

ELECTROMYOGRAPHIC STUDIES ON THE COORDINATION OF ANTAGONISTIC MUSCLES IN CASES OF ABDUCENS AND FACIAL PALSY*

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FROM earlier electromyographic investigations of the human eye muscles (Björk and Kugelberg, 1953b), we know that the internal and external recti muscles manifest a pronounced activity on direct forward gaze. During slow lateral movements of the eyeball, a gradual increase in this activity takes place in the agonist and a corresponding decrease in the antagonist, but even in extreme positions of the gaze the activity in the antagonist does not usually disappear entirely. In rapid movements, on the other hand, there occurs a brief acceleration of activity in the agonist and complete inhibition in the antagonist. The levator palpebrae superioris muscle also shows intense activity with the gaze forward. Lowering of the lid is accompanied by a gradual diminution of the activity which only disappears entirely when the eye has reached the position of extreme downward gaze. Blinking causes an abrupt inhibition of all activity in the levator with a simultaneous contraction of the orbicularis oculi.

The object of the present paper is further to illustrate, with the aid of electromyography, the coordination of antagonistic muscles acting upon the human eye and eyelids by an analysis of cases in which movement is grossly disturbed. Thus cases have been studied of total abducens palsy and total facial palsy, and, furthermore, of non-paretic cases in which the action of the muscles was artificially opposed by traction on the eyeball.

These investigations are closely related to Sherrington's classical studies on the posture and movements of the eye of the monkey after the intracranial section of nerves. Sherrington considered the cooperation between the eye muscles to be a typical example of reciprocal innervation of the kind which he had demonstrated in the limbs.

Material and Methods

Experiments were performed on six patients with total abducens palsy, on ten with total facial palsy (the duration of which had in no case been more than one month at the time of the first examination) and on five "normal" persons. The latter had intra-ocular tumour or absolute glaucoma necessitating removal of the eye. The positions and movements of the eyes were normal and there was no definite deviation on covering one eye.

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The investigations were carried out with the subject lying down. Different points of fixation were indicated by directing a flashlight at the arc of a perimeter set up on the ceiling with the zero point 2 metres vertically above the eye. To keep the head immobile a specially constructed support resting against the outer edges of the orbits was used in some of the tests. The position of the head was kept under continual observation by an assistant. At intervals the electrical activity was recorded during fixation of the zero point in order to check that no change in activity had taken place through alteration of the position of the head or of the needle electrode.

The paretic muscles were explored with the needle electrode on numerous occasions to confirm that the palsy was really total. The majority of cases were also followed after the return of voluntary activity. When recording from the levator, the upper eyelid was either everted over a Desmarres's hook or left in the normal position. In several cases both methods were applied without any observed difference in activity. At the same time the activity was studied in the orbicularis oculi muscle of the sound side, using a needle electrode passing through the skin of the upper or the lower eyelid. In the cases showing normal movements of the eyes a bridle suture of silk thread was sewn to the attachment of the tendon of the internal or external rectus muscle. By this means the eye could be held in position by the examiner or drawn in different directions. The activity in one of the muscles was recorded at the same time.

The technique of recording the electrical activity has been described in earlier reports (Björk and Kugelberg, 1953a).

Results

Activity in the Internal Rectus Muscle with Total Palsy of the External Rectus.—

An electromyographic examination was made of the internal rectus both on turning the gaze from extreme right to extreme left, and on fixating a series of points on the arc of a perimeter at 10° intervals between the two positions. There was close agreement between the results obtained with the six persons tested. The following case will serve as an example.

Fig. 1 (opposite) shows a patient with a total right abducens palsy. With the gaze directed to the left the visual axes were roughly parallel, but as the patient looked more towards the front the right eye lagged, so that it was 20° behind when the left eye was central. After this the right eye scarcely moved at all, and when the left eye looked 50° to the right the right eye had not reached the midline but was directed about 10° inward.

An electromyographic recording from the internal rectus during this movement showed a progressively decreasing activity. The portion of the electromyogram shown in Fig. 2A (overleaf) corresponds to the second half of the movement when the gaze of the left eye shifted from straight ahead (as in Fig. 1B) to the far right (Fig. 1C). The record clearly shows the diminution in activity until only one unit was responding; finally this disappeared also. This total elimination of activity only occurred when an effort was made to look to the extreme outward position. On return of the eyes to the starting point all phases of the process were repeated in reverse.

Records were also taken while the sound eye fixed points within the same range. On forward gaze, activity in the internal rectus of the paretic eye is considerable (Fig. 2B), but it diminishes distinctly when the sound eye fixes a point 10° to the right (Fig. 2C). At 20° to the right a further reduction is observed (Fig. 2D), and at 30° only a few potentials remain (Fig. 2E). At 40° a single potential remains, and this decreases in frequency and finally disappears on further effort to look towards the right (Fig. 2F).

In the two series just described, the activity in the internal rectus of the paretic eye changed from the considerable activity observed with the sound eye looking

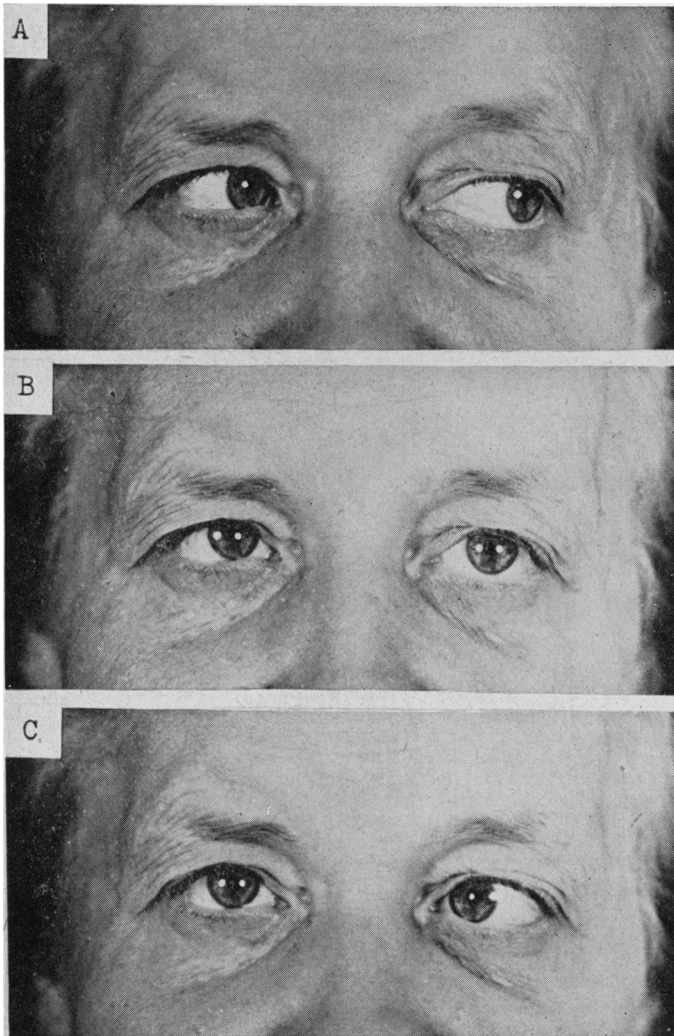


FIG. 1.—Female, aged 52 years, right total abducens palsy. No obvious defect on gaze far to left. (A). On gaze straight ahead, the right eye is turned 20° inward (B). On gaze far to right the right eye is directed 5° to 10° inward (C).

straight ahead to complete elimination of activity when the sound eye is directed to the extreme right, and this despite the fact that the concurrent movement of the paretic eye is at the most 15° , which fails even to carry it to the midline. These changes occur in essentially the same way as in a normal eye (Björk and Kugelberg, 1953b). Thus total paresis of the external rectus with its consequent limitation of movement had no evident influence on the activity of the sound muscle.

In some cases records were made during ocular movements between the two extreme positions, the sound eye being kept entirely covered and the cornea of the paretic eye being covered by a small moist compress. The same characteristic features were observed as before, showing that the factor determining activity during these movements cannot be the act of fixation.

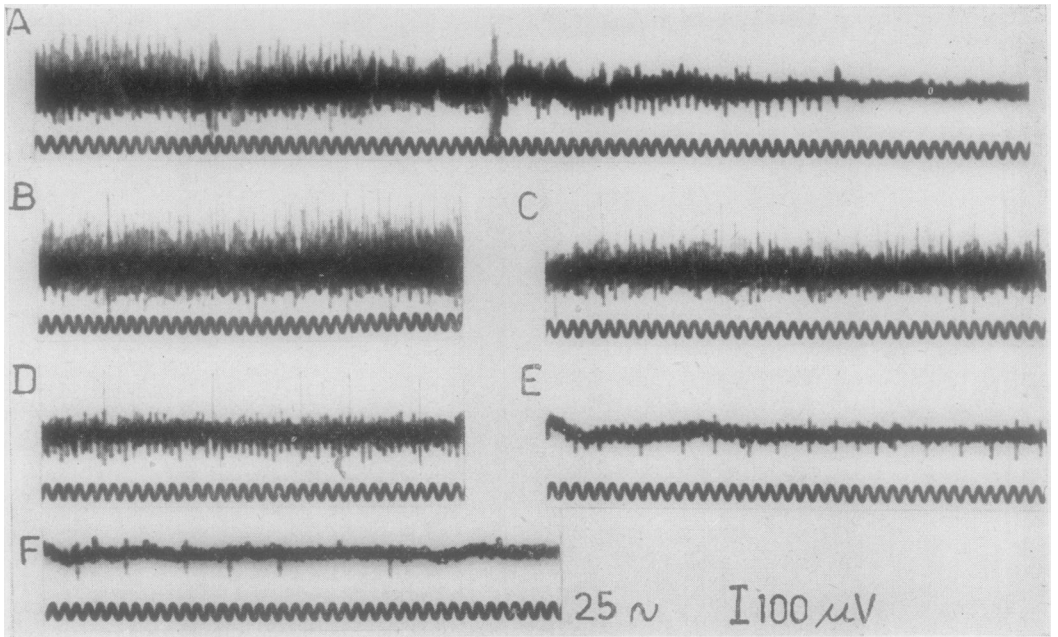


FIG. 2.—Same case as Fig. 1, record from internal rectus muscle on same side as abducens palsy. Progressively decreasing activity to complete cessation (A) is seen on movement of the gaze from straight ahead (Fig. 1B) to extreme right (Fig. 1C).

On gazing straight ahead intense activity is seen (B); on fixation 10° to right the activity is distinctly less (C); at 20° a further reduction in the number of action potentials is seen (D); at 30° only a few potentials remain (E); at 40° a single potential is observed, which decreases in frequency and finally disappears on gazing to the extreme right (F).

Rapid movements have also been examined. Activity was recorded during optokinetic nystagmus produced by looking, with the sound eye, at a rotating drum with vertical white and black stripes. In healthy subjects the records showed during the rapid phase a sudden increase of activity in the muscles producing this movement, together with a rapid onset of total inhibition in those acting in the opposite direction (Björk, 1954b). This is largely in agreement with the results demonstrated in animals with experimental nystagmus produced by vestibular stimulation (Perez Cirera, 1932; Pulfrich, 1952; and other authors). Fig. 3 shows records made of the internal rectus muscle when the rapid phase was in the external direction. The record shows periods of slowly increasing

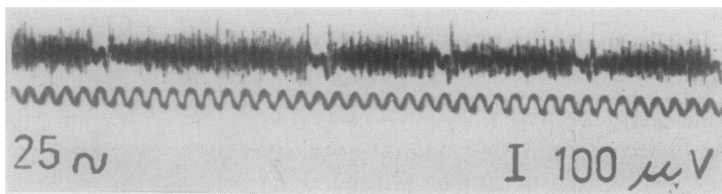


FIG. 3.—Record from internal rectus muscle in a case of total abducens palsy. Optokinetic nystagmus with rapid phase in the direction of paretic muscle. Repeated episodes of slowly increasing activity, abruptly interrupted by total inhibition.

activity separated by the characteristic inhibitions, which thus occur in the internal rectus, despite the fact that the sudden contractions which normally take place in the external rectus are entirely absent.

An investigation on animals by McIntyre (1939) shows a similar result after severing the third, fourth, and sixth nerves on both sides:

Labyrinthine stimulation still produced in the central stump of the sixth nerve motor impulses characteristic of normal nystagmus.

An interesting comparison was obtained in a case of severe oculomotor palsy, in which the electrical activity of the healthy external rectus also behaved as if its opposing muscle was contracting normally.

Activity in the Levator Palpebrae Superioris Muscle in Total Facial Palsy.—Electromyograms were taken during movement of the gaze from far upwards to far downwards and *vice versa*, and during fixation of points between these positions. While the gaze was moving downwards, a continuously decreasing electrical activity was observed in the levator palpebrae, generally ending in a total cessation of activity with the extreme downward gaze. In the orbicularis muscle on the sound side, which was tested simultaneously, only a few isolated action potentials, or none at all, were seen during this movement. A corresponding decrease in activity was found on fixation of different points during a similar movement. An example is seen in Fig. 4 (overleaf), from a case of total left-sided facial palsy. With a directly forward gaze (Fig. 4A) there is vigorous activity; the following three records (Fig. 4B–D) show that the number of action potentials diminishes with fixation at 10°, 20°, and 30° downwards. With 40° downward gaze only one potential remains, and this decreases in frequency on further lowering of the gaze (Fig. 4E). The activity did not disappear completely until the gaze was in the extreme downward direction. Again, no distinct activity is seen in the lower record from the orbicularis muscle on the sound side.

It is well known that in facial palsy the upper eyelid follows the eye downwards in a fairly normal manner when the patient lowers his gaze (Gowers, 1897). This is not surprising in view of the electromyographical evidence that in normal cases the orbicularis muscle takes little part in this movement (Gordon, 1951; Björk and Kugelberg, 1953b). Absence of the power of contraction in the orbicularis cannot therefore be expected to be accompanied by marked consequences.

On the other hand, strong voluntary closing of the eye is accompanied by a high degree of electrical activity in the orbicularis. In normal cases an abrupt and generally total inhibition of the activity in the levator occurs simultaneously with very intense contraction of the orbicularis muscle.

Fig. 5 is an example of a strong and quite prolonged contraction recorded from a case of total facial palsy. The upper record shows the activity in the levator palpebrae muscle on the paretic side. There was, of course, no activity in the orbicularis on the paretic side, and records were therefore taken from this muscle in the upper eyelid on the sound side. A strong inhibition of the activity in the levator palpebrae muscle took place despite the total facial palsy and the evident failure of the patient to close the eye. A long series of somewhat shorter contractions were recorded from a similar case (Fig. 6). Records were taken from the two muscles in the same way as in the preceding cases. The abrupt and total inhibitions in the levator palpebrae (upper curve) corresponding to bursts of activity in the sound orbicularis (lower curve) are well shown in the electromyogram.

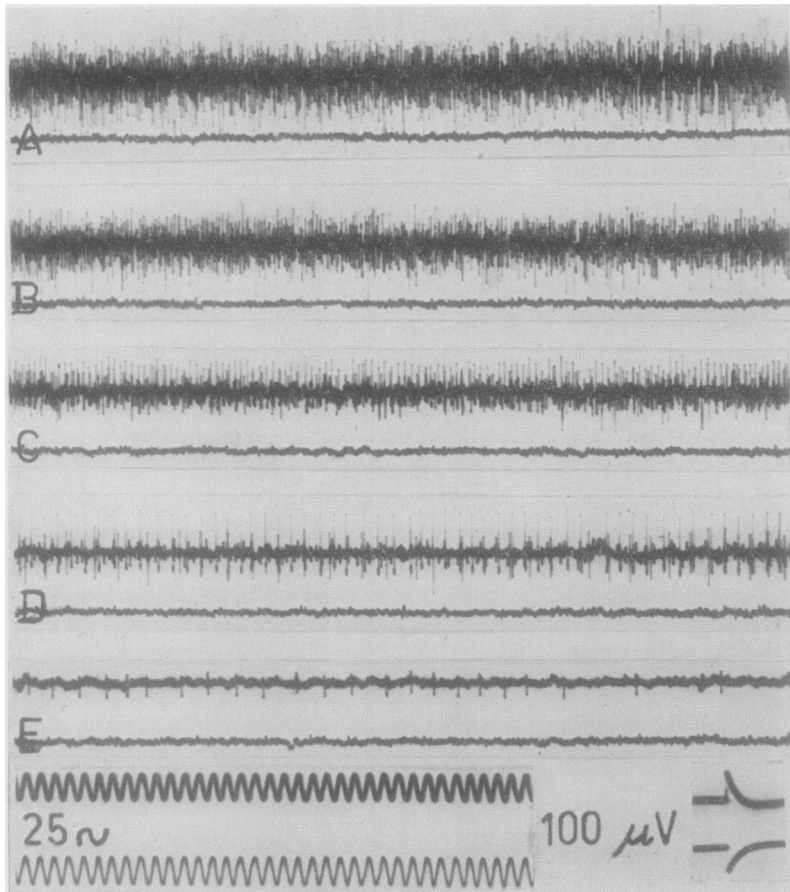


FIG. 4.—Simultaneous recording from levator palpebrae superioris muscle of the paretic side (upper curves) and orbicularis oculi of the sound side (lower curves) in a case of total facial palsy. On gaze straight ahead (A) there is intense activity in the levator; on gaze 10° downward the activity is less (B); at 20° it has decreased still more (C); at 30° several action potentials are still observed (D), but at 40° only one remains (E), which decreases in frequency and then disappears on continued lowering of the gaze. In the sound orbicularis muscle no activity is seen in any position of the gaze.

In the majority of cases Bell's phenomenon was observed, *i.e.* a movement, usually upwards, of the eyeball on attempting to close the eye. Fig. 7 shows simultaneous recordings from the rectus superior muscle on the paretic side (upper curve) and from the orbicularis oculi on the sound side (lower curve). The patient was requested to "screw up" the eyes several times. It is seen that during vigorous activity in the healthy orbicularis an appreciable increase in activity takes place in the rectus superior on the affected side. This increase in activity starts later but continues much longer than that in the orbicularis muscle.

Activity in the Muscles with the Eyeball held or moved by Bridle Suture.—The patient first gazed straight ahead and then moved the gaze in the direction of the captive eye. During this movement the captive eye was held central and a record

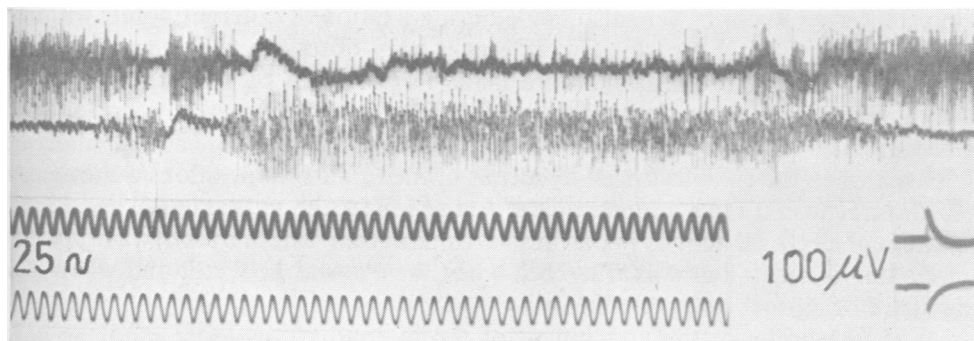


FIG. 5.—Simultaneous recording from levator muscle of paretic side (upper curve) and orbicularis muscle of sound side (lower curve) in a case of total facial palsy. On strong effort to close the eyes, intense activity takes place in the sound orbicularis muscle, corresponding to an almost complete inhibition of activity in the levator muscle of the paretic side.

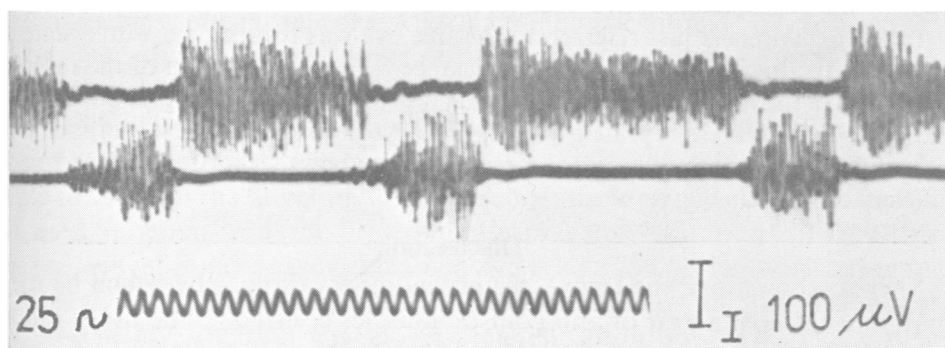


FIG. 6.—Simultaneous recording from same muscles as in Fig. 5 from a case of total facial palsy. As the patient performed a number of brief contractions, episodes of intense activity were observed in the sound orbicularis muscle, and corresponding total inhibitions of activity in the levator of the paretic side.

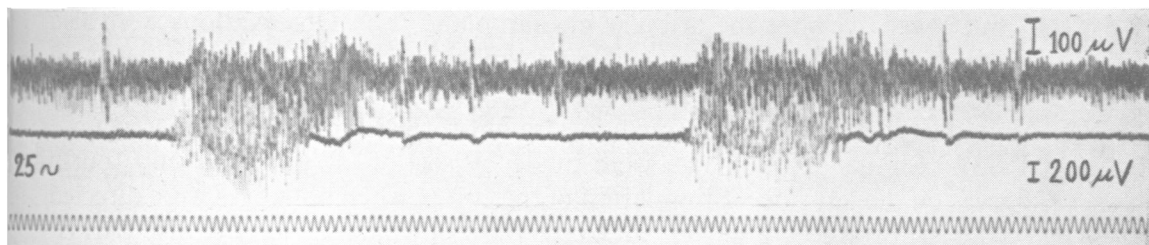


FIG. 7.—Simultaneous recording from superior rectus muscle of paretic side (upper curve) and orbicularis of sound side in a case of facial palsy with total paralysis of the orbicularis. Every time the patient attempts to close the eyes, a burst of activity is seen in the orbicularis of the sound side. Periods of increased activity, starting later but lasting longer than that in the orbicularis, are seen in the opposite superior rectus.

was taken from its internal rectus. Activity decreased progressively and disappeared totally or almost totally when the free eye had reached the end of its travel. The same test was made with the eye released and making its full normal movement. The activity of the internal rectus muscle was, as far as could be judged, identical

in each case. Records were also made during fixation of different points within the same range. Again no distinct difference was observed, whether the eye was captive or free. Modifications were made in two cases by recording the activity from the external rectus muscle and fixing the bridle to the attachment of the internal rectus. The results were in complete agreement with those already described.

Even when the eye was forced by means of the bridle into positions quite contrary to those it would have adopted under the action of the muscles attached to it, the pattern of electrical activity in the muscles (internal and external recti) was apparently quite unaffected. This was true both when the eye was held still and when it was actually being moved by the bridle.

With the bridle in the attachment of the internal rectus loose, and the needle electrode in the same muscle, records made during optokinetic nystagmus revealed the usual characteristic inhibitions. The attempt was then made to imitate the rapid phase by making small pulls at the bridle. No distinct inhibitions were produced. Thus all tests have shown that the activity exhibited under normal conditions by the muscles of the experimental eye does not appear to be affected by artificial disturbance of the position and movements of the eye.

In the experiments just referred to the free eye was fixating the whole time, but the act of fixating is of no decisive importance. The investigation of the rapid and slow passive movements, and the experiment involving the holding of one eye while the other moved, were repeated with the free eye covered and the experimental eye either blind, or with its cornea covered. The inability to fixate produced no significant change in the results.

Discussion

Sherrington coined the term "reciprocal innervation," by which he meant that, when one of a pair of antagonistic muscles contracted the other relaxed. Some of Sherrington's experiments are closely allied to those here described. After sectioning the left abducens nerve in the monkey and stimulating the appropriate part of the cortex giving conjugate movement to the left, the right eye moved normally to the left from its central position. The left eye at rest was directed slightly inwards, and also moved to the left, during stimulation, "but never overshot the primary median plane". Observations were also made of voluntary movements, during which the left eye "frequently rotated from the inner canthus outward conjugately with the right eye, but never passed beyond the primary (median, straight-forward) position" (Sherrington, 1893). Similar experiments were made by section of the third and fourth nerves on the left side. Stimulation of the cortex when both eyes were directed to the left produced a movement to the right in which the left eye also participated to some extent. Since the latter eye only had one active muscle (the external rectus), the movement of the left eye must, according to Sherrington (1893), have been due to a relaxation of this muscle.

Tilney and Pike (1925) criticized Sherrington's studies of reciprocal innervation, and declared, as regards the experiments on the ocular muscles, that Sherrington's observations were not in agreement with clinical experience in certain cases of palsy. Adler (1929, 1930), on the contrary, in an account of cases of palsy of the ocular muscles, demonstrated a close agreement between

the clinical picture and the expectations from Sherrington's theory. He described a case of total bilateral paralysis of the third and fourth nerves as follows:

On extreme abduction to the right, not only did the right eye turn out, innervated by the right external rectus, but the left eye turned in slightly toward the midline. On looking to the left, the left eye could be voluntarily abducted and the right eye followed inward slightly toward the midline.

Adler concluded from this that the inward movement of each eye must have been due to relaxation of the external rectus muscle, which is in agreement with Sherrington's observations.

In the present electromyographic studies, there were six selected cases of total abducens palsy, corresponding to the conditions in Sherrington's first-mentioned experiment. It is, of course, important to establish that the paresis in the external rectus is really total, and thanks to electromyography this can be done (Björk, 1954a). It may be objected that in these cases the internal rectus is not entirely deprived of antagonistic muscles, since the oblique muscles, too, have a partial function in moving the eyeball outward. This action must, however, be of little consequence within the range of movement described in the cases recorded here, in which the eye in its outward movement did not even reach the primary position. In total abducens palsy, the eyeball is able to move in the direction of the paretic muscle roughly as far as the midline, as is apparent from the present and earlier investigations (Björk, 1954a). This movement is most easily explained as a relaxation of the sound antagonist in agreement with Sherrington's postulation from his animal experiments. The present investigation has shown that relaxation does in fact take place, and that during lateral movements of the gaze the electromyogram from the internal rectus of the paretic eye is the same as might be expected from the external rectus of the sound eye. In recording from the external rectus in a case of severe oculomotor palsy, the results were also in agreement.

It may be mentioned in passing that the deviation assumed by an eye in concomitant strabismus starting in infancy cannot be compared with any of the deviations mentioned here, as will be described in electromyographic investigations to be published later. The squinting eye seems to be in muscular equilibrium when directed approximately straightforward whichever eye is fixing. In the squinting position, roughly the same conditions of activity are found as might be expected if a non-squinting eye assumed the same position.

Sherrington has furthermore examined the coordination between the muscles opening and closing the eyes. The facial nerve was divided on the left side:

As the right eye blinked, the upper lid of the left eye quickly dropped three to four millimetres.

This movement of the upper eyelid was assumed by Sherrington to be due to the inhibition of the tonus of the left levator palpebrae superioris muscle:

This brings the coordination of the reaction into line with that which I have described for other movements under the term reciprocal innervation (Sherrington, 1898).

Sherrington's observation is in good accord with clinical experience. Gowers (1879), in his classical work on movements of the eyelids, states that, if the orbicularis is paralysed and an attempt is made to close the eyes, the upper lid falls.

The fact that the upper eyelid, even in total facial palsy, closely follows the movements of the eyeball during movement of the gaze downwards, was also noticed by Gowers. He gave the reasons as a relaxation of the levator muscle, the weight of the lid and its cohesion to the eyeball. Relaxation of the levator has been demonstrated here and must be of importance, but may not be wholly responsible for lowering the lid. According to Sewall (1933) the weight of the lid is not important, for the movement of the lid is the same whether the patient stands on his head or his feet. This is also in agreement with the results of experiments by Walsh (1947).

In attempts to close the eye in facial palsy, the pronounced and abrupt inhibition of the activity in the levator palpebrae muscle that has been demonstrated here is, of course, of functional importance for the contraction taking place rapidly and with the least resistance. It appears as though a similar mechanism is active in respect of the lower lid as well. The rapid increase of activity in the rectus superior demonstrated in conjunction with Bell's phenomenon would appear to be matched by decreased activity represented by relaxation in the rectus inferior, as was also shown in normal cases (Björk and Kugelberg, 1953b). This in its turn is attended by a decrease in the tension on the lower fornix and a greater ease in raising the lower lid, thus again reducing resistance to the closing of the eye.

In the above investigations, in cases of ocular palsy in which the patient fixed with the sound eye or carried out movements of the gaze, the electromyographic pattern from the unaffected muscles of the paretic eye was the same as would have been expected had the eye been able to assume normal positions and carry out normal movements. In experiments on eyes with normal motility, in which one eye is artificially compelled to assume different postures and perform different movements, the activity in the muscles does not appear to be affected by these passive extensions or shortenings. All experiments reveal that central control is predominant. The activity is determined solely by the direction in which the subject intends to turn his gaze, a conclusion perhaps foreshadowed by Hering's celebrated *Gesetz der motorischen Korrespondenz der Augenbewegungen* (Hering, 1868).

Summary

To illustrate the coordination between antagonistic muscles acting upon the eyeball and eyelid, a study was made of the electrical activity in the muscles of six patients with total abducens palsy, and ten with total facial palsy, and of five persons with normal eye movements. The eye was moved artificially in the latter cases by means of a bridle suture sewn to the attachment of the muscle.

(1) *Abducens Palsy*.—In different positions of fixation with the sound eye and during movement of the gaze, the electrical activity in the internal rectus which is normally antagonist to the paretic muscle, showed a picture which would have been expected had the eye been able to assume normal positions and carry out normal movements. Activity successively decreased on movement of the gaze in the direction of the paretic muscle, and it disappeared entirely, or almost entirely, only when the non-paretic eye was turned strongly in that direction. The paretic eye had then not even reached the midline. These changes in activity are not bound to the act of fixation, for they are also observed when both eyes are incapable of fixation.

The inhibitions of activity characteristic of the rapid phase of nystagmus also occur despite the total palsy of the muscle normally producing the movement.

(2) *Facial Palsy*.—The activity in the levator palpebrae muscle followed the pattern seen in healthy subjects. On lowering the gaze the activity successively decreased, becoming entirely extinguished on extreme downward gaze. The lowering of the eyelid which takes place in spite of total palsy of the orbicularis muscle is thus caused, at least partly, by this inhibition.

On strong effort to close the eyes a rapid and generally total inhibition was observed as in healthy subjects.

(3) *Compulsory Movement of Eye with Normal Motility*.—No distinct change of activity in the internal or external recti muscle was caused by forcing the eye to perform movements or to assume various positions in relation to the other eye by means of a bridle suture. The activity corresponded to the subject's voluntary intentions as disclosed by the position of the non-captive eye.

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