cries out "Who goes there?" and if necessary calls up the more accurate vision of the foveae. Owing to the increasing sensitivity of the retina as the fovea is approached the tendency of peripheral retinal stimuli to determine fixation is greater the more closely to it the images fall. Even in adult life these fixating movements are largely reflex: a flash of light or a sudden movement in the periphery of our fields of vision attracts our gaze whether we wish it or not. This reflex which determines the fixation of extra-foveal images is the means by which patients suffering from paralysis of voluntary movement can read, follow a line with their eyes, or count a row of dots: each succeeding letter, dot, or segment of a line tends to excite a movement, and if the impulse which initiates it comes from near the fovea it may be intense enough to interrupt the strong fixation reflex which tends to impede all the other visual oculomotor reflexes as it does voluntary movement of the eyes.

A special feature of these reflexes is that they imply, in addition to conscious perception, interest and attention. It is only the object which occupies attention that excites the fixation reflex; only the succeeding word or dot which interests the patient that draws his eyes towards it; only the gesture in which he recognizes a threat or danger which makes him blink and turn his eyes away.

Other symptoms which some of these patients present throw further light on the nature of this condition. For instance, one man who also suffered from severe pseudo-bulbar palsy was unable to separate his lips, open his mouth, or perform the movements of chewing on command, but when bread was placed in his mouth he masticated it; he could not protrude his tongue, but when sugar was placed on his lips he licked it. In these respects he was simply a reflex machine. If shown appetizing food he merely smiled, but if the food was brought slowly towards his lips his mouth opened at once and he began to champ his jaws as if chewing, but this occurred only when food in which he was interested was approached to his lips. He therefore possessed another visual reflex—that is, a complicated purposive action independent of volition—which was excited by retinal impressions and which entailed not merely perception of an object but also recognition of its nature and of its spatial relations to himself.

The anatomical lesions responsible for the condition characterized by loss or diminution of the power of voluntary movement associated with exaggeration of the fixation reflex may be situated in various parts of the brain. In a few of the recorded cases there were bilateral injuries of the frontal oculomotor centres (Lutz, Tiling), but more commonly the projection fibres from these centres were involved in the internal capsule or caudal to

it. It is an interesting fact that, as in the case of the supranuclear palsies of the facial and bulbar muscles, these paralyses of the voluntary ocular movements are more commonly due to affections of the projection tracts from the cortex than of the cortex itself. In some cases the disease was familial and progressive, probably a primary degeneration of these fibres (von Palláthy, Ballet, Cantonnet, and Taguet).

Effects of Interference with the Visual Reflexes.

On turning from this condition characterized by loss of voluntary movement and exaggeration of the fixation reflex to a study of the effects of direct interference with the visual reflexes we encounter considerable difficulties, for all these reflexes use the same afferent paths as vision, and probably are mediated through the same cortex as that by which visual impressions are perceived. Consequently lesions of their afferent fibres or of the cortical reflex centres cause at the same time loss of vision, and in absence of vision these reflexes cannot be studied. Since, however, the cortico-tectal fibres which constitute the efferent limb of the reflex arc run a dorsal course through the pulvinar they may be involved by lesions which spare the optic radiations as well as the descending fibres from the frontal oculomotor centre. Bilateral injury of these cortico-tectal fibres is very rare, and as part of each fovea, from which the more important visual reflexes are excited, is represented in both hemispheres of the brain, unilateral lesions do not produce striking effects.

When we wish to see an object distinctly we usually adjust or move our heads so that our eyes in their position of rest are directed on it; this posture of the eyes demands little if any effort, and voluntary action alone may suffice to keep it up. It is often by rotating our heads too that we follow a moving point or a series of closely spaced objects, as in reading. The fixation reflex is therefore not essential, and its absence causes no pronounced disturbance. But when the eyes are turned widely from the middle line the maintenance of the new position demands considerable effort and it tires rapidly even when supplemented by a normal fixation reflex, but as long as the deviation is kept up fixation is accurate. If, however, the reflex is defective, fixation cannot be maintained accurately by voluntary effort alone, though the ocular movements are unimpaired. This disturbance is most commonly seen on deviation of the eyes to one side. When the patient is asked to look at an object to this side he moves his eyes promptly towards it, but he fails to keep them directed steadily on it; they quickly recede towards their position of rest and are brought back by a series of jerks which are obviously voluntary. In following a moving object, especially if the rate of movement is not uniform, or if his head moves while he attempts to fix a stationary point, the difficulty in keeping up fixation is even more pronounced; the necessary ocular movements are possible, but the reflex maintenance of the position obtained is deficient. This failure to fix accurately is generally more pronounced the further the object to be fixed is from the middle line; in other words, it is roughly proportional to the muscular effort which the deviation requires.

When this disturbance is bilateral the symptoms are more striking. The patient complains of inability to see distinctly or to focus properly. When his head is not steady, as when he walks or rides in a carriage, the difficulty in obtaining clear vision of any object is even greater. That it is not merely due to diplopia or failure of fusion of the retinal images is evident, as it persists when one eye is closed. Orzechowski has given an excel-

lent description of this condition in two patients: their eyes oscillated about the object they tried to fix; they were unable to "seize" or "hold" objects with their eyes, especially on deviation to one side; in reading they failed to follow accurately letters or lines; moving objects could not be accurately followed by the eyes; and when walking or in motion they were unable to recognize or distinguish objects by vision. Erb and others have observed similar cases.

Here there is no question of ocular palsy or of nystagmus, from which the condition differs in its manifestations and in the disturbances it produces; vision is normal or at least adequate, scotomata are not present, and there is no defect in visual orientation—to any of which inability to fix accurately may be due. There is consequently a state characterized by a failure of fixation, though the muscular apparatus of the eyes and its central innervation is intact; it is essentially an inability to keep the eyes steadily in a position to which they have been brought by voluntary contraction of their muscles.

It is well known that when hemianopia is present the patient often fails to keep his eyes accurately on a point to the hemianopic side even when they are directed towards it. This had been usually attributed to the loss of vision, but as his gaze may remain fixed on a point directly in front of him—that is, when his eyes are in their position of rest—it is obvious that this cannot be the only cause. Further, this failure to fix may be present even when there is some degree of macular sparing. The more probable explanation is that the voluntary movement is not supported by the fixation reflex which is normally mediated by the damaged or isolated visual cortex.

Inadequate fusion or defective accommodation may be partly responsible for the disturbances of vision of which these patients complain. One of my patients said he could not fix his eyes steadily and that they tended to roll about, another that she could not focus and that on attempting to read the letters ran into one another. In neither of these cases could diplopia be demonstrated, yet both read more easily with one eye closed; the fusion reflex by which the coalescence of the two images is effected in binocular vision was evidently at fault. Bielschowsky has also described loss of fusion in a case with lesions in each occipital lobe.

We have seen that when the fixation reflex is not under the control of other cerebral mechanisms there is a tendency to exaggeration of its function, with the result that the eyes cannot easily be diverted from the object on which they are directed. In these cases, on the other hand, the fixation reflex is defective, and post-mortem evidence goes to show that this defect is due to interruption of the cortico-tectal fibres which form the efferent limb of the reflex arc. In my own cases, which were verified, the disease involved the dorsal portion of the thalamus, including the pulvinar.

These two series of observations are complementary. The most striking feature in the one series was loss of deficiency of voluntary movement associated with a tendency to persisting fixation of the eyes on a point in central vision, from which they could not be easily diverted by will or even by the intervention of other reflexes unless central retinal impulses were suppressed. In the other series the subject was unable to keep up fixation accurately, particularly when he or the object to be fixed was in motion, and in some cases fusion and accommodation were probably disturbed too.

These observations have emphasized the reflex nature of fixation, but there can be no doubt that under normal

conditions fixation is partly voluntary. The fixation reflex, however, supplements and steadies the voluntary effort; but it is, on the other hand, under the control of volition. On the normal co-ordination of these two functions the accurate and purposeful use of central vision depends.

The Brain and Oculomotor Activities

We can now consider what parts of the brain are concerned in these oculomotor activities and then discuss how in normal life they work together.

All evidence at our disposal indicates that the frontal oculomotor centre is concerned in those movements and reactions of the eyes which we may call voluntary. Through it we can by an effort of will look or turn our eyes in any direction and converge them on a near object. By it, too, we can keep our eyes directed on any object that interests us, though this is largely a function of the occipital cortex.

The functions of the occipital centre are more numerous. Fusion—that is, the reactions necessary to unify the separate impression from the two retinæ—and accommodation depend on it. The movements of the eyes to an object outside central vision, in so far as it is involuntary, is also excited through the occipital cortex by extrafoveal impulses. And finally the maintenance of fixation on a point, whether it is at rest or in movement, is determined by a cortical reflex mechanism in the occipital lobes.

The abrupt turning of our eyes to an unexpected sound or towards a peripheral stimulus is a more complicated reaction which implies spatial localization; the evidence as to the oculomotor centre through which these movements are effected is incomplete, but the frontal cortex is probably concerned in them, for what we know of its organization indicates that no part of the cortex is devoted exclusively to so-called voluntary activity. In other reactions, as blinking and aversion of the eyes from threatening gestures, and in ocular movements which imply judgment of the nature of the stimulus and of its position in space, more extensive areas of the cortex are involved. The reaction to threats can be, for instance, abolished by small lesions of the parietal lobe, and the experiments of Rademaker and Gelderblom show that in the cat the associated closure of the lids depends on the integrity of the sensorimotor cortex. The movements of our eyes in response to labyrinthine and other proprioceptive impulses is effected by subcortical mechanisms; the forebrain is not concerned in them.

The integration or harmonious working of the different parts concerned in ocular movements and postures is to some extent revealed by the disintegrations of these functions which we have studied, and these serve also to illustrate other activities of the cortex.

In the evolution of the brain vision is the first sense organ to obtain a presentation in the cortex of the forebrain. Even in birds fibres carrying retinal impulses reach what is regarded as the original neopallium; it is only later in evolution that other sense organs attain cortical connexions, and it is still later that so-called "motor centres" appear. With vision, too, localization in the cortex reached its acme, for every point of the retinæ is represented rigidly in it; then the brain, if we may speak teleologically, decided that such a rigid machine was unsuitable to its further development and adopted a more plastic organization for its later-evolved functions. It is consequently not surprising that cortical visual reactions are more highly organized, and possibly organized on a simpler plan, than other cerebral activities.

Even in birds the original visual cortex is connected with the roof of the midbrain by efferent fibres—the tractus occipito-mesencephalicus of Kappers—which are probably the homologue of the cortico-tectal fibres of mammals, and by means of these the cortex may be able to influence reactions, including ocular movements and postures, in response to retinal stimuli. As the cortex became the main, and finally the exclusive, organ for visual perception, the primary visual reactions—as reflex direction of the eyes to light, accommodation, fusion when binocular vision was acquired, and fixation—were transferred to it, till in man they can be evoked through it only. The next step in development was the appearance of associational areas around the visual cortex which enable it to co-operate with other sense impressions and to elaborate further the faculties of spatial perception, discrimination, and recognition. At this stage in evolution control of visual reactions by higher cerebral functions—as consciousness, attention, and discrimination—became necessary, and the newer cortex of the frontal lobe was given this task. Now that the exploration of space by the eyes and the direction of gaze towards any object of interest no longer depended wholly on visual impression, reactions to vision were no longer confined by the fatality of a reflex: there was now a mechanism by which behaviour and reactions to environment could be greatly extended. This is the primary significance of the development of a frontal oculomotor centre.

But in order that a highly evolved function can adequately serve its purpose it is essential that it can control subordinate mechanisms, so the frontal centre became not merely an organ from which ocular movements could be evoked, it acquired also the power of inhibiting inappropriate and undesirable activities of the occipital lobes. The importance in ordinary life of this faculty of inhibition is demonstrated by the exaggeration of the fixation reflex when the voluntary motor centres of the frontal lobes are out of action; the eyes then become fixed on an object, to the exclusion of the rest of the environment.

Conclusion

We can therefore conclude that in normal conditions there is an accurately adjusted co-operation between all parts of the cortex concerned in ocular movements. Through the occipital centres some visual reflexes excite movements which turn our eyes towards objects in the field of vision; other reflexes determine by fusion and accommodation the accurate perception and the unification of binocular images; others keep the eyes fixed on any point which claims attention or excites interest. The frontal centres make possible the turning of gaze in any desired direction and the exploration of space, but they also keep under control, or inhibit, reflexes that are not appropriate to our conduct or our reactions to the world around us.

The College of Physicians of Philadelphia has awarded the Alvarenga Prize to Dr. Richard E. Shope of the Rockefeller Institute for Medical Research, Princeton, N.J., for his brilliant recent researches on the aetiology and epidemiology of influenza. The prize was established by the will of Pedro Francisco de Costa Alvarenga of Lisbon, Portugal, an Associate Fellow of the College of Physicians, to be awarded annually by the College of Physicians on each anniversary of the death of the testator. July 14, 1883, to the author of the best memorial or unpublished essay upon any branch of medicine which may be deemed worthy of the prize.