THE CROONIAN LECTURES

ON

MUSCULAR MOVEMENTS AND THEIR REPRESENTATION IN THE CENTRAL NERVOUS SYSTEM

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Delivered before
The Royal College of Physicians of London,
June, 1903

BY

CHARLES E. BEEVOR, M.D.Lond., F.R.C.P.

PHYSICIAN TO THE NATIONAL HOSPITAL FOR THE PARALYSED AND EPILEPTIC,
QUEEN SQUARE, AND TO THE GREAT NORTHERN CENTRAL HOSPITAL

With the Author's compliments.

London
ADLARD AND SON
BARTHOLOMEW CLOSE
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CONTENTS.

LECTURE I.

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LECTURE I.

Mr. President and Gentlemen—I have first to express to you, Sir, and the Council of this College, my most sincere thanks for the great honour which you have conferred on me in selecting me to deliver the Croonian lectures. I feel very deeply the responsibility of undertaking this duty, and when I regard the roll of distinguished Fellows who have preceded me my task is indeed difficult, and though I fear that I shall not attain the high standard which they have set, my endeavour will be to lay before you to the best of my ability some investigations on muscular movements on which I have been working for some years past.

The choice of my subject will also, I think, be in harmony with the wishes of the founder of these lectures, for while the Croonian lectures at this College are directed to be given on one or more subjects in Anatomy, Physiology, and Pathology, with a view to the prevention, control, and cure of disease, the Croonian lecture to be delivered annually before the Royal Society is required to be on the nature and laws of muscular motion. So that we may infer that the founder himself took a great interest in the muscular system.

Methods of ascertaining the Action of a Muscle.

§ 1. In taking the subject of muscular movements the first question which would naturally arise would be—Which is the best method to ascertain the action of a muscle?

To determine the action of a muscle there are three chief methods.

§ 2. First, the anatomical method, which is employed on the dead subject and consists in dissecting out a muscle, freeing it from its connections, but leaving it attached at its origin and insertion. The muscle is then pulled upon by the dissector, and the resultant position of the limb is taken to be the action which the muscle would exercise during life. Or a muscle is seen to have a certain origin and insertion, so that if it contracted it must produce an approximation of the two parts. As an instance of this may be mentioned the inspiratory action of the latissimus dorsi muscle, which, from its origin from the lowest three or four ribs and its insertion into the humerus, has been looked upon as a muscle of forced inspiration, for it was concluded that if, when the humerus was fixed, the muscle contracted, its only action would be to elevate the ribs, whereas its chief *rôle* is expiratory, as we shall see later.

This—which I may call the anatomical method—is the only means which we have of obtaining knowledge of the action of muscles too deeply seated to be examined during life, such as the quadratus lumborum and the external rotators of the hip-joint.

It has, however, the following great disadvantages: It gives the action of the individual muscle and thereby leads one to imagine that this particular muscle acts by itself. It gives all the possible actions of a muscle, and postulates that in all these possible actions the muscle must take part.

With regard to these objections I think that there is hardly an instance in the whole body of a movement in which only one muscle takes part, and it would therefore be necessary to know first the particular share of the other muscles in the movement and the manner in which they affect the action of the muscle under consideration.

It does not follow because a certain movement can be produced on a joint by traction on the dissected muscle that therefore the muscle must be used during life for this movement, as it may not be advantageous to use the muscle for this purpose.

§ 3. The second method or electrical method is the one which was employed by Duchenne with such great success, and his classical observations on the actions of muscles will always rank as one of the most brilliant achievements in the subject.

The method consists in faradising with the two poles of an induction coil the muscle under examination, and then noting the action produced on the joint or joints over which the muscle acts.

The results of this method have given most valuable information as to the action of the muscles, and where the muscles are superficial enough to be reached by the current this method is much preferable to the anatomical method, in that the movements are produced by the living muscle undisturbed in its relation to surrounding parts.

I venture to think, however, that this method is open to the same objections as the anatomical method in that, although every movement that the muscle is capable of is undoubtedly produced, yet, as the muscle acts alone, we do not know what the influence of the other muscles may be which also enter into the movement; and also there is the second objection that we do not know by this method whether a muscle, which on stimulation gives the movement, let us say, of supination, is included in the movement of supination when this is performed as a voluntary act.

It seems to me that, although the two former methods will tell us what a muscle *may* do, it does not tell us what a muscle *does* do, and we cannot say for certain that a muscle has a definite action without following the precept of the immortal Harvey and going direct to nature and there testing the results obtained by the anatomical and electrical methods.

§ 4. This last method, which we may call the physiological or natural method, differs from the two former in reversing the order of procedure. In the anatomical and the electrical methods one muscle is taken, and by dragging on it or stimulating it to contract certain movements are produced, whereas in the physiological method a living person is told to perform a definite movement, and it is then observed which muscles take part in this movement.

Certain precautions have to be taken in using this method, the most important being that the person shall perform by fixation of the limb the movement only which is required, so that, for example, if a person is told to pronate the forearm he must not at the same time abduct the shoulder and thereby bring into action other muscles than those concerned directly with pronation. The means which I have used for determining whether a muscle is taking part in any given movement are inspection and palpation either of the muscle as a whole or of its tendon. I have examined both normal people and patients who have lost the use of some of their muscles.

§ 5. The movements have been performed in three ways:

(1) By the person moving the limb without any extra weight.

(2) By moving the limb loaded with different weights.

(3) By attempting to move the limb which is fixed by an opposing force.

The first procedure gives the minimum work which the muscles entering into any movement are called upon to do. The least possible work that a group of muscles can do is to overcome the inertia of a joint. This can be accomplished in the elbow by placing the upper arm on a support in a horizontal position and then flexing or extending the forearm on it in a horizontal plane, so that by this means the action of gravity can be neutralised. Or with the upper arm resting horizontally the forearm can be placed vertically, and the movement of pronation and supination can be carried out.

The minimum degree of work in certain positions is that afforded by lifting the limb against gravity, as in flexing the forearm when the humerus is in the vertical position alongside the trunk.

The third procedure gives the strongest work that the muscles can perform, and as by reason of the fixation of the limb there is no alteration in the angle of the joint, the error is avoided of assuming that the tightening of a tendon from the stretching of a passive muscle is evidence of contraction of the muscle.

The second procedure would give the intermediate conditions between the two extremes of maximum and minimum work.

The amount of work done by the muscles was measured by spring balances or by the traction scale of a clinical dynamometer.

§ 6. With the exception of Winslow* and Duchenne I am unable to find that writers on anatomy as a rule take their knowledge of the action of muscles from the living subject. James Benignus Winslow, whom Duchenne rightly styles the Admirable Winslow, and who, although his name has an English sound, was Professor

* 'An Anatomical Exposition of the Structure of the Human Body,' by James Benignus Winslow. Translated from the French original by G. Douglas, M.D. Fourth edition, corrected, 1756, vol. i, sect. iii, No. 784.

of Physick, Anatomy and Surgery, in the University of Paris in the eighteenth century, speaks with no uncertain note when he writes that "The experiments made on dead bodies by pulling the muscles after they have been raised are very fallacious."

Lists of muscles are given under the different heads of flexors, extensors, rotators, abductors, adductors, etc., but how are these lists obtained? They are made by putting into one category, for instance, all the single muscles which are called flexors, etc., but such a list does not express a combination which has been verified by actual inspection during life. I venture to think that, if all the muscles contained in some of these lists contracted, the movement produced would not be the one which was expected, and I trust to be able to show that the actions which are ascribed to some of the muscles cannot be substantiated when put to what I think will be admitted to be the only true test—their actions in the living subject.

When one comes to clinical medicine, as in examining a case of muscular atrophy, the chief difficulty consists in knowing what movements to ask the patient to perform in order to find out whether a particular muscle is acting or not.

I trust the time will come when the actions of muscles will be taught on the living subject, together with the part which they take in the performance of simple movements.

I now propose to take the movements of some of the joints of the body and to describe the muscles which take part in producing the movements as observed on the living subject.

For convenience I shall begin with the movements of the upper limb.

§ 7. I shall use in all cases the Latin names for the muscles, and I would like here briefly to express my regret that in these days, when the idea of a universal language is so much discussed, in anatomy so many nations prefer to use the vernacular to the Latin name, which is intelligible to every one. For instance, the serratus magnus is described in modern foreign anatomical works as the "grande dentelé" and the "vordere Säge muskel," and when we come to the anatomy of the brain the "corpus geniculatum externum" becomes the "corps genouillé" in French and the "äussere Kniehöcker" in German.

I am glad to say that in this country we have not followed this practice, and we do not talk as yet of the "front saw muscle" or the "outer knee-knob." It would save much trouble if every nation adopted the Latin terms, a decision which I believe the International Nomenclature Committee have arrived at.

MOVEMENTS OF THE UPPER LIMB.

Movements of the Fingers.

§ 8. *The flexion of the phalanges.*—Taking first some of the movements of the upper limb, and first those of the fingers, I would remind you that the first phalanges (proximal) of the fingers are flexed on the metacarpal bones by the interossei and lumbricales, an anatomical discovery which was made by Columbus and Fallopius in 1559 and 1561, and which, according to Duchenne, was lost sight of till he (Duchenne) again called attention to it, but this is hardly correct, as it was mentioned by Winslow,* and John Hunter † refers to it in his Croonian lecture delivered before the Royal Society in 1777. The first phalanges are also flexed by the tendons of the flexores digitorum on their way to the terminal digits. If, however, it is required to flex the two last phalanges of each digit, but not the first, the extensor communis digitorum is brought into action, a muscle which extends the first phalanx of each finger more than the last two phalanges. If the movement of flexion of all the phalanges of the fingers is required without any movement of the wrist, then along with the flexores digitorum, the extensores carpi radialis longior and brevior, and ulnaris contract.

§ 9. *The extension of the second and third phalanges* is, as is well known, produced by the two sets of muscles, the extensor communis digitorum and the interossei and lumbricales, which are inserted into the common extensor tendons. The action, therefore, of these small muscles is to flex the first phalanx and to extend the second and third phalanges, and this combined movement cannot be performed when the interossei and lumbricales are paralysed. Duchenne ‡ is strongly in favour of the theory that the action of the extensor communis digitorum on the last phalanges is exceedingly limited, and that it is not an extensor of all the phalanges, but that it only has a true action on the first phalanx, and he proposes to call it the extensor of the first phalanx. He also states in another part of his book ('Physiologie des Mouvements') that the

* *Loc. cit.*, vol. i, sect. iii, No. 966.

† The works of John Hunter, F.R.S., 1837, p. 237.

‡ 'Physiologie des Mouvements,' 1867, § 172. p. 164.

interossei and lumbricales are in reality the sole extensors of the two last phalanges and the sole flexors of the first phalanx.

It is no doubt true that when the extensor digitorum is paralysed, the last two phalanges can be extended by the interossei and lumbricales, and also that in the opposite condition, the "claw-hand," where the extensors of the fingers are preserved and the interossei are paralysed, there is inability to extend the last digits when these small muscles are paralysed. But in the latter case, where the interossei and lumbricales are paralysed, if the first phalanges be kept passively flexed on the metacarpus, I have found that then the patient is able to extend the terminal digits by means of the extensor digitorum. So that it seems probable that in the claw-hand the inability of the extensor digitorum to extend the terminal phalanges is due to its energy being expended on the first phalanges, which are not prevented from over-extending by the interossei and lumbricales, as these are paralysed.

§ 10. *The extension of the proximal phalanges* on the metacarpus by the extensor communis digitorum is accompanied, as Duchenne* pointed out, by contraction of the flexors of the carpus, viz. the flexores carpi radialis and ulnaris, and palmaris longus. The contraction of the extensores carpi cannot be felt, when the fingers are extended slowly and without resistance, until the phalanges are nearly fully extended, but if the phalanges are quickly extended the extensores carpi seem to act at once. In lead poisoning, in those cases where there is paralysis of the extensor communis digitorum and not of the extensores carpi, according to Duchenne, "the patient can, if he keeps his fingers flexed, extend the hand on the forearm, but if he wishes to extend his fingers, his first phalanges remain immovable, and his hand is flexed on the forearm with as much energy as he makes in his greatest effort to obtain extension of the fingers." The explanation of this combination will be discussed later when we consider the synergic action of muscles.

§ 11. The lateral movements of the fingers are adduction toward the middle finger and abduction away from the line of the middle finger. *Adduction* is performed by the palmar interossei, and *abduction* of the three large fingers by the dorsal interossei, but with abduction of the index finger and the little finger other muscles come into action. It is exceedingly difficult to abduct the index finger without adducting or flexing the thumb, from the

* *Loc. cit.*, § § 168, 169.

fact that the first dorsal interosseus or abductor indicis arises from the metacarpal bone of the thumb, as well as from that of the index finger, so that if it is required to abduct the index finger alone the extensores ossis metacarpi and extensor brevis (or primi internodii) of the thumb are called into action to prevent the thumb moving. *Abduction of the little finger* is performed by the special abductor minimi digiti, but as this arises from the pisiform bone this latter has to be fixed by the flexor carpi ulnaris. To obviate the special action of the flexor carpi ulnaris on the wrist, the extensor ossis metacarpi pollicis contracts, and when the hand is in a line with the forearm it is apparently impossible to abduct the little finger without the extensor ossis metacarpi contracting; if, however, the hand be first adducted to the ulnar side the contraction is less marked.

Movements of the Thumb.

§ 12. The movements of the thumb are flexion and extension of all three joints, which take place in a plane parallel to the palm of the hand, and abduction and adduction of the metacarpo-carpal joint in a plane at right angles to that of the palm of the hand. In addition there is opposition of the thumb to the fingers.

First, a few words with regard to the change of position of the first metacarpal bone on the carpus. In the movements of flexion and extension, which take place in a plane parallel to that of the palm of the hand, the palmar surface of the thumb keeps at right angles to the palm of the hand, but in the movement of abduction it is difficult to perform this movement without rotating the thumb inward, so that the palmar surface of the thumb is opposed to that of the fingers. Therefore in abducting the thumb it passes naturally into the position of opposition, and from that position it can be advanced towards the tips of the fingers in succession, but more rotation will be required to oppose it to the index finger than to the fourth finger.

§ 13. Taking the terminal phalangeal joint of the thumb first, *flexion*, as is well known, is performed by the flexor longus pollicis and, if this movement alone be required, the extensor primi internodii or extensor brevis pollicis as it is now called, and the extensor ossis metacarpi contract to prevent the first phalanx and the metacarpus being flexed. *Extension of the last phalanx* is performed by the extensor secundi internodii pollicis, or extensor longus pollicis according to the new nomenclature, but, as was pointed out by Duchenne, this simple movement cannot be performed without also calling in the action of the adductor pollicis, the flexor brevis pollicis, and the adductor pollicis, as these small muscles send prolongations to the tendon of the extensor secundi internodii (Sabatier, Bouvier, and Duchenne) ; so that by the action of these small muscles the last phalanx can be extended without extending the first phalanx.

The movements of the metacarpo-carpal joint of the thumb are more complicated, and besides flexion and extension there is opposition.

§ 14. *Flexion of the metacarpal bone* of the thumb is caused by the opponens pollicis and by the abductor, flexor brevis and adductores transversus et obliquus pollicis, as they are now called, when flexion of the first phalanx is also required ; but when flexion of the metacarpal bone is required with extension of the phalanges there is also some action of the extensor primi internodii pollicis. Flexion of the metacarpal bone is also affected by the flexor longus pollicis after the phalangeal joints are flexed.

Extension of the metacarpal bone is performed by the extensor ossis metacarpi, and also by the extensor primi internodii or extensor brevis pollicis. At the same time, as was pointed out by Duchenne, it is not possible to extend the metacarpal bone and the first phalanx of the thumb without putting into action the extensor carpi ulnaris and also I would add the flexor carpi ulnaris, which, however, does not come into action so soon as the extensor. The reason why these muscles are brought into action will be discussed later on ; at present I would lay stress on the impossibility of extending the thumb without putting these other two muscles into action, and also that this action occurs in all positions of the wrist, even when it is in that of extreme abduction, a position in which it would not be possible for the extensor ossis metacarpi to move the wrist further in the direction of abduction.

Abduction of the thumb is performed by the small thumb muscles, viz. the abductor pollicis, opponens pollicis, and outer head of the flexor brevis, and also by the extensor ossis metacarpi and extensor brevis.

This is not in accordance with Duchenne * who from electrical observations states that the extensor ossis metacarpi is one of the opposing muscles of the thumb, while the extensor primi internodii (or extensor brevis pollicis) is not an extensor of the first metacarpal bone but is the only direct abductor. If by

* *Loc. cit.*, § 216.

abduction is meant carrying the thumb away from the first finger in a plane at right angles to the palm, I think that there is no doubt that the tendon of the extensor ossis metacarpi can be felt to contract. The extensores carpi radialis brevior (not the longior) and ulnaris take part in abduction of thumb.

There is one important point with regard to this movement, and that is that though it is possible to abduct the thumb fairly well when the extensor of the metacarpus is paralysed, it is quite impossible for the extensor of the thumb to abduct it in the slightest degree when the small thumb muscles are paralysed, in fact, inability to abduct the thumb is one of the best tests for the absence of the small muscles of the thumb.

In adduction of the thumb from the position of abduction it rotates from within outwards, and the movement is performed by the adductor transversus and probably the obliquus, and by the extensor secundi internodii (or extensor longus follicis), as shown by Duchenne. When, however, the thumb has passed the middle point of its movement I find that the flexor carpi ulnaris also contracts, probably to counteract the extension of the wrist by the extensor secundi internodii.

Opposition is best performed after abducting the thumb, and from the position of abduction advancing it to meet the fingers ; the muscles which take part in this movement are the abductor pollicis, the opponens pollicis, the flexor brevis, the adductores pollicis.

According to Duchenne * the abductor pollicis, as I have already stated, chiefly opposes the thumb to the two first fingers, while the flexor brevis opposes the thumb to all the fingers ; in the list of opposers he also includes the extensor ossis metacarpi, which, according to him, is one of the chief opposers of the metacarpal bone and not its abductor, but it seems to me that, although it does act in abducting the thumb and putting it in the position of opposition, it ceases to act as soon as the thumb advances to meet the fingers. The movement of opposition is therefore preserved when the extensor ossis metacarpi is paralysed, and lost when the thenar muscles are paralysed.

It is interesting to note that Duchenne,† from electrical observations, ascribes to the adductor pollicis four different actions on the metacarpal bone of the thumb, viz. adduction, abduction, extension, and flexion. With this I am not able to agree, as I cannot find that

* *Loc. cit.*, § 306, xxvii, p. 315. † *Loc. cit.*, § 306, xxix, p. 316.

this muscle takes part in abduction or extension in any position of the bone, and I think it is an instance where the actions obtained by electrical stimulation of a muscle do not find their counterpart in the voluntary movements in the living body. It also postulates that a muscle may act as a primary mover in two movements which are diametrically opposed to each other, a condition which I believe hardly exists in the human body, and which I shall refer to later.

§ 15. We have next to consider the *combined movements of the fingers and thumb* as in grasping an object.

Here all the muscles which flex the different joints of the fingers and thumb come into action, and in addition to these muscles the extensors of the wrist take part in the action just as they take part in that of flexion of the first phalanges of the fingers. This combination was definitely pointed out by Duchenne,* who stated "that the synergic action of the extensors of the wrist is absolutely necessary to the flexion of the fingers, and the force of their contraction is then proportional to the energy of this flexion."

Movements of the Wrist.

§ 16. The movements of the wrist are flexion, extension, radial lateral movement or abduction, and ulnar lateral movement or adduction.

Flexion of the wrist.—In addition to the definite flexors of the wrist, viz. flexor carpi radialis, flexor carpi ulnaris, and palmaris longus, the flexors of the fingers may become also flexors of the wrist and the amount of work which they do may be tested by fixing the forearm, and by making traction against the movement of flexion of the wrist by a band passed over the palmar surface of the metacarpal bones. If a dynamometer be interposed in the line of the band and traction be made at right angles to the metacarpal bones, it will be found that it takes more traction to overcome the flexion of the wrist when the flexores digitorum are acting—and they can be made to act as flexors of the wrist by pressing the fingers against the palm of the hand and so fixing the insertions of the tendons—than when the flexores carpi alone act. In my own case the maximum strength with the extensores digitorum and extensores carpi was 20 kilogrammes (about 45 lbs.), while with the extensores carpi alone 16 kilogrammes. With regard to the thumb muscles, the extensor ossis metacarpi, as stated by Duchenne,† is a flexor of the wrist.

* *Loc. cit.*, § 158, p. 154. † *Loc. cit.*, § 218.

§ 17. *Extension of the wrist* is performed by the three extensors of the wrist and also by the extensor secundi internodii to a slight degree, but not by the other two extensors of the thumb. The question of the part played by the extensores digitorum will be discussed presently.

§ 18. *Abduction of the wrist* is performed by the flexor carpi radialis, the three extensors of the thumb, and the extensor carpi radialis longior ; and *adduction* by the flexor carpi ulnaris, and the extensor carpi ulnaris. It is interesting to note that Duchenne* from electrical stimulation denies that the flexor carpi ulnaris is an adductor, or that the flexor carpi radialis is an abductor of the wrist. In reply to that I would say that in performing the movement of adduction and abduction these muscles can be felt to contract, and it shows how important it is that results obtained by electric testing should be verified by reference to the living body. The action obtained by electrical stimulation is that of the muscle acting alone, a condition which does not exist in the body unless all the other muscles are paralysed. In passing round from flexion of the wrist to adduction, the flexor carpi ulnaris is either contracting with the palmaris longus in flexion or with the extensor carpi ulnaris in adduction. It is quite possible, that if the extensor carpi ulnaris were absent, the flexor carpi ulnaris would not be able to adduct the wrist alone. Now, according to Duchenne,† faradisation of the extensor carpi radialis longior and of the extensor carpi ulnaris separately produces extension of the wrist with abduction and adduction respectively, so that these two muscles acting alone could not produce pure abduction or adduction ; to do so each must act with the flexor carpi radialis and ulnaris respectively.

§ 19. In reference to the movements of extension and flexion of the wrist, an important question arises as to the part taken respectively by the extensors and flexors of the fingers in these movements. I will take first the movement of extension of the wrist. It is mentioned by Duchenne‡—but whether he was the first to point it out I do not know—and it is an observation which has been frequently confirmed, that in lead paralysis affecting the extensor communis digitorum but not the extensores carpi, as long as the person "keeps his fingers flexed, he can extend with force his hand on the forearm." Also Sir William Gowers,§ in his work on 'Diseases of the Nervous System,' states, in speaking of lead paralysis, in

* *Loc. cit.*, § 161.
† *Loc. cit.*, p. 149.
‡ *Loc. cit.*, § 168.
§ Vol. ii, p. 949.

which the extensores digitorum are paralysed but not the extensores carpi, that "as long as the special extensors of the wrist retain power, this joint can still be extended when the fingers are flexed so as to close the fist, although the wrist cannot be extended when the fingers are also extended. The reason for this seems to be physiological. When in health the hand and fingers are both extended; the special extensors of the wrist act very little if at all; the movement at the wrist joint is effected by the long extensor of the fingers, if, however, the fingers are flexed the extension of the wrist is effected by the special extensors." So that according to Duchenne (see § 10), if a person with paralysis of the extensor digitorum tries to perform the movement of extending his fingers the only result he obtains is flexion of the wrist, and, according to the extract from Sir W. Gowers just given, a patient with paralysis of the extensor digitorum has no power to extend the wrist as long as he tries to do it with the fingers straight. These conditions are frequently met with in cases of lead paralysis (see Figs. 1 and 2).

§ 20. Now the problem which is before us and which has, as far as I know, never been explained is:—Why do not the extensors of the wrist, which in this case are healthy, come to the rescue and help the paralysed extensors of the fingers to extend the wrist? They certainly do *not* contract, and there must be some explanation of the inability of the person to make them do so.

Now let us observe what happens in the normal condition. With the fingers flexed so as to form a fist, if the wrist be extended, the work is done by the three extensores carpi and their tendons at the wrist and especially the extensores carpi radialis longior and ulnaris can be felt to contract. If now, in the course of this extension the fingers be suddenly extended, the extensors of the carpus immediately cease to contract, and the work of extension of the wrist is done by the extensors of the fingers. But the extensors of the fingers cannot act without at the same time causing the flexors of the wrist to contract, and by putting one's thumb and finger on the tendons respectively of the extensor carpi radialis and the flexor carpi ulnaris during this movement it will be found that when the fingers are extended the extensor carpi radialis can be felt to relax and the flexor carpi ulnaris to contract. The wrist can therefore be extended fully by the extensors of the fingers without the help of the extensors of the wrist, but as the extensors of the fingers have to do this against the contraction of the flexors of the wrist there is a feeling of constraint. Now what will happen if

Paralysis of the Extensors of the Fingers from Lead.
(From photographs taken by Dr. F. Buzzard.)

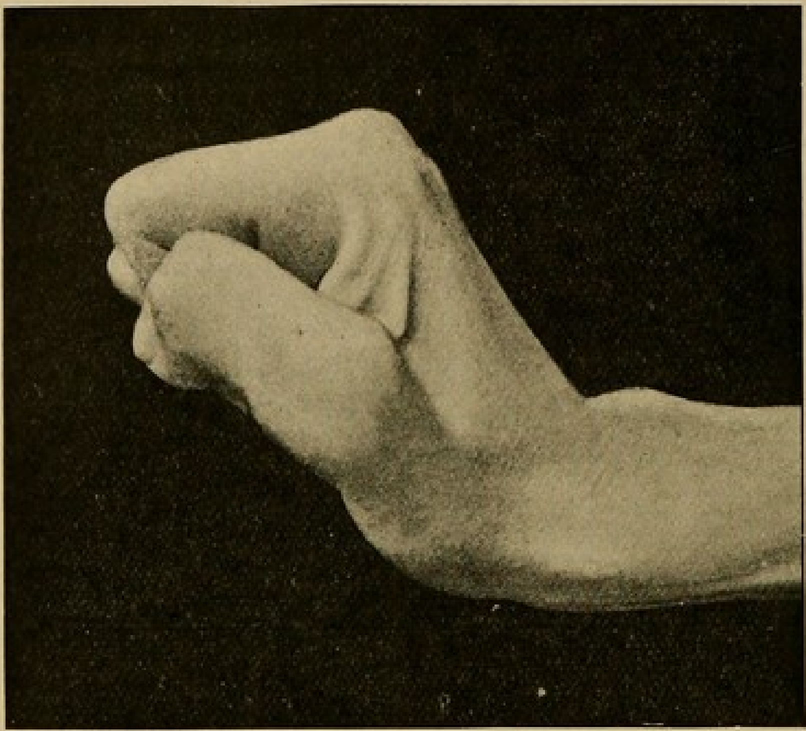


Fig. 1 shows the maximal (normal) extension of the wrist when the fingers are flexed.

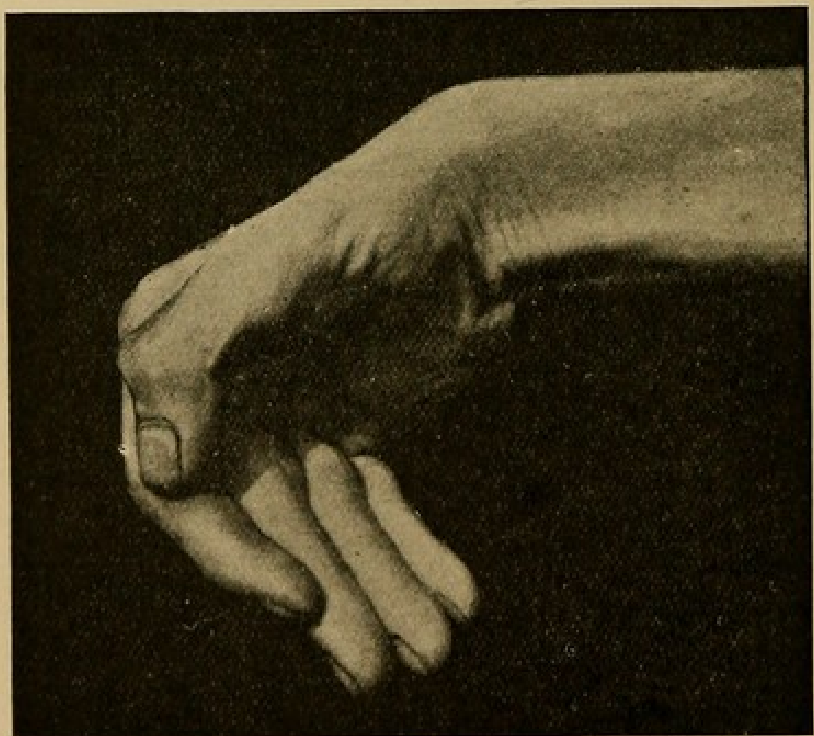


Fig. 2 shows the maximal extension of the wrist in the same case when the fingers are straight. The strong contraction of the tendons of the flexores carpi is well seen.

strong resistance be made against the movement of extension of the wrist when it is performed by the extensors of the fingers, which are weak muscles? Will the extensors of the wrist—so to say—come to the rescue and take part in the movement of extending the wrist? As a matter of observation I have found that they will come and help. But—and I think that this is a most important point, and one which I believe has not been shown before—as long as the fingers remain extended the extensors of the wrist will not help until a certain resistance has been reached, and only when this amount of resistance is reached will the extensor tendons of the wrist be felt to act. (It is a question whether this secondary action of the extensores carpi, auxiliary to the extensores digitorum, is not to be looked upon as that of fixation muscles. See page 64.) On the other hand, if the extensors of the fingers retire from the contest and let the fingers flex, the extensors of the wrist instantly contract, no matter how slight the resistance may be. It therefore seemed to me important in extending the wrist by means of the extensors of the fingers to find out: firstly, the amount of resistance necessary to cause the extensores carpi to take part in the movement; secondly, the amount of resistance necessary to cause the flexores carpi to cease contracting. The experiment was made either with the forearm placed on the flat surface of a table with the palm downwards and with the hand projecting beyond the edge of the table in a line with the forearm, and with the fingers extended; or the forearm was placed midway between supination and pronation, so that the ulnar edge of the forearm and also the hand rested on a smooth table, and by this means the weight of the hand was supported and no muscular action was required to counteract the influence of gravity.

To determine the first question—the amount of resistance necessary to cause the extensores carpi to contract—the resistance or the amount of work exerted by the extensors of the fingers was ascertained in one of two ways. One way consisted in passing a broad band over the extended fingers and attaching it at one end to a fixed point with a dynamometer interposed, and extending the fingers against this fixed point, while the finger of the observer was placed on the tendon of the extensor carpi radialis longior. The other method consisted in the person keeping the fingers extended, and by means of an assistant increasing the traction on the band in the direction opposed to that of extension until the tendon of the extensor carpi could be felt contracting. The latter was found to be the better method, as the wrist being stationary it was more easy to ensure that other movements should not be made which would prevent the tendon being felt. The observations of several trials in my own case gave different results according to the place where the resistance was applied. In the first place, if the resisting band were placed over the two terminal phalanges and traction were made at right angles to the long axis of the fingers against the extending action of the fingers, the tendon of the extensor carpi radialis was not felt until from 4—5 lbs. traction had been used; the same result was obtained when the wrist was actively extended from the position of slight flexion against a fixed point, and also provided that the terminal phalanges were kept fully extended it did not make any difference whether the resisting band was over the phalanges or over the metacarpal bones. In the second place, if the resisting band were placed over the proximal phalanges, and if the extension of the wrist were performed by the extensors of the metacarpo-phalangeal joints with the phalangeal joints passively flexed, the extensor carpi radialis tendon could be felt rather sooner, when the dynamometer showed 3 lbs. On the contrary, if the band were placed over the metacarpal bones with the three joints of the fingers passively flexed, the tendon could be felt at once when ¼ lb. or less of resistance to extension had been registered. Also, if the fingers were passively put into the position of extension, and while in that position of easy extension without using any active muscular exertion, if the band were put over the distal phalanges and active extension of the wrist were made against the resistance of the band, or active traction were made on the band, the tendon of the extensor carpi radialis would be felt when only the resistance of ½ to 1 lb. had been made. In this last case the extensores digitorum must be acting, or the fingers would flex from the traction made on them, and in fact their tendons could be seen. It therefore seems to be a matter of intention, so that if the intention or the predominant idea is to extend the fingers, and while so doing to secondarily extend the wrist, the extensores carpi will not assist until a certain amount of resistance (3—5 lbs.) has been encountered; whereas if the intention, as in the last case, is to extend the wrist the extensores carpi will contract at once, and if the resisting band be on the phalanges the extensors of the digits will assist to prevent them being flexed.

In determining the second question it might be thought that the flexores carpi would cease to contract as soon as the extensores carpi took up the work. But this was not found to be the case, and in some observations much more pressure was required, as much as 10 lbs. having to be applied before the tendons of the flexores carpi relaxed, and in some cases they did not relax at all. The time of relaxation of the flexors of the carpus is a much more difficult matter to determine, as in some trials they seemed to leave off contracting at once, while in others they were still contracting even with a pressure strong enough to overcome the resistance of the wrist. I think that the following is the explanation of this discrepancy:—If the fingers be vigorously extended to the full amount, or if they be quickly extended, the flexors of the wrist are felt to contract synergically, and if in this condition pressure be made against extension of the wrist according to the method just described, either with the band on the phalanges or the metacarpals, the flexors of the wrist will not relax; but if the extension of the fingers be made very slowly and not to the full degree, the flexors of the wrist will hardly be felt to contract, or very slightly, and in that condition very little pressure against the extension of the wrist suffices to relax them altogether. It therefore appears that, as in the case of the extensores carpi mentioned above, so here, if the predominant idea is extension of the fingers, then the flexors of the wrist contract and remain contracted, even if this combination be required to take part in the superadded movement of extension of the wrist; whereas if the movement of extension of the fingers be not made to the full extent, and the superadded movement of extension of the wrist become the predominant idea, or if the wrist be extended with the resisting band against the phalanges while they are in a condition of passive extension, the flexors of the wrist will cease acting as soon as pressure is applied to the dorsum of the first phalanges, although the extensor communis digitorum is taking part in the movement and its tendons can be seen to stand out.

I think that these experiments show that if the movement of extending the wrist be performed with the fingers actively and fully extended, the extensors of the fingers have to do all the work themselves and against the contraction of the flexores carpi until the amount of work done amounts, as in my own case, to 4—5 lbs. before the extensores carpi will join in and help them.

§ 21. Now to apply this to what we find in lead paralysis. In paralysis of the extensores digitorum due to lead, if the movement of extending the wrist be started by that of attempting to extend the fingers, the two terminal phalanges are extended by the interossei, but the extensores digitorum being paralysed cannot move at all, and so cannot possibly reach the amount of 3 lbs., which, as we have seen, it is required for them to attain before the extensores carpi will come in and help them. The important point is that the patient has apparently no power to make the extensors of the carpus contract and the only resulting movement is flexion of the wrist due to the synergic action of the flexores carpi (Fig. 2). It rather reminds one of some highly organized establishments where if one of the servants are incapacitated it is no one's place to do the work, which is consequently left undone.

§ 22. Following on the results obtained from examining the action taken by the extensors of the fingers in extending the wrist, I have examined the movement of flexion of the wrist to see the part taken in that movement by the flexors of the thumb and fingers.

I have already mentioned that the flexors of the fingers take part in the flexion of the wrist. With regard to the relation of the flexores digitorum to the flexores carpi I was unable to find that there was the same delay in the action of the flexors of the carpus when the movement of flexion of the wrist was started by the flexores digitorum as was found in the case of the extensors of the carpus. In employing the same method with the resisting band acting at right angles to the palm of the hand against the direction of flexion, it was found that, when the band was over the phalanges, the palmaris longus tendon was felt when as little as $\frac{1}{2}$ lb. traction was made, and the flexores carpi radialis et ulnaris when $\frac{3}{4}$ lb. traction was made. Also that the figures were the same whether the resisting band was placed over the phalanges or over the metacarpal bones. I was therefore unable to find that, when flexion of the wrist is performed by the flexores digitorum, a certain strain has to be experienced before the flexores carpi will take part, as they act at once.

It is also to be noted that when the flexores digitorum act as flexors of the wrist the synergic action of the extensores carpi does not occur.

§ 23. When however we cause the fingers and thumb to contract powerfully as in grasping, and while this is occurring we flex the wrist, we get an entirely different condition.

Here we have taking part in the movement of grasping, the flexors of the thumb and fingers and also the synergic action of the extensors of the wrist, and the question is what will happen if we now flex the wrist? Will this movement be done by the flexors of the fingers, or will the flexors of the wrist come and help, and lastly will the extensors of the wrist relax? It will be observed that if the movement of flexion of the wrist be attempted while a strong grasp is maintained, and also if the flexion of the wrist be made slowly, there is a considerable feeling of strain and a certain amount of tremor due to the antagonism between the acting muscles.

To determine the three above-mentioned points the following method was used :

(1) It was first necessary to ensure that the grasp of the hand was being maintained throughout the observation, and this was done by means of a dynamometer which was grasped in the hand and the index of which could be watched, for it was found that in flexing the wrist against resistance, as soon as the grasp was relaxed, the flexors of the wrist immediately contracted even in the slightest degree of flexion, and as I have already mentioned, the whole experiment depended on the grasp being maintained.

(2) The forearm was fixed in the position midway between supination and pronation and a band was passed round the metacarpal bones, and either traction was made horizontally in the direction opposed to flexion of the wrist or flexion was made by the wrist against a fixed point; a spring balance was attached to the band, and the amount of traction was read off at which the tendons of the flexors of the wrist were felt contracting, and also the amount of traction required to make the tendon of the extensor carpi radialis relax.

In my own case I found that when the resistance was slight, flexion of the wrist was performed by the flexores digitorum only, and the tendon of the palmaris longus could not be felt until the balance measured 3 lbs., whereas the tendons of the flexores carpi radialis and ulnaris were not felt till from 5 to 6 lbs. traction was made; further the tendon of the extensor carpi radialis did not relax till as much as from 14 to 16 lbs. traction had been made.

The strained feeling would therefore be due to the antagonism between the extensors of the wrist and the flexors of the wrist.

§ 24. These experiments would seem to show that the association between the extensores digitorum and flexores carpi, and also between the flexores digitorum and extensores carpi is so strong that the muscles, which flex and extend the wrist, will oppose each other rather than give up their connection with the finger muscles, in the movements where the wrist is being extended in conjunction with extending the fingers, or flexed in conjunction with flexing the fingers and thumb.

§ 25. While discussing the question of the action of the extensors of the wrist with the flexors of the fingers it will be advisable to say a few words about the nature of this combination.

Duchenne called attention to the definite association between the flexors of the fingers and the extensors of the wrist as well as to that between the extensors of the fingers and flexors of the wrist, and that between the extensor ossis metacarpi pollicis and the extensor carpi ulnaris.* He spoke of the "moderating synergy" and he stated "that the synergic contraction of the flexors of the hand on the forearm is inseparable from the muscular function which ought to produce voluntary extension of the first digital phalanges. To place the common and special extensors of the fingers in the greatest elongation in order to augment their dynamical power: such is the useful end of this instinctive combination of the flexors of the hand during extension of the fingers." He referred to the over-extension of the wrist which occurs in extending the fingers when the flexors of the wrist are paralysed, and the explanation which he gave was that "the common extensors of the fingers being up to a certain point at the same time extensors of the hand on the arm, their contraction renders necessary the moderating synergy of the flexors of the wrist."

One of the earliest mentions that I can find about a muscle passing over two or more joints is that of William Cowper,† who in his 'Anatomy' reproduces Bidloo's splendid anatomical plates. He gives various reasons why a muscle passes over two joints, but he does not mention that other muscles are brought into the movement. John Hunter,‡ in his second Croonian Lecture delivered before the Royal Society in 1777, was as far as I can ascertain the first to enunciate the doctrine of synergic muscles. He says: "Muscles often go over two, three, or four joints and only move the third and fourth, as the flexors of the last joints of the fingers; but to prevent the first and second joints being moved by this action, the extensors of the intermediate joints are obliged to interfere and keep them from bending." This I consider is really the use of these synergic muscles, and although the result of the action of the flexors of the wrist is to place the extensors of the fingers in the greatest elongation so as to augment their dynamical

* *Loc. cit.*, p. 161, § 169. † 'Myotonia Reformata,' 1724.

‡ *Loc. cit.*, p. 238.

power (and to such a degree that when the wrist is flexed to a right angle the grasp in a normal person is about one half of what it is when the hand is in a line with the forearm), yet that, I think, is not their object. For if the wrist be extended passively as far as it will go with the fingers flexed, and if then the fingers be actively extended, the flexores carpi will still be felt to contract, without however remedying the position of the wrist-joint, even though the extensors of the fingers are working at a great disadvantage. If the function of the flexors of the carpus was to put the extensors of the fingers in the most advantageous position, they would flex the wrist and bring the hand into the position in a line with the forearm. Their function appears to be to fix the wrist in whatever position it happens to be, so that the fingers will have a secure basis to work upon.

§ 26. Following the opinion expressed above by John Hunter I think that the condition may be stated thus: *When a muscle by passing over two or more joints has two or more different actions, then, if only one of these actions be required, other muscles are brought into the movement whose actions are antagonistic to those of the muscles which are not required.* In the above quoted movement of extending the fingers the extensors of the digits, by passing over the wrist, are extensors of the wrist as well as extensors of the fingers, and as extension of the wrist is not required the antagonists to this action, viz. the flexors of the wrist, are brought into the movement and the resultant movement is extension of the fingers without extension of the wrist. This rule applies, as far as I have been able to observe, throughout the muscular system. These muscles which are brought into a movement to neutralise an action which is not required are called " synergic muscles," a term used by Duchenne.

LECTURE II.

Movements of the Radio-Ulnar Articulations.

Mr. President and Gentlemen—The next movements that we have to consider are those of the radio-ulnar articulations, pronation and supination.

§ 1. The muscles producing *pronation* are the pronator teres and pronator quadratus, and if the resistance to the movement be applied to the hand, as it usually is, the flexor carpi radialis and palmaris longus contract. The pronator quadratus cannot be felt contracting, but it is one of the muscles whose action must be inferred from its position.

Supination is performed by the supinator brevis, biceps, and when the resistance is applied to the hand, by the extensor carpi radialis longior and brevior and by the extensor carpi ulnaris. The strongest supinator is the biceps, and its action as such was described by Winslow.*

In the above list I have omitted the supinator longus or, as it is now called, the brachio-radialis. This muscle has had a very chequered career at the hands of anatomists. According to Winslow, it "was believed to be only concerned with supination till Mr. Heister observed that it was a flexor of the elbow-joint," and he adds, "before it can act as a supinator the hand must be in the greatest degree of pronation, and even then it can do little more than bring the radius back to its natural position." According to Duchenne† the supinator longus flexes and pronates the forearm, if it is previously completely supinated, into the mid position between pronation and supination, and its denomination of long supinator is inexact since the muscle exercises a contrary action. In the anatomical

* 'An Anatomical Exposition of the Structure of the Human Body,' by James Benignus Winslow. Translated from the French original by G. Douglas, M.D. Fourth edition, corrected, 1756. Vol. i, sect. iii, No. 888.

† *Loc. cit.*, p. 142.

text-books at the present time the teaching is that the supinator longus pronates when the forearm is fully supinated, and supinates when the forearm is fully pronated. In the midst of so much conflicting evidence it seems to me that the only way to settle the question is to go direct to Nature and examine what takes place in the living body. Ten years ago I published in 'Brain' * an observation on this muscle, and came to the conclusion that while it took an active part in flexing the forearm, no action in it could be discerned in the movement of pronation or supination. This is a point which anyone can prove for himself by supinating or pronating the forearm against resistance, taking care that no flexion of the forearm occurs. I think it will be found that no contraction of the supinator longus will be seen either on pronation or supination, but the moment that the slightest flexion is made the muscle instantly stands out in strong outline. I therefore conclude that the supinator longus, or the brachio-radialis as it would be better to call it, does not take part in supination or in pronation.

§ 2. It is interesting to note that Duchenne † according to his electrical observations considered "that the biceps could not be put isolatedly into contraction without producing supination at the same time as flexion of the elbow," and he cites a case where a person had lost the brachialis anticus, supinatores longus et brevis, and the pronators, but not the biceps, with the result that he "could not flex the forearm without supination, owing to the atrophy of the pronators," and from this he argues that we must conclude "that the biceps only supinates during flexion of the forearm," and he considers that it ought to be called the flexor supinator. He also seems to hold the opinion from this, that simple supination is performed by the supinator brevis and simple pronation by the pronatores teres and quadratus, whereas the biceps only takes part in flexion supination and the supinator longus in flexion pronation.‡ But what are the facts of the case? No doubt the biceps is a flexor as well as a supinator, and yet if one examines one's own biceps when the forearm is being supinated against resistance without flexion of the elbow,—and this is a movement which everyone can perform,—the biceps is found to be vigorously contracting, and it certainly can act without producing flexion of the elbow. The question therefore arises: Why does not the elbow flex in supinating the forearm when the biceps is contracting

* "On Some Points in the Action of Muscles," 'Brain,' vol. xiv, p. 53.

† *Loc. cit.*, § § 146, 147. ‡ *Loc. cit.*, p. 142.

so strongly? There must be some opposing force to prevent flexion. We have here in fact an example of a muscle, the biceps, having two actions, supination and flexion, of which the latter flexion is not required, and therefore, according to the rule given in the last lecture, the antagonist to this flexor action must be brought into the movement. The antagonists to the flexors of the elbow are the extensors of the elbow. In other words, it is not possible to have strong pure supination without contraction of the triceps. If, however, while supinating it be required to flex the elbow, the triceps at once ceases to contract. Further, if the triceps be paralysed the patient cannot supinate without flexing his elbow, because the flexor action of the biceps is not neutralized; on the other hand, if the biceps be partially paralysed and weaker than the triceps the elbow is extended during strong supination, just as the wrist is overextended in grasping when the flexors of the fingers are weak. It is also to be noted that in moderate supination apparently it is not the whole triceps which takes part in this movement, for of the three heads by which the triceps arises, the fibres of the outer and inner head contract, but not those of the long head arising from the scapula, unless the supination is very strong when the long head contracts. The reason for this is evident when we consider, as we shall see later, that the long head of the triceps is an adductor of the humerus. Now the only counteraction required in this movement of slight supination is extension of the forearm, but when the movement becomes extreme the pectoralis major contracts with adduction of the humerus, and then the part of the triceps which performs this movement of adduction contracts.

To demonstrate the action of the biceps and triceps in pure supination without flexion of the elbow I have used the following apparatus. It consists of a spiral spring, such as is used for closing doors, one end of which is fixed to the table, and to the other end a handle is attached at right angles to the long axis of the spring. By this means supination of the forearm can be made against the resistance of the coil of the spring, and the elbow being free to move, it can be seen that the movement of supination can take place without producing any flexion of the elbow, and that in this movement the biceps and triceps both contract, and that therefore the biceps can take part in supination of the forearm without necessarily producing flexion of the elbow.

§ 3. As we shall see later on the pronator radii teres is also considered to be a flexor of the forearm on the arm as well as a pronator—though Winslow * states that it can have no action but pronation—and to neutralise its flexor action there is also contraction of the triceps, but to a much less degree than in the case of supination in proportion as the flexor action of the pronator teres is much less than that of the biceps.

Movements of the Elbow-Joint.

§ 4. The movements are flexion and extension; the muscles which take part in *flexion* are the biceps, brachialis anticus, brachio-radialis, pronator radii teres; and when the hand is closed there is very slight action in the flexores carpi but none in the extensores carpi. In the above list the brachialis anticus is certainly a pure flexor of the elbow, and as the brachio-radialis does not, according to my observations, take part in the movements of supination, I look upon it as a pure flexor. We have, therefore, the pronator radii teres acting as a flexor pronator and the biceps as a flexor supinator.

With regard to the part taken by the different muscles in flexing the elbow in the different positions of the forearm I have found that when the elbow is at a right angle and the forearm is in the position of extreme supination or in the midway position, the tendon of the biceps can be felt to tighten when flexion of the elbow has to overcome only $\frac{1}{4}$ lb. (about 100 grammes), whereas in the position of extreme pronation the tendon of the biceps does not tighten till a resistance of 4 lbs. (1·8 kil.) has to be overcome. In the position of supination when the elbow is at a right angle the brachio-radialis (supinator longus) just becomes visible when the resistance to flexion is 2 lbs., but it is difficult to say whether it may not have started acting before it contracts sufficiently to lift up the skin. From this it would appear that in moderate flexion of the elbow when the forearm is in the position of pronation the biceps does not act.

Now flexion of the forearm can be performed when it is in the position of extreme pronation, or supination, or in any position intermediate between these two, so that the muscles which pronate and supinate the forearm at the same time that they flex, must be in equilibrium; but the opposing muscles are the pronator radii teres as pronator, and the biceps as supinator—muscles so different and unequal in strength that it does not seem possible that the

* *Loc. cit.*, No. 889.

former can balance the biceps when the forearm is midway between supination and pronation. I can only suggest, though I have not yet come across a case of isolated paralysis of the pronator quadratus, that this muscle may assist the pronator teres in neutralising the supinator action of the biceps in flexion of the elbow in the midway position of the forearm and in strong flexion in the pronated position.

§ 5. The association of flexion or extension of the elbow with pronation or supination produces some interesting combinations. For instance, if while flexing the elbow the forearm be supinated, the pronator radii teres, which was acting as a flexor of the elbow, ceases to contract as soon as the movement of supination is performed, but on the other hand the biceps does not cease acting in strongly flexing the elbow and pronating the forearm at the same time. Now what will be the action of the biceps, if during supination the forearm be extended? Will it continue to act by virtue of its position as a supinator, or will it cease when the movement of extension, to which the biceps action of flexion is an antagonist, is superadded? The answer is that the biceps contracts during the combined movements of extension of the elbow and supination of the forearm, and therefore the action of the extensors of the elbow must be stronger than the flexor action of the biceps, otherwise there would be no extension.

§ 6. What part do the flexors and extensors of the carpus take in the movements of the elbow? According to Duchenne* the flexors of the wrist are auxiliaries to the flexors of the elbow, and when these are weak the flexors of the wrist are put on the stretch by extending the wrist and can then assist to flex the elbow. My experience is that the action of the flexors and extensors of the carpus is exceedingly slight as flexors of the elbow. In cases which I have seen, where the brachio-radialis was absent and the biceps was very feeble, the patients in flexing the elbow first pronated the forearm, the extensors of the wrist then contracted, hyper-extending the wrist, and finally the elbow very slowly flexed. It was difficult in these cases to say whether the flexion was performed by the pronator teres and flexores carpi, or by the pronator teres and the extensores carpi. William Cowper† expressed the opinion that the flexors of the carpus when they act together as they do when they bend the wrist, destroy each other's action on the elbow and have little or no effect on it.

* *Loc. cit.*, § 167. † *Loc. cit.*, p. xxvii.

§ 7. To ascertain the share of work taken by the flexors and extensors of the carpus in flexing the elbow, I have tested the amount of work done by flexion of the elbow when the flexors of the wrist took part in the movement and when they did not. The trial was made first with the resisting band over the hand just above the heads of the metacarpal bones, so as to include the carpal muscles, and on flexing the elbow the maximum amount of work was found to be about 40 lbs., whereas on placing the band over the lower end of the radius and ulna and flexing the elbow when the wrist was lax, the amount went up to 50—54 lbs., so that there was apparently more force without the action of the carpal muscles. This increase is due to the shortening of the arm of the lever of the third power by transferring the weight from the hand to the lower end of the forearm. To obviate this the resistance band was applied to the lower end of the forearm and the elbow was flexed with (*a*) the fist clenched and (*b*) with the wrist lax. In several observations identical figures were given in the two cases: in one observation when the wrist muscles were used the force was 2 lbs. more. The proportion of 2 in 50 is so small that the power of flexing the elbow by the muscles of the carpus is proportionally very slight, and is almost a negligible quantity. The extensores carpi also contract probably to fix the wrist. The effect of shortening the arm of the lever is very well shown by putting the resisting band in the middle of the forearm when the amount of work done goes up to 70 or 80 lbs. as against 50 lbs. when the band is over the lower end of the radius, and it is well exemplified by a person who, when carrying a heavy basket by the handle on the bent arm, puts the handle as near to the elbow as possible.

§ 8. The extensor carpi radialis longior, which arises from the lower third of the outer condyloid ridge of the humerus, has been considered to be a flexor of the elbow-joint, but when the wrist is lax I cannot find that there is any contraction of this muscle when strong flexion of the elbow with the forearm pronated is made against resistance.

§ 9. To determine the question of the relative strength of the flexors of the elbow in the various positions of supination and pronation of the forearm I have taken the maximum in myself when the forearm was completely pronated, when it was completely supinated, and also when in the mid-position between the two. When fully pronated the amount was 40 lbs., and in the other two 42 lbs., so that, as before said, in the position of pronation the supinating action of the biceps must be neutralised, as the flexor force is nearly the same in all three positions.

§ 10. *Extension of the elbow* is performed by the triceps and anconeus, and I am unable to find that the extensors of the wrist or fingers take any part in the movement.

Movements of the Shoulder.

§ 11. The movements of the humerus on the scapula are so involved with the movements of the scapula itself that it will be more convenient to take them together and afterwards those movements of the scapula which are performed without the participation of the humerus. The movements of the humerus are best described in terms of the planes corresponding to the three dimensions of space, viz., antero-posterior, latero-vertical, horizontal. In the antero-posterior plane, the humerus starting from the hanging position is advanced forwards—flexed as it is also called—to the horizontal line, and thence it is elevated to the vertical position ; on the return journey the humerus is depressed through 180° to the hanging position, and thence it can be carried backwards or retracted. In the lateral plane the hanging humerus can be abducted to the horizontal line, and thence elevated to the vertical position, and on the return journey it is adducted through 180° to the hanging position. In the horizontal plane the humerus is horizontally adducted when it is moved from the lateral plane towards the middle line and horizontally abducted when away from the middle line to the lateral plane, behind which it is horizontally retracted. Besides the above movements there is rotation in and out.

§ 12. In *advancing the humerus* the anterior fibres of the deltoid, the clavicular fibres of the pectoralis major, the biceps, and probably the coraco-brachialis contract and carry the humerus forward, nearly to the horizontal line. This action of the deltoid tends to rotate the scapula with the acromion downwards, and to push its inferior angle backwards and towards the spinal column, but this is prevented by the contraction of the acromial fibres of the trapezius —which Duchenne showed to be the fibres taking part in this movement and not the clavicular fibres—and it is also prevented by the contraction of the inferior fibres of the trapezius. As shown by Duchenne the deltoid and the other muscles cannot carry the humerus further than the horizontal line. Beyond this point the serratus magnus comes to their assistance and draws the lower end of the scapula forwards, raises the acromion with the humerus, and thus the arm is elevated to the vertical position.

Now the serratus magnus is considered to fix the lower end of the scapula at the beginning of this movement of advancing the humerus, but I have seen cases in the last few years which seem to negative this idea. The first case which drew my attention to this point was that of a girl whom I showed at the Neurological Society in 1898, and who had wasting of the lower part of the trapezius below a line drawn horizontally from the spine of the scapula to the vertebral column. The rest of the trapezius acted well, and the serratus magnus was not affected, a point which was well shown by the patient being able to push forward with the advanced arm against resistance. On telling the patient to advance the arm slowly I observed that the first action on the scapula was to rotate it so that the inferior angle moved half an inch towards the vertebral column and the posterior border of the scapula projected like a wing; this projection reached its maximum when the humerus was advanced through about 45°. Then the serratus magnus contracted, and as it drew the lower end of the scapula forwards the deformity diminished and finally disappeared. The explanation that I would offer for this occurrence, which does not happen with normal muscles, is that though the serratus magnus is mechanically in the position to fix the scapula and prevent its lower angle being pushed backwards and rotated towards the vertebral column, it is not its function when the movement is one of advancing the shoulder, to act on the scapula until the humerus has been moved by the deltoid through about 45°. The inferior part of the trapezius apparently is the proper muscle to fix the scapula in advancing the humerus, and when these inferior fibres are paralysed the serratus will not step into the breach—so to say—and do the work for the trapezius, which consequently is not done at all. I think that this is another instance of what I described in the previous lecture (p. 13) in the case of paralysis of the extensors of the fingers due to lead poisoning, where the extensors of the wrist were unable to help the extensors of the fingers until the latter have experienced a certain degree of resistance. I consider that in a movement such as advancing of the humerus certain muscles are told off to come into action at a certain period of the movement and not before.

§ 13. The description just given of advancing the humerus applies equally well to the movement of *abducting the humerus* with the exception that the middle part of the deltoid and the supra-spinatus abduct the humerus and the pectoralis major does not act, but the same condition is met with in regard to the movements of the scapula and its relation to the trapezius and serratus as in advancing the humerus. In paralysis of the trapezius the inferior angle of the scapula in the first part of the movement of abduction moves more towards the spine, and does not project so much backwards as in the movement of advancing the humerus.

§ 14. This is well shown in the photograph (Fig. 3) which I give here of a case under the care of my colleague, Dr. Ormerod, with paralysis of the lower fibres of the right trapezius and also with some weakness of the right serratus magnus, but not enough to prevent it acting. I have marked on the skin the situation of the posterior border of the scapula in the three positions of abducting the humerus. The centre line on the right side (I) denotes the position of the posterior scapular border with the humerus hanging at rest; the line next to the spinal column (II) shows the amount of movement of the scapula towards the middle line when the humerus is actively abducted through 30°; and the outer line (III) shows the position of the posterior border of the scapula when its inferior angle has been drawn forwards and outwards by the serratus in elevating the humerus to the vertical position. [The case was shown at the College.] On the left side, which was normal, the three positions occupied by the posterior border of the scapula, when the humerus was hanging vertically, when abducted through 30°, and when elevated to the vertical position, are shown in successive order from the spine outwards (Nos. I, II, and III). This case shows that while on the normal left side the posterior border of the scapula moves away from the spinal column as the arm is abducted to 30° and to above the horizontal line, on the paralysed side the posterior border of the scapula actually recedes towards the spine from position I to position II in abducting the arm through 30°, but after the arm has passed the horizontal line it occupies the position III, as on the normal side.

I have lately had the opportunity of examining a case under the care of my colleague, Dr. James Collier, where the whole trapezius had wasted and practically disappeared owing to a lesion of the spinal accessory nerve in the neck, with the result that when at rest the scapula was half an inch lower than on the other side, and the acromion was rotated downwards and forwards, so that while the base of the scapula spine was two inches further away, the inferior angle was only half an inch further away, from the vertebral column than on the other side. On making this patient abduct or advance the humerus it was seen that the inferior angle moved inwards or

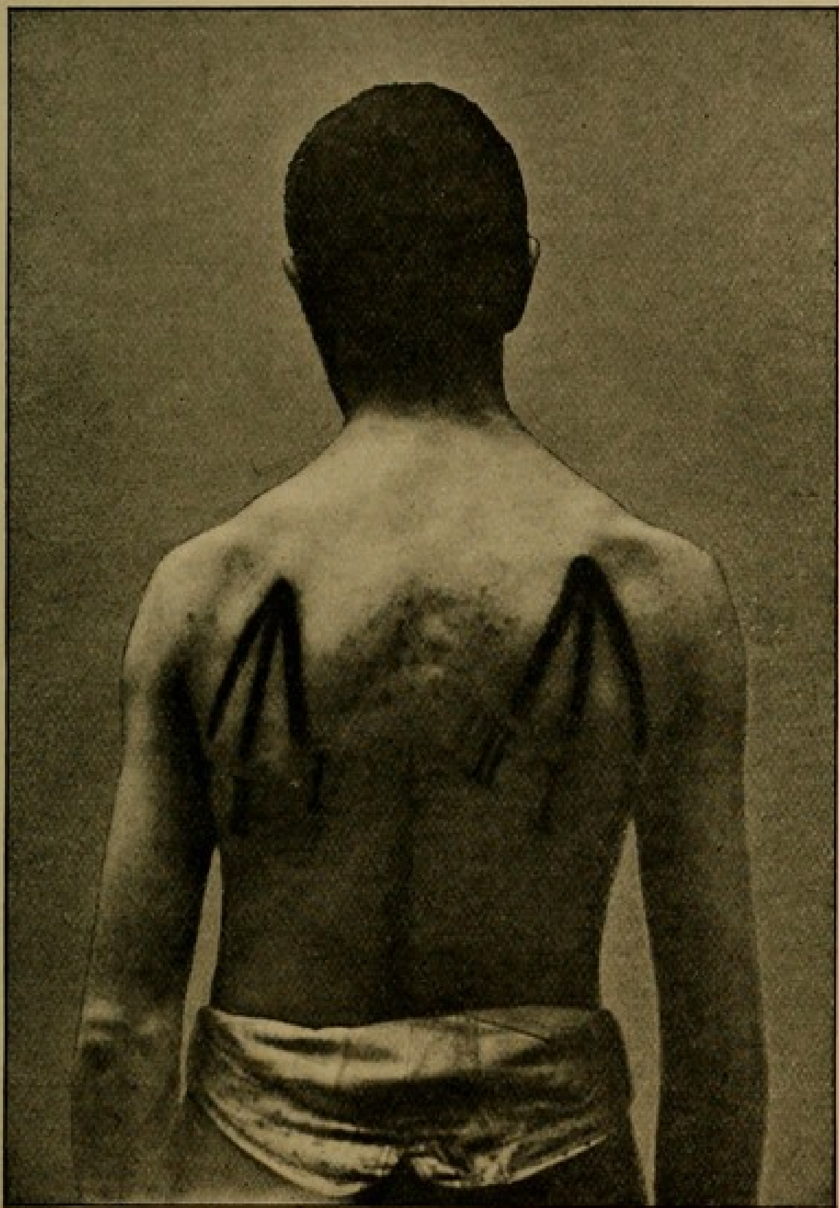


FIG. 3 is a photograph (taken by Dr. Howland) of a case of Dr. Ormerod's with paralysis of the lower fibres of right trapezius. The position of the posterior border of the scapula when the arm is hanging (I), when it is abducted through 30° (II), and when it is elevated vertically (III), is shown by the three marks and numbers on either side. On the left side (normal) the positions from the spine outwards are in the order of I, II, III; on the right (paralysed) side the positions are in the order of II, I, III.

backwards for half an inch, and that when the movement of the arm was resisted, for as much as an inch, until the humerus had moved through an angle of 45 , when the inferior angle of the scapula was drawn forwards by the serratus the deformity disappeared and the humerus was powerfully carried upwards to the vertical position. In this case, as the trapezius was the only muscle paralysed the deformity and backward movement of the scapula must have been due to its absence, and the only conclusion that we can draw is that although the serratus magnus is in the anatomical position of being able to act, and is generally supposed (see Duchenne, *loc. cit.*, p. 115) to fix the scapula, the Will has apparently no power to make it act before its appointed time, and take the place of the paralysed trapezius. Whether it would be possible to educate the serratus and by practice to induce it to contract sooner I am not in a position to state, but if the condition may be taken as the same as that of paralysis of the extensors of the fingers in lead paralysis I should think it doubtful.

[Since delivering these lectures Professor Thane has brought to my notice a work by S. Mollier * on the movements of the shoulder girdle, which I had not before seen. The author used a model, made from a cadaver in which the muscles were replaced by strings passing over fixed pulleys so that the direction of the muscle was preserved; these strings were put in motion by keys which could be depressed at will. By means of this model the author has made a most laborious and exhaustive series of experiments on the action of the individual muscles and parts of muscles in the movements of the shoulder girdle, and he has also compared his results with cases of paralysis in man. With regard to paralysis of the trapezius, though I cannot find any mention of the movement of the scapula towards the spine, the photographs which he gives, especially Figs. 53, 56, and 66 on the movement of advancing the arm in the sagittal direction, show very well on the paralysed side that when the arm is advanced the inferior angle of the scapula moves nearer to the spinal column than when at rest, and that when the arm is carried above the horizon to the vertical position, the inferior scapular angle passes outwards and forwards away from the spine, thus confirming the results given in my Fig. 3.]

§ 15. What determines the period at which the serratus begins to act, it is difficult to say, but it seems to have some relation to the angle which the humerus makes with the scapula, or to the degree of contraction of the deltoid, and the tension it produces on the scapula. Normally, in advancing the arm the scapula

* 'Ueber die Statik und Mechanik des menschlichen Schultergürtels unter normalen und pathologischen Verhältnissen von S. Mollier,' Jena, 1899.

hardly moves at all till the humerus makes an angle of about 45°, and then the inferior angle begins to move outwards by the commencing action of the serratus, and when the humerus is horizontal the angle with the scapula remains constant, and the elevation of the humerus to the vertical position is completed by the serratus; according to Cathcart * at the end of the movement the scapula ceases to rotate and the last part is performed by the humerus alone moving over the glenoid cavity. If, however, the deltoid be paralysed or the shoulder be ankylosed, the serratus begins to act at once and the scapula moves outwards at once; so much so that this movement of the scapula is almost a diagnostic sign of one of the two above conditions. Now it is quite easy to normally imitate this movement by rotating the inferior angle of the scapula forwards and the acromion upwards without first moving the humerus, but in neither of these conditions is the movement initiated by the action of the deltoid, and there is no tendency to the displacement of the inferior angle of the scapula backwards or towards the spine, as the first movement is now that of the scapula forwards and outwards.

§ 16. Another point of interest, occurring incidentally, is that the projection or winging of the scapula may be caused by paralysis of the trapezius and especially of its lower fibres, as well as by the well-known paralysis of the serratus magnus. The difference between the two conditions is, that the deformity due to the absence of the trapezius is less than that of the serratus, the scapula projecting only a half to one inch; that the projection reaches its maximum when the humerus is advanced through about 45°, after which the deformity diminishes and disappears when the humerus is horizontal; and that the humerus can be elevated to the vertical position. With paralysis of the serratus magnus, the deformity increases as the arm is advanced and reaches its maximum when the humerus is horizontal, beyond which level there is no muscular power to raise it. The diagnosis of paralysis of the serratus is also confirmed by the ease with which the scapula can be displaced backwards by pushing against the advanced arm, which is not the case with the trapezius paralysis.

§ 17. The action of the upper fibres of the pectoralis major in advancing the arm is important and was described by Winslow.† It is an action which does not appear in some people until the arm

* 'Journal of Anat. and Phys.,' vol. xvii, part 2.

† *Loc cit.*, No. 836.

is advanced to a point nearer to the middle line than the antero-posterior plane.

Advancing and abduction of the shoulder are also attended by contraction of the erectores spinæ, a subject which will be discussed when the muscles of the trunk are considered.

§ 18. *Depression of the humerus* in the antero-posterior plane from the vertical position above the head through 180° is performed by the sternal fibres of the pectoralis major, the latissimus dorsi, the teres major, the teres minor, the infra-spinatus, and by the long head of the triceps, and perhaps by the subscapularis, while the pectoralis minor fixes the scapula.

The superior or clavicular fibres of the pectoralis major are not from my observations depressors of the humerus, and I cannot agree with Duchenne* that these fibres are at the same time depressors and elevators of the humerus according to the position of the limb, *i. e.* depressors only from the vertical to the horizontal line, or that they are, as Duchenne gracefully describes, the agent used equally by the enemy to strike with a sword, or by the priest to bless the faithful. I cannot discover that the upper fibres contract at all in forcibly depressing the humerus in any position, and I was interested to find, what I was not aware of, that Winslow† states that the superior fibres serve chiefly to raise the arm forward. Duchenne's opinion was evidently founded on the fact that if the humerus be elevated vertically and the superior fibres be stimulated electrically, they will depress the humerus to the horizontal line, but according to my observations they do not contract voluntarily to depress the humerus, and although they are in the anatomical position to depress the humerus they are not included in the group of muscles told off to perform this movement.

Of the other muscles depressing the humerus I would refer to the long head of the triceps. Now as this muscle cannot contract without extending the elbow there is also, if only pure adduction be required, slight synergic action on the part of the biceps and brachio-radialis to neutralize the extensor action of the triceps. This action of the long head of the triceps is very well seen in cases, of which I have one under my care at the present time at the National Hospital, where the triceps is unaffected while the flexors of the elbow are paralysed. Here every time that the patient depresses or adducts the humerus against resistance the elbow is extended by the unopposed action of the long head of the triceps.

* *Loc cit.*, § 103. † *Loc cit.*, No. 836.

In the same way in advancing of the humerus when the biceps acts through its short head, to prevent flexion of the elbow which is not required, the triceps is felt in some cases, apparently not in all, to contract, but not the long head, presumably because its adductor action is not required.

§ 19. *Retraction of the hanging humerus* posteriorly to the vertical line is performed in addition to the latissimus dorsi and teres muscles by the posterior half of the deltoid. The pectoralis minor takes part in the movement, but not I believe the pectoralis major, so this movement is a means of separating the action of these two muscles.

§ 20. *Adduction of the humerus* is performed by the same muscles that take part in depressing the humerus, with the addition that both parts of the pectoralis major and also the posterior fibres of the deltoid act as adductors, as Winslow* pointed out. According to Duchenne† "Electrical experiment shows that the posterior third of the deltoid acts synergically with the other fibres of the same muscle to elevate the humerus, through an angle of 45°, but above this point the posterior fibres become depressors of the humerus, and antagonists to the other fibres down to that point of elevation which results from the contraction of the posterior bundle." "This," he says, "justifies the opinion of Bichat, ‡ contested by many anatomists, that the deltoid can be at the same time both an elevator and a depressor of the humerus." My observations would make me join the ranks of the contestors of this opinion, as I cannot find that the posterior fibres of the deltoid take any part in elevation or abduction of the humerus, and they are in my opinion adductors. On this question I would again like to point out that because a muscle can produce two opposite movements when stimulated by faradisation, we cannot be certain from this that this muscle performs these two opposite movements when acted on by the Will. We have first to prove that the muscle is actually contracting in each of these opposite conditions, for it does not follow that because a muscle is in the anatomical position to take part in a movement therefore it *must* do so.

§ 21. In both movements of depressing the humerus and adducting it, the scapula has to be fixed by the rhomboids and the lowest fibres of the trapezius, so that when the rhomboids are absent and the humerus is forcibly depressed or adducted, the inferior angle of

* *Loc cit.*, No. 825. † *Loc cit.*, § 66.

‡ 'Anatomie descriptive,' p. 226, Paris, 1846.

the scapula is drawn into the axilla by the teres muscles, as was first pointed out by Erb, and when the lowest fibres of the trapezius are absent the scapula is lifted upwards by the rhomboids and the teres muscles in performing the same movement. The contraction of the rhomboid is, however, stronger than that of the trapezius, and in some cases the latter appears not to act in adduction. Conversely, when the adductors are weak and the rhomboid is normal, it overacts and carries the inferior angle of the scapula to the spine in adducting the humerus.

The pectoralis minor also fixes the scapula in depressing the humerus, and when it is absent, as I have lately seen in a case, the scapula is elevated, and the coracoid process projects under the skin.

§ 22. In depression and in adduction of the humerus from the horizontal line there is contraction of the abdominal muscles, as was pointed out by Winslow,* and especially of the rectus abdominis and obliquus externus, which fix the ribs and prevent them from being drawn up by the pectoralis major. In depression of the humerus I have found that the recti of both sides act, but that of the same side rather sooner than that of the opposite side, while in adduction of the humerus the rectus of the same side only contracts, but in addition the erector spinæ of the same side also takes part. The question is whether the abdominal muscles are essential for the performance of the movements, or whether it is possible to perform them without co-operation of these muscles.

I have, therefore, ascertained the amount of work that is required to be done before the recti abdominis contract in the movement of depressing or adducting the upper limb from the horizontal line. I find that the amount is exceedingly small, and that in the erect position when the humerus was depressed with the arm in the horizontal position, the rectus abdominis of the same side could be felt to contract when the scale only registered 4 lbs., and as this includes the dead weight of the arm, which was found to be $2\frac{1}{2}$ lbs., the actual work done by the muscles was $1\frac{1}{2}$ lbs., and this small amount was sufficient to bring in the fixing action of the rectus abdominis. The rectus abdominis of the opposite side was felt, in depressing the humerus, to contract a little later, viz. when 6 lbs. pressure was registered on the scale. The smallness of this amount is further shown when compared with the maximum amount of force which can be produced by this movement. In my case it was 30 lbs., so

* *Loc. cit.*, No. 839.

that the earliest contraction of the rectus abdominis occurred when only about one fifteenth of the maximum strength had been used. It therefore occurs not at the end of a strong movement, but so early that the movement can hardly take place without it. As this action of the rectus takes place equally well in standing, sitting, or lying down, its participation is not necessary for maintaining a certain position, and therefore I think it must be included in the list of muscles which are essential for the movement of depression and adduction of the humerus.

§ 23. The movement of *horizontal adduction*, which takes place after the humerus has been passively abducted to the horizontal line and is then actively carried to the middle line, is performed by the anterior fibres of the deltoid, the coraco-brachialis, and by the pectoralis major, and where there is no resistance by the upper fibres only, but where an obstacle is to be overcome both parts of this muscle act.

§ 24. I would here say a few words about the pectoralis major, one of the most interesting muscles of the body. The pectoralis major is a muscle consisting of two parts, clavicular and costo-sternal, which can either act in unison or in antagonism. The best way to bring out the actions of the two parts working together is to passively advance the upper arm to the horizontal line and then to tell the patient to carry his arm towards the middle line against resistance. If while in that position he then raise his hand upwards against resistance the upper fibres alone contract, and if he depress his hand against resistance the lower fibres alone contract. In fact, as Winslow said, the pectoralis major may be looked upon as two distinct muscles, and I have published* cases of complete absence of the lower fibres due to infantile paralysis with perfect preservation of the upper fibres. Associated with the loss of the lower pectoral fibres there was complete paralysis of the latissimus dorsi and triceps.

§ 25. *In horizontal abduction* of the humerus from the middle line, the different fibres of the middle part of the deltoid successively come into action from before back until the posterior fibres act, together with the latissimus dorsi, teres muscles and subscapularis (?).

Associated with horizontal abduction of the humerus is the fixation of the scapula by the trapezius in which all but the clavicular and acromial (?) fibres take part. This is the best movement to bring out the middle part of the trapezius, which it is often very difficult

* 'Roy. Med.-Chir. Trans.,' 1885.

to make out. For this purpose the upper limb is put in the horizontal advanced position parallel to the middle line, and it is then passively pushed backwards so as to make the posterior edge of the scapula visible. If now the patient be directed to horizontally abduct the humerus against resistance, the fibres of the trapezius, and especially those inserted into the spine of the scapula, will be well seen against the sharp edge of the posterior border of the scapula, and they have a direction almost horizontal and not so oblique downwards and outwards as the fibres of the rhomboideus minor with which they might be confounded. In horizontal adduction the abdominal muscles act, and in horizontal abduction the erector spinæ of the same side.

§ 26. Of the rotators of the humerus, the *rotators in* are the pectoralis major both parts, deltoid anterior fibres, teres major, latissimus dorsi, and probably the subscapularis.

I have nothing to add to the muscles usually included as *rotators out*, viz. teres minor, infra-spinatus, and deltoid (posterior fibres), except to point out that in some cases, when the humerus is horizontal, in rotation in the rhomboid chiefly acts to fix the scapula, and in rotation out the lowest fibres of the trapezius perform this function. Consequently in paralysis of the trapezius of there is great displacement of the scapula in rotation out of the humerus, but not with rotation in.

§ 27. The scapula has also the movements which are independent of those of the humerus, viz. elevation, depression, advancing, retraction, and rotation with the acromion upwards, which has already been described.

§ 28. *Elevation* of the scapula is performed by the trapezius, and especially by the acromial fibres, while the clavicular do also contract in some patients, though apparently not in all, by the levator anguli scapulæ and the rhomboids. According to Duchenne* the inferior part of the serratus magnus is an elevator of the shoulder, as shown by electrical faradisation, for on being stimulated the serratus first rotates the scapula with the acromion upwards, and then elevates it. Nevertheless, Duchenne states (*loc. cit.*, § 45) that when he made a person elevate the shoulder and he applied strong resistance to its point he found that the trapezius, rhomboid, and the upper third of the pectoralis major alone contracted as long as the person kept his arm close to his side, but not the serratus magnus. Yet as soon as the patient raised his arm the

* *Loc. cit.*, p. 30, § 39.

muscle contracted at once. He explains that the reason why the serratus magnus does not act is "probably because its contraction would interfere with respiration in keeping elevated the ribs on which it takes its origin" (§ 46). I venture to think that the Will has not the power to leave a muscle out of a group if it is included in it, even if it interferes with respiration, and that the explanation is rather to be found in the fact that the serratus magnus is not an elevator of the shoulder, and also that the electrical results are not to be relied upon unless they are corroborated by voluntary movements. I also think that Duchenne is not distinguishing between the two different movements of (1) elevation of the acromion where the scapula is rotated by the serratus magnus, and (2) elevation of the whole scapula as in shrugging the shoulders where the serratus magnus does not act.

I have nothing special to remark about the other movements of the scapula, except that the levator anguli scapulæ in some cases takes part with the serratus magnus in advancing the scapula, and perhaps it counteracts the rotation of the scapula with the acromion upwards by the serratus magnus, unless the movement of advancing the scapula is performed by the upper fibres of the serratus and not at all by the lower fibres. The levator does not take part in the rotation of the scapula in advancing the humerus beyond the horizontal line.

MOVEMENTS OF THE SPINAL COLUMN.

§ 29. The chief movements of the lumbar spine are flexion and extension, lateral flexion to either side and rotation to either side.

§ 30. The *flexors of the spine* are best tested when the person is lying down. The chief of them are the recti abdominis with the pyramidales, and also the external obliques, but whether the internal obliques also take part I have had no means of ascertaining. In testing the action of the recti abdominis the person lies flat on his back and crosses the arms on the chest, and the thighs are then fixed by passive pressure. It is then often sufficient for the person to bend the head forwards for the recti to tighten up sufficiently to be felt. The complete movement of sitting up from the recumbent position consists of two stages ; in the first the ensiform cartilage is approximated to the pubes by the recti abdominis flexing the lumbar spine, and then the pelvis with the spine is flexed on the femora by the psoas and iliacus and the other flexor muscles of the hip.

§ 31. It is often important to know, especially in cases of tumour of the spinal cord, if any part of the recti abdominis are paralysed, as they are long muscles which are supplied from the sixth to the twelfth dorsal spinal roots. I observed some years back a symptom which enables the investigator to tell if there is any weakness of the upper or lower parts of the recti. This symptom is the movement of the umbilicus. In health, in the movement of sitting up the umbilicus does not alter its position, but, if from a lesion of the lower part of the spinal cord or its nerves, the part of the recti below the umbilicus be paralysed, the normal upper part of the recti will draw up the umbilicus, sometimes to the extent of an inch. As the abdominal wall at the level of the umbilicus is supplied by the tenth dorsal root, any marked elevation of the umbilicus in the act of sitting up would show a lesion between the tenth and twelfth dorsal segments of the cord, or the roots coming off from them. In the case where I first observed this symptom there was a malignant growth involving the cord at the level of the eleventh and twelfth dorsal roots. In two cases, one a myopathy and the other a case under the care of my colleague, Dr. Ormerod, I have seen the umbilicus drawn *downwards*, due, I have no doubt, to weakness of the part of the recti situated above the umbilicus.

In cases where the recti abdominis are completely paralysed, as in one case of myopathy which I have seen, the patient cannot approximate the ensiform cartilage to the pubes, and he has first to fix the spine by the erectores spinæ, and then to flex the pelvis on the femora and draw the spine with the abdomen convex forwards by the psoas and iliacus, and the flexor muscles of the hips.

§ 32. *The extensors of the spine* are the erectores spinæ, which can be well felt at their origin on either side of the lumbar spine, but whose divisions into ilio-costalis and longissimus dorsi I do not think that it is possible to make out. The action of these muscles can best be seen by making a person, while lying down prone on a bed, lift up the neck and the upper part of the trunk, when the muscles can be felt and seen on either side of the lumbar spinal column; or by making the patient extend the spine from the position of bending forwards either in the standing or sitting position.

In connection with the actions of the flexors and extensors of the lumbar spine are the muscular movements which regulate and maintain the erect posture.

§ 33. In the erect posture, *i. e.* standing with the feet together in the position of attention, the muscles have to be continually counteracting the influence of gravity, and although when work is being done, as in pushing forwards against an obstacle or as in keeping a door shut, the flexors of the spine act, yet when a person bends forwards from the erect position without having to overcome an obstacle, it is not the flexors of the spine which act but the extensors, and conversely in extending the spine, as in leaning backwards from the erect position, it is not the extensors of the spine which act, but the flexors.

This condition has been, I venture to submit, much overlooked in books of general anatomy, and also in special books on anatomy for artists. In the one by Marshall* I cannot find any allusion to this point. And in a recent similar work † the following passages occur:—"This bulging of the muscles on either side is particularly noticeable when these muscles (erectores spinæ) are in a powerful state of contraction as when a person . . . . is bending backwards." And again on page 121: "If the figure be bent backwards the median furrow is deepened and the erectores spinæ are rendered more prominent owing to the fact that they are now in a powerful state of contraction."

If in the above description the movement of bending backwards starts from the erect posture and is not made against resistance, I could not agree with it.

Merkel ‡ also states that in bending forwards without resistance the groove in the middle of the back disappears and vertebral spines become visible, and the back becomes smooth and round; in bending the body backwards the long back muscles become very tense and appear in the lumbar region as thick swellings. On bending to the side (presumably without resistance) the long back muscles of the bent side form a stronger projecting swelling than those on the stretched side.

On the other hand, according to W. Adams,§ "the muscles of the spine are in a state of least action when the spinal column is in the erect position. Instead therefore of the muscles of the spine in this position being in a state of active tension, it is more correct, he says, to describe them as in a state of vigilant repose; . . . as soon

* 'Anatomy for Artists.'

† 'Anatomy for Art Students,' by Prof. Arthur Thomson, 2nd edit., 1899, p. 37.

‡ 'Topographische Anatomie,' zweiter Band, 1896, p. 185.

§ 'Curvature of the Spine,' 2nd edit., p. 41.

as the equilibrium is disturbed and the body is inclined to one side the spinal muscles on the convexity of the curve are . . . put on the stretch."

Richer * also states that on bending forwards the extensors come into action and on bending backwards the flexors of the spine, so that the action is somewhat of a paradox.

But we must go further back to find similar opinions expressed by Winslow,† who stated that "the musculi recti serve to support the trunk of the body when inclined backwards . . . for when we stand straight they have no hand in bending the body forward, except we be striving to overcome some resistance."

I should certainly agree with the opinion expressed above by W. Adams that in the erect position there is a state of least action of the muscles.

From my own observations—and it is an experiment that any one can make by putting one hand on the erector spinæ and the other on the rectus abdominis—there is no action to be felt in the erectores spinæ or in the recti abdominis in the erect position when standing "at attention," but by producing a forward movement of the trunk, as by bending the head forward, so as to displace the centre of gravity, the erectores spinæ instantly contract and prevent the trunk moving further in the direction of flexion, while the flexors *i. e.* the recti abdominis, are relaxed. In the same way by extending the head backwards, the centre of gravity is displaced backwards and the recti abdominis contract and check any further movement in backward direction, while the erectores spinæ are relaxed. And, if it be desired to bend the trunk gradually forward, the contracted erectores would gradually relax and let out the weight of the trunk in the same way as a heavy weight is slowly lowered to the ground by a crane. In the erect position when neither the erectores spinæ nor the recti abdominis are acting, if it be desired to flex the spine and bend the body forwards without first moving the head, the flexors of the spine, *i. e.* the recti, would start the movement, but as soon as the centre of gravity was displaced in front of the base line the recti would cease acting—unless the movement was made against resistance—and the erectores spinæ would be the acting muscles.

§ 34. This action of these muscles can best be illustrated by the upper limb. If, when the upper limb is in the horizontal position, the forearm be slowly flexed on the upper arm in the vertical plane,

* 'Anatomie artistique,' 1890. † *Loc. cit.*, No. 126.

the flexors of the elbow contract until the forearm is just past the vertical line and comes under the influence of gravity, when they cease to act and become quite flaccid, while the triceps then contracts and lets the forearm gently flex on the upper arm. The actions of these muscles will be more readily understood if the same movement be attempted by a patient with paralysis of the triceps; in this case the first half of the movement is properly performed, but as soon as the forearm has passed the vertical position and comes under the influence of gravity the forearm falls on to the upper arm as there is no triceps to counteract gravity and let the forearm flex slowly on the upper arm. Conversely, if in the position of flexion the forearm be slowly extended the triceps contracts until just past the vertical line, when it ceases, and then the biceps and the other flexors contract and let the forearm be gradually extended. So that in flexing the bones of the forearm, through the vertical plane, on the humerus the first half of the movement against gravity is done by the flexors and the second half with gravity by the extensors.

§ 35. This mode of action applies to all the muscles of the body and it may be expressed thus:—In every slow unresisted movement which is made in the direction of gravity the muscles, which act in the direction of the movement are relaxed, while their antagonists contract and support the part, and if the movement be continued the latter gradually relax to their full extent.

The contraction of the erectores spinæ, when the body falls forward, occurs automatically and apparently without any effort of the Will, and it can be demonstrated by leaning forwards supporting the weight of the body on one hand. On suddenly taking the supporting hand away the body falls forward and the erectores spinæ instantly contract. The contraction is an instinctive preservative action performed automatically, and it always takes place unless a voluntary effort is made to inhibit the contraction, when it can be prevented from acting.

§ 36. In *lateral flexion* to one side where an obstacle has to be overcome, the rectus abdominis and erector spinæ of that side can be felt to contract together with the external oblique and latissimus dorsi, and probably the quadratus lumborum; but in inclining the trunk to one side—let us say the right—in the direction of gravity, where no obstacle has to be overcome, the muscles of that side start the movement, but as soon as the centre of gravity of the trunk is displaced to the right of the middle line, the muscles on the right side are relaxed and the muscles on the opposite (left) side—the antagonists—contract, just in the same manner as the erectores spinæ contract in flexing the spine forwards. In *rotation of the spine* to the right the left external oblique acts, but neither the erector spinæ nor the rectus abdominis can be felt to contract, but whether the internal oblique of the same side (right) contracts it is difficult to say.

§ 37. While speaking (on page 34) about the movements of advancing or abducting the humerus, it was stated that these movements were attended by the contraction of the erector spinæ. This is a point to which attention has been directed by Dr. Hughlings Jackson.*

When a person stands erect so that there is no contraction of the erectores spinæ, and then advances one upper limb to the horizontal line, both erectores spinæ contract, and if the advanced arm be slowly carried outwards through an angle of about 45° the erector spinæ on the same side as the advanced arm ceases to contract, and on the arm being carried through another 45° the rectus abdominis of the opposite side will be felt to take part in the movement.

The question arises, whether this contraction of the erectores spinæ is an essential part of the movement of advancing the shoulder, in the same way as the abdominal muscles take part in depressing or adducting the humerus, *i. e.* whether it is possible to advance the humerus without bringing the erectores spinæ muscles into action. I think the matter can be proved in the following way :—If when the arm is advanced and the erectores spinæ are felt contracting the spine be extended, the erectores will be felt to relax when the weight of the trunk behind the centre of gravity just balances the weight of the advanced arm in front, and if now the arm be dropped and then advanced again no fresh contraction of the erectores will be felt. I think that this shows that the contraction of the erectores is not an essential part of the movement of advancing the humerus, as it does not always occur, but is of the nature of a postural contraction, and only takes place to prevent the equilibrium of the trunk being disturbed.

§ 38. This point whether the erector spinæ muscle of say the left side is an essential component of the movement of abducting the right arm is interesting in relation to hemiplegia. In right hemiplegia where a patient has lost the power of abducting the

* 'Brit. Med. Journ.,' March 5th, 1892.

right arm the question arises as to whether he has any paralysis of the left erector spinæ which, as we have seen, acts when the right arm is abducted. If the action of the erector spinæ were an essential component of this movement of abducting the arm, one would expect that when this movement of the arm was paralysed all the components of this movement would also be paralysed, including this particular movement of the erector spinæ, but if the action of the erector spinæ were not an essential component, but only acted to preserve the equilibrium of the spine, then we should not expect it to be paralysed. I have not examined a sufficient number of cases to say from personal experience whether the left erector spinæ is paralysed or weakened in right hemiplegia, but Dr. Hughlings Jackson* has expressed the opinion that in some cases of hemiplegia the erector spinæ on the side opposite to the paralysis is weaker than on the other side, *i. e.* in right hemiplegia the left erector spinæ is the weaker, and that the muscle is probably supplied by the direct (ventral) pyramidal tract.

* 'Brit. Med. Journ.,' March 5th, 1892.

LECTURE III.

Mr. President and Gentlemen—I will now describe the

MOVEMENTS OF THE HEAD.

§ 1. With regard to the muscles which are usually given as flexors and extensors, adductors and rotators of the head, I would refer especially to the sterno-mastoids, which are the chief *flexors of the head.* These muscles can be seen strongly acting when a person is told to raise his head from the pillow while lying on his back, and when this is done powerfully the recti abdominis also contract to fix the sternum, an action which was pointed out by Winslow.* These two sets of muscles are associated together in certain rhythmical spasmodic contractions, as in a case which was under my care lately, where a man had clonic spasm of both recti abdominis and also in both sterno-mastoids. In addition to the sterno-mastoids, the platysma myoides, the omo-hyoids, and the other depressors of the hyoid bone act. (I might add in passing, that the depressors of the hyoid bone and the muscles between the hyoid bone and the lower jaw are well brought out when the lower jaw is opened against resistance.)

§ 2. With reference to *extension of the head,* the only muscles which can be felt to contract are the clavicular part of the trapezii, the complexi and splenii capitis, and probably the trachelo-mastoids also take part. The sterno-mastoids have been described as extensors of the head when the head is in the extreme position of extension, and this is still taught in the most recent books on anatomy.

Duchenne † also stated as the result of electrical stimulation that

* *Loc. cit.*, No. 1069, p. 320.

† *Loc. cit.*, p. 715.

the sterno-mastoids "produce on the contrary extension of the head when it happens to be in a certain degree of reversal backwards." With this opinion I find that I cannot agree. Some time ago I made some observations on this point, and I failed to find that the sterno-mastoids acted in any position as extensors of the head. To test this, let the head be placed as far back in extension as it will go, and then direct the person to press the head backwards against resistance. The tendons of the sterno-mastoids will then not be felt to tighten, but if on the contrary flexion of the head forwards be made in that position against resistance, the tendons immediately become tense. I was therefore glad to find that Winslow* had made this statement, of which I was not aware at the time: "The insertions of these muscles," he says, "in the posterior part of the mastoid apophyses has made some anatomists believe that they are more proper to bend the head backward than forward; their insertions being behind the condyloid articulation of the os occipitis," but in opposition to this view he adds that "the moveable point [of the insertions] can only be determined to that part which is nearest the fleshy body, and the most anterior; and consequently not situated so far back as is imagined." And on the same subject he remarks, "that experiments made on dead bodies have been apt to mislead," an opinion which I should wish to endorse.

§ 3. With regard to *rotation of the head*, say with the face turning to the right, I have nothing much to add to the usually received teaching, except to remark that the left sterno-mastoid and the clavicular fibres of the left trapezius act with the right splenius capitis and the right platysma; the right omo-hyoid also contracts, and its use is probably to ensure that the hyoid bone moves round with the chin.

[Subsequently to delivering this lecture, I have noticed that on slowly rotating the head without encountering any resistance, the sterno-mastoid cannot be felt to act throughout the whole movement. For instance, if the head be passively put in the extreme position of rotation with the face to the left, and if it then be voluntarily rotated slowly to the right, no contraction of the left sterno-mastoid will be felt in the passage of the head to the front position. Further, if the head be slowly rotated from the front position to the right, no action of the left sterno-mastoid will be felt until the head has rotated through about 30°, and from this point to that of

* *Loc. cit.*, No. 1075, p. 320.

extreme rotation to the right the left sterno-mastoid will be felt to be strongly contracting. It is also to be noted that when the head is rotated to the full extent with the face to the right, if it be desired that the head should be left in that position, the left sterno-mastoid does not relax, which seems to show that the head would not remain in that position if it were not kept there by the action of the sterno-mastoid. In movements of rotation which are opposed, and in rapid unopposed movements, the left sterno-mastoid acts in all positions of the movement from extreme left to right.]

§ 4. In *lateral movement of the head* or adduction, say towards the left shoulder, the left sterno-mastoid, the left trapezius, the left splenius capitis, the left omo-hyoid and the left platysma all act together. It has been observed that in rotation of the head the sternal fibres of the sterno-mastoid chiefly act, and in adduction of the head the clavicular fibres, but though this is generally true I have seen both parts of the muscle act in both these movements.

The adductors or lateral flexors of the cervical spine, viz. the levator anguli scapulæ and scalenus medius, take part in powerful lateral movement of the head.

§ 5. It should be remarked that in all slow movements of the head in the direction of gravity, as in the movements of the spine (p. 42), the direct acting muscles are relaxed as soon as the head comes under the influence of gravity, and the antagonists contract and let the head fall gradually forwards or backwards or to one side. So that in the erect position in bending the head forward, as in nodding, if the centre of gravity of the head be behind the condyles the sterno-mastoids contract to transfer the weight of the head to the front of the condyles, and when this is accomplished they become quite inactive, and the extensors of the head contract and let the head fall gradually forwards.

THE RESPIRATORY MUSCLES.

§ 6. I have no special observation to make on the ordinary muscles, but as regards the extraordinary muscles of respiration I have observed in several cases of dyspnœa that among the first muscles to come into action are the sterno-mastoids, and as these muscles then take their fixed point from the skull, the head has to be fixed by the extensors of the head. Of the other muscles I have never seen any action of the pectoralis major in dyspnœa, and I think that the action which is attributed to this muscle is really performed by the pectoralis minor. This muscle could be seen acting as an inspiratory muscle in the cases which I have observed, where the pectoralis major was absent. The origin of the pectoralis major from the cartilages of the ribs and the direction of its fibres is also against its having much power as an inspiratory muscle, and it does not come into action till at the end of a forced inspiration. Of the other extraordinary muscles the latissimus dorsi, the serratus magnus, the scaleni—though the actions of these muscles were doubted by Winslow—the elevator anguli scapulæ, and the claviculo-occipital fibres of the trapezius are the chief ones that can be observed. The latissimus contracts chiefly in strong inspiration, such as sniffing.

§ 7. With reference to the expiratory muscles and especially those used in such violent efforts as coughing and sneezing, I would refer to one of the muscles which is usually described as a muscle of inspiration only, the latissimus dorsi. I observed a few years back that it is a powerful expiratory muscle, and this is an action which anyone can prove for himself by putting the hand on the posterior fold of the axilla, and on coughing, a strong contraction of the latissimus dorsi will be felt. As I have already mentioned, this muscle acts also as an inspiratory muscle, using the fibres which take origin from the lower ribs to elevate them, and therefore it is a muscle which acts in both inspiration and expiration, a circumstance which it is rather difficult to explain. In expiration it doubtless acts by compressing the posterior part of the abdomen, in which action it is joined by the external obliques and recti muscles so that the abdominal cavity is compressed in all directions, and as the origin of the latissimus dorsi from the lower ribs interdigitates with the origin of the external oblique muscle, and as this latter muscle contracts violently in expiration, it seems probable that the costal origin of the latissimus dorsi may act in expiration to fix the ribs to allow of the external oblique muscle to act with precision.

Another muscle which contracts in expiratory cough is the lower part of the trapezius, but whether its action is for the purpose of fixing the scapula it is difficult to say. The action of all the respiratory muscles is bilateral, and the relation between the bilateral and the unilateral actions of the latissimus dorsi will be referred to later on.

The time at my disposal will not permit me to say anything about the movements of the lower limb, or of the ocular or facial movements.

Having described the muscles which enter into and produce the movements of some of the different joints I propose now to say a few words about the manner in which the several muscles which take part in producing any movement are associated together.

THE MODE OF ASSOCIATION OF MUSCLES.

The Action of the Antagonists.

§ 8. In describing the muscles which take part in any movement, I have not made any mention of the action of the antagonists, and as they are considered by some authors to take a very important part in every movement, it is necessary in any account of the action of muscles to consider the various views which have been held on the subject.

Before however considering these views, we must first define what is meant by the antagonists of a movements. The antagonists of a movement are those muscles which move the joint in a direction which is diametrically opposed to this movement. This definition, or one similar to it, is so obvious that it seems hardly necessary, but in the movement of closing the fingers and thumb, which, as we have already seen, is produced by the flexors of the fingers and thumb acting with the extensors of the wrist, the latter have been described as the antagonists of the flexors of the fingers and thumb. Now the movement to be performed is flexion of the fingers and thumb, and the movement which is diametrically opposed to this is extension of the fingers and thumb, and this movement cannot be performed by the extensors of the carpus, but by the extensors of the fingers and thumb, which are the true antagonists. The extensors of the carpus are the synergic muscles in this movement.

The question of the part played by the antagonists in a movement has exercised men's minds from the time of Galen to the present day, and it is still a matter of controversy.

§ 9. According to Galen,* "Each muscle has only a single movement which is active; it does not possess the opposite movement except accidentally. On the other hand a muscle acts, when it draws towards itself the part which is in movement, but it does not act when it is drawn to the opposite side by another muscle. . . . For each part, put into movement by the muscles as by reins, being

* Galen's works, 'De usu partium,' part vii, book 1, chap. iv, p. 331, translated by Dr. Daremberg, Paris, 1856.

obliged to take part in the activity of the two sides, presents in turn one of the two muscles tense and the other relaxed."

It is evident from the above quotation that Galen considered that the antagonists to a movement do not contract when that particular movement is being executed.

I am unable to find any other reference to the question of the antagonist till Winslow's work.

§ 10. Winslow* defined the antagonists in the following terms: "*To move any part or to keep it in a determinate position, all the muscles belonging to it must co-operate*" (the italics are mine), "some of them drawing the part directly to the situation or attitude designed, some moderating this first motion by acting in a contrary direction and others directing it laterally. The first kind of these muscles I call principal movers, the second moderators, and the third directors. The moderators in general are the same with those termed antagonists, and the want of their action is in many cases supplied by the weight of the part to which they are fixed, or by the additional weight or resistance of some other body."

From this extract it is evident that Winslow considered that to move a part, all its muscles including the antagonists co-operate; but he makes the important proviso that the want of their action is supplied by the weight of the part or by external resistance. This proviso limits very considerably the occasions when according to Winslow the antagonists act; for if they do not act when a movement is being performed against gravity, or when any resistance has to be overcome, the occasions are narrowed down to unopposed movements taking place in the horizontal plane, where gravity does not act. Such a movement would be that of flexion or extension of the terminal phalanges of the fingers in the horizontal direction, or of the elbow in the same plane, or of the rotation of the head to the right or the left.

§ 11. In his Croonian lecture before the Royal Society, John Hunter † describes the actions of muscles as immediate and secondary; the first produces immediate action of the part, the second produces the assistant supporting regulating actions, as in walking when the right leg moves, the muscles of the left side of the trunk act to support the whole on the left leg. On page 262 he states that "the relaxers which become the sustainers of the muscles in action never allow themselves to relax to their full extent while the contractors are carrying on the motion of a part as it

* *Loc. cit.*, vol. i, sect. iii, p. 159, No. 41. † *Loc. cit.*, p. 249.

would produce weakness." The contractors, I conclude, correspond to Winslow's principal movers and the relaxers to his moderators or antagonists. If this be so, Hunter evidently considered that the antagonists are never fully relaxed, but I am unable to find any expression of opinion as to whether this is modified when the movement is resisted.

§ 12. Duchenne, to whom we owe so much for his extensive work on the actions of muscles, has given much attention to the action of the antagonists.

Duchenne * is very explicit in his opinion about the action of the antagonists and he says : " In the main all voluntary movement to be executed with precision ought to be moderated by its antagonist muscles." He goes on to state that this opinion is contrary to the theory of Galen—which I have already mentioned—and has been propagated to the present time in spite of a kind of resistance made against it by the illustrious Winslow. Duchenne quotes Winslow but he omits the proviso of Winslow that the antagonists are excepted when any weight or assistance supplies their action. Further on in the same chapter † Duchenne states that he has "demonstrated experimentally that all the movements of the limbs and trunk result from a double nervous excitation by virtue of which the two orders of muscles . . . the impelling and the moderating associations are put simultaneously into action, one to produce the movements, the other to moderate them. Without . . this *entente* of the antagonists the movements lose inevitably their precision and certainty." I gather from this, that Duchenne's opinion is more comprehensive than Winslow's, and that he considers that in all voluntary movements the antagonists take part.

§ 13. Of other observers Brucke ‡ agrees in the main with Winslow and states "that in drawing, or in playing the fiddle and where slow movements with only slight opposition take place with great precision and sharply defined range, the antagonists are put into activity with the principal muscles."

§ 14. On this subject of the antagonists interesting papers have been published by Beaunis § and by Demeny.||

The latter has made some most important observations by means of two Marey's myographs fixed on to the biceps and triceps

* *Loc. cit.*, p. 759. † *Loc. cit.*, p. 766.

‡ 'Sitzungs berichte der K. Acad. der Wissensch.,' Bd. 75, abt. 3, 1877.

§ 'Archiv. de Physiologie,' 5th series, tome 1, 1889.

|| 'Archiv. de Physiologie,' 5th series, tome 2, 1890.

respectively, by which tracings of these muscles under varying conditions were obtained. The conclusions which he arrived at were :—

In energetic static contractions, as in tightening up all the muscles without producing any movement and without meeting any external resistance, the antagonists contract synergically, either to immobilise firmly an osseous segment or to prevent the separation of the articular surfaces when the two segments are in the prolongation of one to the other.

If static resistance is made against an effort tending to produce flexion or extension, the antagonists of this movement relax. The antagonists are relaxed also during the movement every time that an external resistance acts in the way of their action, whether this resistance be overcome or not by the muscles contending against it, and whether these muscles shorten or elongate.

In natural movements (where there is no resistance), where they are of a slow and uniform rate, there is a simultaneous action of the antagonists; where the rate is variable, the antagonists act as moderators of the rate and come into play a little before the movement has ceased or changed its character.

I cannot find that Demeny makes any mention of the action of gravity on the contraction of the antagonists.

Demeny's observations are therefore in confirmation of Winslow's rather than those of Duchenne.

§ 15. On the other hand, experiments have been made by Sherrington* on the action of the antagonists, by electrical stimulation of the excitable cortex, and he has found that in addition to contraction of the principal muscles taking part in a movement there is not only relaxation but inhibition of the tone of the antagonists of this movement.

§ 16. Sherrington and Hering† have also shown more recently the same thing by electrical stimulation of the part of the cortex where movements of flexion of the elbow were represented. They found that when the biceps contracted there was relaxation of the triceps. It therefore seems probable that the inhibitory action of the antagonists starts in the same part of the cortex and takes the same course in the pyramidal tract as the excitatory action of the principal movers.

Sherrington's observations therefore agree with those of Winslow and of Demeny so far as strong opposed movements are concerned.

* 'Proc. Roy. Soc.,' 1893, vol. liii, p. 407.

† 'Proc. Roy. Soc.,' 1897, vol. lxii.

With regard to weak movements, Prof. Sherrington has informed me that even with minimal stimulation of the motor cortex he still obtains relaxation of the antagonists. There is therefore a difference between the results obtained by stimulating the excitable cortex in the monkey and those of making a person perform a slow unopposed movement, as the antagonists were found to be relaxed even on stimulation, according to Sherrington, and to contract in the case of slow voluntary movement according to Demeny.

§ 17. From my own observations I have held that, in strong movements against resistance the antagonists are always relaxed, and I expressed that opinion in a paper which I wrote in 1891.*

This power of relaxing a group of muscles by getting the patient to powerfully contract the antagonists against resistance I have for some time employed for clinical examination. The cases in which it is most useful are in affections in the region of the shoulder joint, where a patient is unable to abduct the arm without the inferior angle of the scapula moving outwards at once. This is a sign that either the deltoid is paralysed or that, owing to painful rheumatic changes, the joint is kept fixed by the muscles about it, or that the joint is ankylosed. If, in the second case, the deltoid be one of the fixing muscles, it can be relaxed by first passively abducting the humerus as near the horizontal line as possible, and then directing the patient to actively adduct the humerus against resistance, when the deltoid will be felt by the finger and thumb placed on either side of it to be relaxed; on then again directing the patient to try and keep the arm abducted the deltoid will be felt to contract, thus showing that the deltoid is not paralysed.

With regard to the question as to whether the antagonists act in all unopposed movements, as the experiments of Demeny show, I should like to point out that in the movement of rotation of the head we have an exceptional opportunity of examining the sterno-mastoid muscles, and in addition, the movement of the head being in the horizontal plane there is no chance of any error from the action of gravity. Here one of the sterno-mastoid muscles is a principal mover while its fellow of the opposite side is its antagonist, so that, in rotating the head with the face turned to the patient's right, the left sterno-mastoid is a principal mover and the right sterno-mastoid is its antagonist (see p. 47 on rotation of the head). On rotating the head slowly or quickly I am unable to find either on inspection or on palpation that there is any contraction of

* "On Some Points in the Action of Muscles," 'Brain,' vol. xiv, 1891.

the right sterno-mastoid in any part of the movement; and further, if the head be turned very quickly and be suddenly checked there is still even then no contraction of the right sterno-mastoid. It is quite possible that some of the other rotator muscles may act as a check to the movement, but from my observations the right sterno-mastoid does not do so, and the muscle is so superficially situated that it would hardly be possible to escape observation. On the other hand, if the elbow be quickly extended horizontally, and suddenly stopped, the biceps is felt to contract at the moment of stopping.

To sum up, I should myself agree with Winslow that in all movements where there is resistance to the movement, or where the weight of the limb has to be moved against gravity, the antagonists do not act. In unopposed movements, where gravity does not act, the opinion of Winslow is that the antagonists do contract, and this is confirmed by the experiments of Demeny, although he makes no mention as to whether gravity alters the conditions; but in the unopposed movements of rotating the head to the right where gravity does not act I cannot find that there is any action of the right sterno-mastoid, the antagonist to this movement, and Sherrington also found by cortical stimulation that the antagonists to the resulting movement were relaxed. There is, therefore, some difference of opinion as to whether the antagonists take part in slow unopposed movements where gravity is not acting.

§ 18. Before leaving this question I should like to mention a clinical case where the antagonist muscles acted in a way which I have not seen before.

It was the case of a girl, aged 18, who had incomplete right hemiplegia and hemianæsthesia. She had, however, no signs of organic disease, and the case was considered to be one of functional or hysterical paralysis. The great point of interest about the case was that whenever she was asked to perform a certain movement, the first action observed was that of the antagonist muscles. For instance, on being told to extend the elbow, the first muscle observed to contract was the supinator longus, one of the antagonists to the movement of extension. This contraction of the supinator longus was followed immediately by that of the triceps, and there was then a confusion with to and fro movements due to the alternate contraction of the extensors and flexors of the elbow. A similar thing occurred when she was told to flex the elbow, then the triceps was felt to contract first, and was followed by a movement of the flexors of the elbow, and then the joint moved to and fro with much confusion. I have observed a similar condition occur in dorso-flexing the ankle, a joint in which the typical to and fro hesitating confused movement is so often seen in these cases of hysterical paralysis. In another case on asking the patient to extend the knee, the first contraction was felt in the flexors of the knee. In all these cases, as the patient improved, this symptom passed off, and the joint was then moved in the normal way.

This condition of the antagonists acting before the principal movers begin, I have never seen in any other conditions besides those of so-called hysterical or functional paralysis. I therefore venture to think that it is a diagnostic symptom of this condition.

In relation to the movements in which a muscle may take part is the condition of

Paralysis of a Muscle for One Movement and not for Another.

§ 19. A muscle may take part in two different movements, as for instance the biceps brachii takes part with the supinator brevis in the group of muscles set apart for the movement of supination, and also takes part with the brachialis anticus, brachio-radialis and pronator teres in that for the performance of the movement of flexion of the forearm. It is therefore possible that if one of these movements be lost owing to an organic lesion of the central nervous system and not the other movement, the biceps which takes part in both movements may be paralysed for the one movement and not for the other. I have seen cases of hemiplegia where the action of the biceps for the movement of supination was lost but not for that of flexion of the elbow. Another movement which is often lost in hemiplegia, when the arm is paralysed, is that of elevation of the shoulder. Now the muscles which take part in the elevation of the shoulder, can also, taking their fixed point from the shoulder, draw down the head and neck to that side; such muscles are the trapezius (clavicular fibres), and levator anguli scapulæ. I have observed cases of hemiplegia where these muscles were paralysed when they acted as elevators of the shoulder, but not when they acted as lateral flexors of the neck, a condition which would probably signify that the movement of elevating the shoulder was represented in a different part of the excitable cortex to that of adducting the head to that shoulder. The same thing occurs with the ocular muscles where each internal rectus can act with the external rectus of the opposite eye, when it takes part in conjugate movements, but when the two internal recti act together in converging the eyes, they are paralysed.

§ 20. The above cases are instances of paralysis of a muscle for one form of unilateral movement and not for another; there is, however, another class of cases where a muscle may be paralysed for a unilateral movement of the arm but is not paralysed when it takes part in the bilateral action of respiration.

Dr. Hughlings Jackson was the first to call attention in hemiplegia to the paralysis of the clavicular part of the trapezius in elevating the shoulder while it was still able to act as a bilateral muscle in deep inspiration. I have already described (p. 49) how the latissimus dorsi takes part in inspiration and expiration, and that it can be readily felt to contract on coughing. The muscles of both sides here act together, and, as far as I know, it is not possible for a person to voluntarily inspire or expire as in coughing by using only the muscles of one side of the chest. Besides this bilateral movement there is the unilateral action of the muscle as an arm muscle, where it takes part in the movement of adducting the humerus. As I pointed out in a paper read before the British Medical Association in 1898* the latissimus dorsi of both sides takes part in the violent expiratory movement in the production of a cough or a sneeze. A cough can be produced reflexly or voluntarily, but a sneeze only reflexly, and we have therefore three conditions under which the latissimus dorsi may act, viz.:

(1) Acting with the muscle of the opposite side chiefly as an expiratory muscle:

(*a*) Reflex coughing or sneezing.

(*b*) Voluntary coughing.

(2) Acting independently of the other side, as an arm muscle.

The next question is, What will be the action of this muscle in cases of hemiplegia? I have now examined a great many cases of hemiplegia in which the arm was paralysed and in which there was complete loss of the movement of adducting the humerus to the chest wall, and where consequently the action of the latissimus dorsi as an adductor was absent. Of the twelve cases which I described in my original paper, in ten the lesion was presumably cerebral and probably in the internal capsule, while in two of the cases the lesion was ascertained, and was in one case a tumour of the ascending frontal convolution and in the other a tumour of the

* "On the Bilateral Action of the Latissimus Dorsi in Hemiplegia," 'Brit. Med. Journ.,' October 1st, 1898.

centrum ovale. In all of the cases, with the exception of two, the following conditions were found :

1. In reflex coughing or sneezing the expiratory action of the latissimus dorsi was about equal on the two sides.*

2. In voluntary coughing the action of the latissimus dorsi was obtained on both sides, but it was frequently diminished in action or occurred later on the paralysed than on the normal side.

3. On attempted voluntary adduction of the humerus there was no action of the latissimus on the paralysed side.

In two of the cases of hemiplegia where there was an exception to the general rule given above, it was found that no movement was obtained on the paralysed side in voluntary coughing, but in reflex coughing or sneezing, the latissimus dorsi on the paralysed side was seen to contract. In both of these cases of hemiplegia it was noticed that the paralysis of the face was very complete and that unlike most cases of hemiplegia the face movements were not only lost to voluntary efforts but also in one case to the emotional movements of laughing and in the other case the face movements only occurred when the motion was intense. Whether the absence of the movement of the latissimus dorsi in voluntary coughing is a sign that the lesion affects the pyramidal tract below the basal ganglia, the optic thalamus of which is considered by some (Nothnagel) to be the seat of the emotional movements, I have as yet had no opportunity of verifying.

A lesion therefore of the—let us say left—motor cortex or of the internal capsule will paralyse the right latissimus dorsi as an unilateral arm muscle, but will not paralyse it when it acts as a bilateral muscle of respiration reflexly or in most cases when it acts so voluntarily.

§ 21. Before leaving this subject I should like to mention that this bilateral action of the latissimus is of great value in diagnosing cerebral lesions from those of the spinal cord and peripheral nerves in those cases where the arm and leg of one side are involved without the face. In the case of a lesion, such as a tumour, pressing on one side of the spinal cord between the respiratory centre and the brachial enlargement, if there were paralysis of the latissimus dorsi, all its movements, including the unilateral arm movement, the bilateral movements of voluntary coughing and reflex coughing, would be lost; while in lesions above the level of

* I have since found that this movement is sometimes greater on the paralysed side, agreeing with Dr. Jackson's observations on inspiration.

the respiratory centre, though the unilateral arm movement would be lost, the reflex bilateral movement of coughing would be preserved. On the other hand a case, in which voluntary movement of this muscle is lost, can be shown not to depend on a lesion of the brachial cord or plexus, if the muscle contracts on coughing.

§ 22. Another example, but of a different kind, of paralysis of a muscle for one movement and not for another I described when I delivered this lecture, and I considered that I had observed it in the case of the upper or clavicular fibres of the pectoralis major. This upper part of the muscle I have already (p. 37) referred to as one which has two actions: first, it acts with the lower or sternal fibres of the pectoralis major in adducting the humerus in the horizontal plane to the middle line; and secondly, it also acts with the deltoid in advancing the humerus. In certain cases where the deltoid is paralysed, although the clavicular fibres of the pectoralis major appear to act well in conjunction with the sternal fibres of the muscle in horizontally adducting the humerus, they make no attempt to advance the humerus, or when it is passively advanced, they have no power to contract and keep the humerus in that position. The first case of this kind which I published* was one of paralysis after an accident, and was due to a lesion of the brachial plexus or of the cells of the anterior horns of the spinal cord. I have seen several other cases where the paralysis was due to lesions of the cord or brachial plexus.

These cases of paralysis of the pectoralis major (I considered) differed from the preceding ones of paralysis of the latissimus dorsi in that we have here apparently paralysis of a muscle for one movement and not for another, arising not from a cerebral lesion but from a lesion of the cord or of the brachial plexus.

[While these lectures were going through the press, I have seen at the Great Northern Hospital a case of paralysis of the brachial plexus, in which along with the deltoid, biceps, and brachio-radialis, the clavicular fibres of the pectoralis major were also paralysed, and did not contract in trying to advance the humerus, and on careful examination I could not make out that they contracted on horizontal adduction. On electrical testing, the clavicular fibres of the pectoralis major on the paralysed side required a stronger faradic current than on the normal side, while the costo-sternal fibres reacted normally on the two sides. Further, on examining a normal person I find that, as stated on page 37, § 23, if the humerus be

* 'Brain,' vol. xiv, 1891.

passively advanced or abducted to the horizontal line and then be actively adducted horizontally, the clavicular fibres do act; but if the weight of the arm be supported by resting the hand on a flat surface or by suspending it, then on horizontally adducting the humerus, the clavicular fibres do *not* act, but only the costo-sternal. I have, therefore, come to the conclusion that normally the action of the clavicular fibres in horizontal adduction of the humerus is to support the humerus in the horizontal plane against gravity, and not to horizontally adduct it, and that consequently in a lesion of the brachial plexus the clavicular fibres are paralysed for advancing the humerus, and take no part in horizontal adduction. The clavicular fibres of the pectoralis major must therefore in their action be considered as part of the deltoid rather than of the pectoralis major, to whose costal fibres their action is chiefly antagonistic; and in connection with this point Dr. Harris* has pointed out that in monkeys below the gibbon the clavicular fibres of the pectoralis major are replaced by the anterior fibres of the deltoid. When I delivered this lecture I stated that I was unable to explain this apparent selective paralysis of the clavicular pectoralis fibres from a lesion of the brachial plexus, but I now think from further examination that the apparent contraction of these fibres in horizontal adduction was due to the elevation of the skin over the clavicular fibres by the sternal fibres of the pectoralis major, and that there is no evidence that the clavicular fibres are paralysed for one movement and not for another.]

Action of a Muscle in Diametrically Opposite Movements.

§ 23. Another question which has arisen in the examination of the actions of muscles is whether a muscle ever takes a principal or direct action in a movement which is diametrically opposed to its usual action.

In considering this point it is obvious that the query could not be made in the case of a hinge joint (ginglymus) such as the elbow, as the triceps could not possibly take a direct part in the action of flexion of the elbow. It is, however, in joints like the radio-ulnar (rotatory) articulations, or in ball and socket (enarthrodial) joints that it would be possible for a muscle to take part in two opposite movements.

If a list be made of the muscles which are considered by anato-

* 'British Medical Journal,' October 24th, 1903.

mists to have this double action it would be found to contain the following :—The supinator longus, the pectoralis major clavicular fibres, the deltoid posterior fibres, and both sterno-mastoids acting together.

§ 24. As I have pointed out in a previous lecture (p. 22) the supinator longus has been considered by many anatomists to be both a pronator and a supinator, and in one of the most recent works on anatomy* it is stated that "the brachio-radialis (or supinator longus) assists in flexion and pronation on the one hand, and in extension and supination on the other hand." This, therefore, expresses the opinion that the same muscle does take part (as a principal mover I conclude) in two movements which are diametrically opposed to each other. With this opinion I cannot agree, as from the examination of the muscle on the living subject, as I stated in the second lecture, I consider that it certainly does not take part in extension, and I cannot find that it contracts in supination or in pronation.

Again, the clavicular fibres of the pectoralis major were stated by Duchenne to be both elevators and depressors of the humerus, when the arm was above the horizontal line. From my observations, to which I have already referred (p. 34), I consider that these fibres never act in depressing the humerus—a movement which is performed by the inferior or sternal fibres of the pectoralis major.

The posterior fibres of the deltoid were considered by Duchenne† to be, together with the rest of the deltoid, elevators of the hanging humerus as far as an angle of 45° to the vertical, beyond which the posterior fibres became depressors, and antagonists to the rest of the deltoid; in other words, after acting as elevators through an angle of 45° the posterior one-third of the deltoid suddenly changes its mind—so to say—and takes part in a movement of depression (or adduction) which is diametrically opposed to the direction of its previous movement of elevation (or abduction). From my observations (p. 35) I should say that the posterior one-third of the deltoid only takes part in adduction and never in abduction, an opinion which I was glad to find was expressed by Richer.‡

The last movement which I have cited is that of the two sterno-mastoids acting together. Their ordinary action is to flex the head forwards as in lifting the head from a pillow, but most anatomists

* 'Text-book of Anatomy,' edited by D. J. Cunningham, F.R.S., p. 335, 1902.

† *Loc. cit.*, § 66.

‡ 'Physiologie Artistique.'

describe that when the head is put back far enough these muscles act as extensors of the head. I have already expressed the opinion that I do not think that this action occurs, and the following proves the same thing. In cases of progressive muscular atrophy affecting the extensor muscles of the head at the back of the neck but not the sterno-mastoids, the head falls forward till the chin rests on the chest, due to the inability of the extensors to hold up the head against gravity. If, now, the patient leans far back in a chair, so that the head can be allowed to extend backwards as far as it will go, there will still be a slight contraction of the flexors, viz. the sterno-mastoids, to counteract gravity. If, while in that position with the head extended, the patient be told to further extend the head against resistance he will not be able actively to do so owing to the paralysis of the extensors at the back of the neck, but the sterno-mastoids, so far from contracting, will actually relax, thereby showing that they are flexors of the head and not extensors in any position.

§ 25. There may be other muscles which might act in two opposite ways, but of those which I have cited I cannot find that any one of them takes a principal part in a movement which is diametrically opposite to its usual action.

There is, however, one muscle which certainly does take part in two opposite movements, viz. the latissimus dorsi, which contracts in both inspiration and expiration, though the action is much stronger in expiration than in inspiration. I have already referred to this point (p. 49) and I would only again express the opinion that the part of the muscle arising from the three lower ribs probably has a different action to the main part arising from the spine and the iliac crest. In inspiration this costal origin acts by elevating the ribs; on the other hand in violent expiration these costal fibres may fix the ribs and enable the external oblique muscles—whose orgins interdigitate with those of the latissimus dorsi—to vigorously contract and act with the main part of the latissimus as a principal mover in compressing the abdominal cavity. I should therefore look upon the costal fibres as prime movers in inspiration and as synergic or fixing muscles in expiration. I think, therefore, that one is justified in making the statement that a muscle does not take a principal part in a movement which is diametrically opposed to its usual action, or in other words in two movements which are opposite in direction. I make this qualification with regard to muscles taking a principal part in a movement, as in my first paper in

'Brain' * I did not make this qualification, but I had not then noted the various synergic muscles taking part in a movement. For instance in both supination and pronation of the forearm the triceps acts to counteract the flexor action of the biceps and of the pronator teres, but as the triceps is not a principal mover in either of these movements its action would not be against the statement I have made.

Sequence of Muscles in Single Movement.

§ 26. In the first place it is necessary to ascertain whether all the muscles which can take part in a movement always act whether the movement is a weak one or a strong one.

§ 27. I believe that in the case of a single muscle which is stimulated through its nerve, physiologists formerly held that all the fibres of the muscle contract, and that the minimal amount of work is produced not by using only some of the muscle fibres, but by using all the fibres to a slight degree of contraction, while when the maximum work is required the same fibres contract strongly. Gotch has, however, recently put forward proofs that the submaximal effects in muscle and nerve are mainly though not entirely determined by the number of elements which are in a state of activity. ('Jour. of Phys.,' December 15th, 1902.) The question arises whether the same principle can be applied to groups of muscles, and we have to determine in producing the minimal force whether all the muscles which can take part in the movement contract or only certain muscles in the group. Or, to take a simile from marine engineering, whether, when a ship is travelling at half speed, all the boilers are working at half their full pressure, or whether only half the boilers are working at full pressure.

§ 28. It is not very easy to find a group of muscles the individual members of which can be examined, and the order in which they take part in a movement noted. I think that the movement of supination, which is effected by the supinator brevis and the biceps, is one in which it is possible to ascertain how soon the biceps takes part in the movement. For this purpose if the upper arm and elbow be rested on a table and the forearm be placed in a vertical position midway between flexion and extension so as to obviate the action of gravity, and at right angles to the upper arm, it will be found that the forearm can be supinated, if there be no resistance, without any contraction of the biceps, a point which can

* 'Brain,' vol. xiv, p. 57, 1891.

be ascertained by hooking the forefinger round the tendon of the biceps at the elbow. If now resistance be made against the supinating forearm, the biceps will be felt to contract after the resistance has reached a certain amount. I have measured this amount and find that it comes to 1 lb. It therefore appears that the supinator brevis will do the work of supination when only the inertia of the bones has to be overcome, but as soon as work of over 1 lb. is required to be done, the biceps is called into help.

Again, in the first lecture it was pointed out that in extending the wrist with the fingers straight the extensors of the carpus would not assist the extensores digitorum until a certain amount of work had been done by the extensores digitorum.

§ 29. These two examples I think show that there is a definite order in which the muscles for the performance of a movement come into action.

Therefore all the muscles which are grouped together for the performance of a movement do not come into action when only slight effects are required, but a certain increase of work has to be encountered before they all act.

§ 30. In connection with this it is interesting to note that Sherrington* has found a similar condition in reflex actions. On stimulating electrically the posterior root of the fifth cervical nerve with a Kronecke secondary coil at 15, good contraction of the supinator group was obtained in the monkey, but to evoke contemporaneous action of the biceps with the supinator a much stronger current of 90 was required.

Fixation Muscles.

§ 31. Besides the muscles which are directly concerned in taking part in a movement, other muscles, which act on joints of the limb between the joint in question and the trunk, are seen to contract. For instance, in performing the different movements of flexing the fingers, of flexing the fingers and thumb as in grasping, or of flexing or extending the wrist, we put into action only the muscles which are directly concerned with these movements, if the force exerted is slight or moderate; but if these movements are performed more powerfully other muscles are seen to join in the movement. These other muscles which are brought into the movement are the flexors and extensors of the elbow. The muscles about the shoulder joint are also brought into action in such move-

* 'Phil. Trans.,' series B, vol. cxc, 1898, p. 154.

ments as flexion or extension of the fingers or wrist, but I was not able to make out any action of the shoulder muscles except in the strongest movement of grasping, *i.e.* flexion of the fingers and thumb. I have not as yet paid special attention to the character of the action of the shoulder muscles following movements of the fingers, but I hope to do so later.

§ 32. I have therefore made some observations to ascertain which of the movements of the wrist and digits are accompanied by contraction of the flexors of the elbow, which by the extensors of the elbow, and which by both of these sets of muscles. I have also measured the amount of force required to be exerted before these muscles, acting on the elbow, join in the movement. In order to test the influence of position these observations have been made when the forearm was in the position of pronation as well as when in that of supination.

Table I.

Sequence of the actions of muscles in the upper arm to movements of the hand in the positions of supination and of pronation, and with the arm in a horizontal plane.

Movement performed.	Position of fore-arm.	Amount of work done before triceps contracts.	Amount of work before biceps contracts.
Fingers flex	Supinated	No contraction	$\frac{1}{2}$—1 lb.
,,	Pronated	$\frac{1}{2}$—1 lb. (225—450 grammes)	No contraction.
Fingers extend	Supinated	$\frac{1}{2}$—$\frac{3}{4}$ lb.	No contraction.
,,	Pronated	No contraction	$\frac{1}{2}$—$\frac{3}{4}$ lb.
Thumb and fingers flex (grasping)	Supinated	11 lbs. (5 kil.)	35—38 lbs. (15—17 kil.).
,,	Pronated	9—11 lbs. (4—5 kil.)	45—54 lbs. (20—24 kil.).
Wrist flex	Supinated	No contraction	$\frac{1}{4}$—$\frac{1}{2}$ lb.
,,	Pronated	$\frac{1}{4}$ lb.	No contraction.
Wrist extend	Supinated	$\frac{1}{4}$—$\frac{1}{2}$ lb.	No contraction.
,,	Pronated	No contraction	1 lb.

§ 33. In these observations the arm and forearm were laid flat on a raised table in the same horizontal plane, with the latter in the position of pronation or supination, and with the hand projecting over the edge of the table. The elbow was placed at a right angle and relaxed, and the amount of work done was either registered by a dynamometer, which was grasped in the hand, or traction was made on the joints at right angles to the line of the forearm by a band passed over the phalanges or the metacarpal bones; the band was connected with a spring balance to register the amount of work which the movement had to resist before the biceps or triceps contracted. The contraction of the biceps was ascertained by the finger hooked round its tendon near its insertion, and the contraction of the triceps was easily felt by the finger and thumb placed on either side of it just above the elbow.

[I must here state that some of the figures in Table I differ from those given when the lecture was delivered and subsequently reported in the medical journals. I had then remarked on the much greater traction required to bring out contraction of the biceps when flexion of the fingers was performed in the supinated position, than that required to bring out contraction of the triceps when the fingers were flexed in the pronated position. These observations were made with the humerus in the vertical position and the forearm lying flat on a table. It occurred to me that the difference between the action of the triceps and the biceps might be due to the fixation of the elbow joint by the forearm lying on the table and thereby preventing extension of that joint and thus, as there was no movement of the elbow, there would be no necessity for the biceps to contract to fix the joint. I have therefore made fresh observations with the arm and forearm resting on a horizontal surface, along which the elbow was free to move; traction was then made in a direction parallel to the horizontal plane in which the forearm moved on the upper arm. By this means the action of gravity on the forearm in the one direction and the opposition of the table in the other direction were avoided. The result has been a great diminution in all the figures, and especially in the case of the biceps, so that, whereas in the former observations, when flexion of the fingers was made in the supine position against the resistance of the traction band acting vertically downwards, the elbow was so far fixed by the opposition of the table against the forearm that the biceps did not act till 22 lbs. traction had been experienced, in the present observations with the forearm horizontal contraction is felt when the resistance is $\frac{1}{2}$ to 1 lb.].

§ 34. The following generalisations may be made from Table I:

First, taking the forearm in the position of supination it will be seen on looking at the Table of the sequence of the actions in the upper arm muscles, that in flexion of the fingers, whereas the biceps contracts when the resistance to the movement of flexion amounts to so little as $\frac{1}{2}$ to 1 lb. (225 to 450 grammes) the triceps does not contract at all. Also in extension of the fingers, when the forearm is in the supine position the triceps contracts when so little resistance as $\frac{1}{2}$ to $\frac{3}{4}$ lb. is experienced, and no contraction of the biceps occurs even with a resistance which can overcome the extension of the fingers. These observations show that in the supinated position of the forearm, flexion of the fingers, when opposed, is followed by contraction of the biceps, and extension of the fingers, when opposed, is accompanied by contraction of the triceps.

Secondly, that in grasping with the fingers and thumb, which, as we have seen in a previous lecture, is performed by the flexors of the thumb and fingers and the extensors of the wrist, the contraction of the biceps and triceps both occur, but that of the triceps first. Also, it makes no difference whether the forearm is in the pronated or supinated position.

In other words the muscles producing flexion or extension of the elbow are brought into that movement of the fingers or wrist, which is in the direction of flexion or extension of the elbow respectively, either to reinforce the movement or to counteract the tendency of the resistance to move the elbow in the opposite direction. But in a movement like grasping, which is not in the direction of flexion or extension of the elbow, both sets of muscles (triceps and biceps) contract and the elbow is kept fixed. That this sequence to flexion of the fingers is very much due to the position of the limb is shown by the opposite results which are obtained according as the forearm is pronated or supinated. For instance in flexion of the fingers or of the wrist in the supinated position the biceps contracted at $\frac{1}{2}$ to 1 lb. and at $\frac{1}{4}$ to $\frac{1}{2}$ lb. respectively, but not at all in the pronated position. This is probably because, when the fingers or wrist are flexed against resistance in the supinated position, the resistance to the movement tends to cause extension of the elbow and the biceps contracts so as to prevent the elbow being extended when the resistance to the wrist or fingers reaches a certain amount. But when the forearm is in the pronated position the conditions are reversed, the resistance to the flexion of the wrist tends to cause flexion of the elbow, and to prevent the elbow being flexed, it is now the triceps which contracts and not the biceps.

§ 35. To still further elucidate this question of fixation I have made experiments on the movement of grasping with the fingers and thumb, (*a*) with the forearm resting free on a flat surface, (*b*) with the forearm fixed immovably on a flat surface. The humerus was vertical or horizontal, and the results were about the same in either position. It will be seen on looking at Table I, that in the movement of grasping or closing the fist, the contraction of the triceps occurs sooner than that of the biceps. As there was evidently some disturbance of the position of the elbow which necessitated contraction of the triceps before that of the biceps, the forearm was fixed to prevent any movement of the elbow. On looking at Table II it will be seen that in the position of supination, whereas with the forearm resting freely the triceps contracted when the grasp registered 11 lbs (5 kil.), with the forearm fixed it did not contract till the grasp was trebled, *i. e.* 33 lbs.; while in the position of pronation also with the forearm free the triceps contracted when the grasp was 11 lbs., and with the forearm fixed when it was 33 lbs. Similar conditions were obtained when the forearm was in the mid-position between supination and pronation. On the other hand the contraction of the biceps was not influenced by the condition of the forearm being free or fixed. These observations show that the contraction of the triceps must be to counteract some action of flexion of the elbow by the muscles taking part in grasping, and on carefully watching the movement of grasping, when the forearm rested free on a flat surface, a certain degree of flexion of the elbow was seen. I have measured the force of this flexion of the elbow by a band round the lower end of the forearm, which was attached to a fixed point with a spring balance interposed, and I find that the force exerted by the elbow in grasping amounts to one pound. I have also ascertained that it makes no difference whether the grasp is moderate or the maximum (54 lbs.), as the amount of force produced by this slight flexion of the elbow is in both cases, one pound. This would mean that in the supinated position whatever the strength of the grasp, the triceps is so adapted, probably by the sensory nerves, that it will not permit flexion of the elbow of more force than one pound.

Table II.

Sequence of contraction of triceps and biceps to the movement of flexion of the fingers and thumb (grasping) with the forearm free and fixed and with the humerus vertical or horizontal.

Position of forearm.	Triceps contracts at.	Biceps contracts at.
Supinated, free	11 lbs. (5 kil.)	33 lbs (15 kil.).
,, fixed	33 lbs. (15 kil.)	
Midway between supination and pronation, free	11 lbs. (5 kil.)	33 lbs. (15 kil.).
Midway between supination and pronation, fixed	33 lbs. (15 kil.)	
Pronated, free	11 lbs. (5 kil.)	? 45 lbs (20 kil.).
,, fixed	33 lbs. (15 kil.)	? 45 lbs. or no contraction.

LECTURE IV.

Mr. President and Gentlemen,—In my last lecture I described that in the movements of the wrist and fingers, when they were performed normally, there was a contraction of the muscles acting on the elbow joint, either of the biceps or the triceps, or of both. And I pointed out that when the forearm was in the position of supination in flexing the fingers and wrist the biceps contracted, and in extending the fingers and wrist the triceps contracted, while in closing the fist the triceps acted first, followed by the biceps.

§ 1. This fixation action of muscles was described by John Hunter in his Croonian lectures on 'Muscular Motion,' delivered before the Royal Society in 1777,* where he stated that "there is in every animal, therefore, a fixed point from which the parts of the body take their principal motions. In the human body this fixed point seems to be in the joints of the thigh bones, which point being in the middle of the body must be common to the extremities. . . . Besides this there are many fixed points, so that the body is to be looked upon as a chain of joints whose general centre of motion is in the joints of the thighs." Now this centre of motion of John Hunter corresponds to the point of centre of gravity described by subsequent observers.

§ 2. It seems to me that the determination of the position of this fixed point depends on the attitude of the person, and on the place where his body comes in contact with the ground, and where it gets a firm foundation, as, for instance, if a person advances the upper limb when lying on his back on the ground, the fixed point will be the cervico-dorsal spine; if he perform the same movement sitting on a chair the fixed point will be the pelvis; if, however, the same movement be performed in the erect posture the fixed

* 'The Works of John Hunter, F.R.S.,' edited by James F. Palmer, 1837, p. 245.

point will be where the soles of the feet come in contact with the firm ground. We therefore, it seems to me, have to differentiate in any movement between the muscles which take part directly in that movement and the muscles which are used to fix the joints which lie between the joint which is actively engaged, and the fixed point or base on which the structure works. Again, these fixing muscles have to be separated into those which always take part in the strong movements irrespective of the posture of the person, which we may call *essential*, and those which depend on the position of the person and where his fixed point or base is, which we may call *postural*.

As an example of the essential muscles, we may take the contraction of the triceps and biceps which accompany the movements of grasping of the hand, and which I have already described. And as an example of the postural muscles, the contraction of the erector spinæ of, let us say, the left side when the upper limb of the opposite side, the right, is advanced or abducted, and which, as I showed in a former lecture, only contract in certain positions of the spine to prevent the equilibrium being disturbed.

CLASSIFICATION OF MUSCLES.

§ 3. I should classify the various muscles taking part in any movement as:

(A) Prime movers.

(B) Synergic muscles.

(C) Fixation muscles: (1) Indispensable or essential.
(2) Postural.

(D) Antagonist muscles in occasional movements.

I take first as an example the movement of grasping an object or closing the fist. Here the prime movers are the flexores digitorum and flexor pollicis, and small thumb muscles. The synergic muscles are the extensores carpi, and the essential fixation muscles are the triceps and biceps.

Another example is the movement of advancing the humerus. Here the prime movers are the deltoid (clavicular fibres), pectoralis major (clavicular fibres), biceps; the synergic muscle, the triceps (outer and inner heads), which comes into play to counteract the flexor action of the biceps; and the fixation muscles (1) essential, the trapezius, (2) postural, the erectores spinæ.

§ 4. The principal or prime movers are the muscles which directly produce the action required and are called by some authors the agonists; the synergics are the muscles which, as I have previously stated, are brought into the combination when a prime mover has, by passing over two or more joints, two or more actions of which only one is required, and the synergics are the muscles which neutralise these undesired actions; they are represented in the first example given above by the extensores carpi. The fixation muscles, as I have already described them, are (1) those which are essential to the movement in all postures and which are not influenced by the position of the person, and (2) those which only act to prevent the equilibrium of the trunk being disturbed by the movement, and which I have therefore called *postural*. The antagonists produce the movement which is diametrically opposed to that of the prime movers.

Before proceeding to describe the relation of these different classes of muscles to each other I must refer to the classifications of previous observers.

§ 5. According to Winslow* the muscles may be divided into:

(A) Principal movers.

(B) Moderators or antagonists.

(C) Directors or collateral muscles which are wanting in hinge joints (ginglymus).

As an illustration he cites† the muscles employed in standing, where the principal movers are the gastrocnemii and soleus; the moderators are the tibialis anticus and peroneus medius and minimus; and the directors are the tibialis posticus and peroneus maximus. Winslow does not mention the action of the synergics, *i. e.* the action of the extensors of the wrist in the movement of closing the fist, but he states that the extensor digitorum moderates the flexion of the fingers in all the determinate degrees of action.

§ 6. Duchenne ‡ divides the muscles into:

(A) Associations musculaires impulsives.

(B) Associations musculaires antagonistes:

(*a*) Associations musculaires moderatrices.

(*b*) Associations musculaires collaterales.

He includes under (A) the synergic muscles as well as the principal movers, so that in the movement of extending the fingers, which he gives as an example, he enumerates the extensor digitorum, the interossei and lumbricales, and the synergic muscles,

* Winslow, *loc. cit.*, p. 159. † *Loc. cit.*, p. 332.

‡ *Loc. cit.*, § 676, p. 759 *et seq.*

the flexores carpi, as being included in group (A). As an example of the action of the antagonists Duchenne takes the movements of the vertebro-cranial column presiding over the erect position, and states that we must consider two kinds of principal phenomena :— 1st, the muscular association which produces its extension; 2nd, the harmony of the antagonistic muscles, which moderate and assure this extension and the normal attitude of the spine. The erectores spinæ form the muscular associations producing extension of the spine, and Duchenne goes on to say that "On the harmony of the antagonist muscles, or rather, on the degree of force of the muscles moderating the extension or flexion of the spine depend necessarily the different degrees of the lumbo-sacral curves." He also cites as collaterals in the same position of standing, the lateral movers of the vertebral spine, the quadratus lumborum, to prevent the trunk inclining to one side or the other.

§ 7. This illustration which Duchenne gives, viz. the muscles of the vertebro-cranial column during the vertical position, does not to my mind touch the question of the action of the antagonists and the collaterals, and the same objection applies to Winslow's statement about the tibialis anticus and peronei being antagonists to the calf muscles in standing. According to my observations the flexors and extensors of the ankle, and the flexors and extensors of the spine are respectively not acting in antagonism to each other, but each in turn contracts as a prime mover to counteract and rectify the displacing movements due to gravity. In the spine according as this displacement is forwards, backwards, or lateral, the erectores spinæ, the recti abdominis, or the lateral movers of the spine on the side opposite to the movement respectively contract. It is of course possible to throw all the muscles of the leg into a static contraction so as to convert the leg into a rigid pillar as in skating a large "outside edge," but here no movement of any joint is taking place, and it would not be possible to say which muscles were the prime movers and which were the antagonists, as they are all probably prime movers.

The Manner in which the Different Classes of Muscles Taking Part in a Movement Act.

§ 8. John Hunter * stated in his Croonian lectures that "there is no one known muscle in the body that we can throw into action separately and independently of the collateral effects of others." Duchenne † has expressed the opinion that partial muscular contractions do not exist in Nature, that they are only produced artificially by means of faradisation, and Dr. Hughlings Jackson has laid down the dictum that "nervous centres know nothing of muscles, they only know of movements." This in other words means that the ordinary individual has no power to make any one muscle contract by itself; he can only order a movement; he cannot pick out one muscle from a group and order that to contract; he can, on requiring to attain a certain object, order a certain movement, but the mechanism by which that movement is produced and the muscles which are required to perform that movement, and the order in which they act, is not known to the brain; the order for a movement is given and the movement is performed.

Throughout these lectures I have used the word "movement" to denote the change of position in a joint brought about by the muscles taking part in the movement, while keeping the word "action" for the individual muscles, the resultant of whose actions is the movement.

§ 9. Take the following example, to which I have referred in a previous lecture. Extending the wrist against resistance by means of the extensors of the fingers the muscles come into action in a definite order, which apparently cannot be altered. At first the prime movers are the extensors of the fingers and the interossei and lumbricales, and the synergic muscles are the flexors of the carpus; later on, if the resistance be increased, at a certain point the extensores carpi come to the assistance of the extensores digitorum, but apparently the individual has no power to make the extensores carpi contract before the pressure has reached the required amount. This, as I have already shown, is well exemplified in lead paralysis of the extensors of the fingers. Here, although the extensores carpi are not affected, the individual is unable to put them into action because apparently it is not their place to extend the wrist with the fingers straight when this movement is begun by the extensores

* *Loc. cit.*, p. 248. † *Loc. cit.*, § 676, p. 760.

digitorum, until the strain to be overcome reaches a certain amount. (It is quite possible, as was pointed out in Lecture I, p. 15, that the extensores carpi are to be considered as fixation muscles to the extensores digitorum, and that this is the reason why they will not contract until a certain strain is reached.)

Another example of the intimate association between the principal movers and the synergic muscles is in the extension of the thumb. Here the extensors of the thumb are the prime movers, and the extensor and flexor carpi ulnares are the synergic muscles, and it is quite impossible to extend the thumb in the slightest degree and in any position of the wrist without contracting these ulnar muscles, and if the extensors of the thumb are paralysed by a peripheral lesion, the wrist is adducted to the ulnar side in trying to extend the thumb.

§ 10. Now although the use of the ulnar muscles is doubtless to counteract the abductor action on the wrist of the extensor ossis metacarpi, the contraction of the ulnar muscles is not dependent on the displacement of the wrist, for it takes place even if the thumb be extended after the wrist has been passively abducted to its full extent. There is now no chance of the wrist being further abducted and consequently there is no necessity for the ulnar muscles to contract.

We can only therefore conclude that the two sets of muscles are so intimately associated in this movement of extending the thumb that they act together in all positions of the wrist, and when one of the group is paralysed by a peripheral lesion the other set of muscles goes on acting, as the innervation from the brain passes down just as if the whole complex could be thrown into action. As, however, one group is paralysed, the movement occurs only in the other group, showing that they are a true synergic combination.

§ 11. It seems therefore that an individual has no power voluntarily to leave a muscle out of a combination to which it belongs. Whether it would be possible to do so by long practice I am not in a position to state.

§ 12. Another question is, Is it possible to voluntarily add suddenly to the list of muscles which are told off for a certain movement, or to supplement by another muscle when one is paralysed? For instance, it has been said that the anterior portion of the deltoid can replace part of the functions of the pectoralis major, but it must be remembered that the only function to which this could refer would be the action of advancing or adducting the humerus. Now the deltoid is naturally associated with the clavicular part of the pectoralis major in this movement, and if the pectoralis were paralysed by a peripheral lesion, the deltoid would continue to act exactly as before, the movement being imperfectly carried out; one muscle would not replace the other. On the other hand when the muscles proper to the movement are paralysed the difficulty may be overcome by a series of other movements. I remember seeing a case with paralysis of the flexors of the elbow in a man who managed to produce flexion of the elbow by advancing the humerus with the forearm hanging, rotating it out and by this means letting the forearm be flexed by gravity. The paralysed muscles were, however, not supplemented by other muscles but an entirely different group was thrown into action by which the desired change of position was obtained. I think therefore that although by exercise and training it may be possible to alter the arrangement of the muscles taking part in any one simple movement, the inability of a patient with lead paralysis to induce the extensores carpi to act out of their proper order is against this possibility. By mechanical means such as transplantation of tendons, first recommended by Nicaladoni * in 1882, it is possible to take a muscle out of one group and put it into another, and I have had the opportunity of seeing the results of some of these cases under the care of Mr. Muirhead Little † and Mr. Tubby ‡ at the National Orthopædic Hospital.

It is also possible to interchange the cut ends of the nerves of a limb as in the interesting experiments of Kennedy,§ and change the localisation in the cortex of the flexor and extensor centres for a limb.

§ 13. From a consideration of the above statements, I think that one is justified in saying that for every single voluntary movement there is a definite number of muscles, usually two or more, which come into action in a definite order which cannot be altered. Further, that the individual members of this group can neither be omitted nor, when paralysed, be supplemented, except by long training and exercise, or by operative procedure.

§ 14. It will thus be seen that in every single voluntary move-

* 'Archiv. für Klin. Chir.,' Bd. xxvii, Heft 3, p. 660.

† Cf. 'Pediatrics,' vol. xi, No. 3, 1901.

‡ 'Brit. Med. Journ.,' September 7th, 1901.

§ 'Philos. Trans. Roy. Soc.,' vol. 194 B, 1901.

ment, there must take part a *minimal* number of muscles below which it is not possible to go. This combination of muscles I would call the ultimate or the minimal components of a movement. For instance, such ultimate components of the movement of extending the metacarpal bone of the thumb are the extensor ossis metacarpi pollicis, extensor carpi ulnaris, and further on in the movement the flexor carpi ulnaris; and in the movement of extending the first phalanges of the fingers the extensores digitorum and flexores carpi.

§ 15. The next question that we have to answer is, Where in the central nervous system are these ultimate components linked together or represented as one movement?

There are three places where they may be represented: in the spinal cord corresponding to Dr. Jackson's lowest level, in the cerebral excitable cortex, or so-called motor area (Dr. Jackson's middle level), or in the centres postulated to preside over the so-called motor area (Dr. Jackson's highest level). With regard to the last place, I have no evidence to offer at present. The time at my disposal will not permit me to discuss the part taken by the cerebellum in the co-ordination of movements, and I shall have to confine my remarks to the spinal cord and cerebral cortex.

REPRESENTATION IN THE CENTRAL NERVOUS SYSTEM.

Representation in the Spinal Cord of a Single Movement.

§ 16. Taking first the question of the spinal cord we have to consider the relative share taken by the anterior and posterior cornua in the representation of the ultimate components of a movement.

Localisation in the spinal cord of the different muscles of the limbs has been studied both experimentally and clinically, and the first question that has to be answered is whether the grouping of the cells of the anterior cornua of the spinal cord is of a morphological or a physiological type. In other words, whether in the brachial enlargement the cells, which supply the muscles forming the ultimate components of any one movement like that of extending the thumb (the extensors of the thumb and the ulnar flexor and extensor of the carpus), are aggregated together so that a lesion in that particular place would cause paralysis of this movement only.

§ 17. I do not propose, and I have not the time, to describe all the numerous observations which have been made, but experimentally the chief ones have been done on the roots entering into the brachial and lumbo-sacral plexuses by Müller, Van Deen, Panizza, on frogs; by Peyer, Krause, on the rabbit; by Risien Russell on the dog; and by Ferrier and Yeo, Forgues, and Sherrington, on the monkey. Anatomically the question has been worked out by Herringham and by Paterson by dissection, and clinically by Erb, Thorburn and many others. I also read a paper to the Royal Medical and Chirurgical Society in 1885 on "Cases Illustrating Localisation in the Spinal Cord," where I showed cases of infantile paralysis with paralysis of the lower half of the pectoralis major, the triceps and the latissimus dorsi only, and I have also published other papers on brachial plexus paralysis.

§ 18. Opinions have differed as to whether the arrangement of the cells in the anterior cornua is anatomical or physiological. The arrangement of the cells in the anterior cornu and also of the anterior roots forming the brachial plexus in a physiological order would be supported by a condition which I had observed and which I have already referred to, viz. the paralysis of the pectoralis major (clavicular fibres) for one class of movements but not for another. In lesions of the anterior cornu or of the brachial plexus, especially of the fifth cervical root, the deltoid is paralysed, and when the humerus is passively advanced it is seen that along with the paralysis of the deltoid, the clavicular fibres of the pectoralis major do not make any attempt to contract when the patient makes an effort to keep the humerus advanced. On the other hand if the patient be directed to horizontally adduct the humerus, the clavicular fibres of the pectoralis major apparently contract in combination with the sternal fibres of this muscle.

[Since delivering this lecture I have seen a case (see page 59) which makes me believe that the pectoralis major clavicular fibres do not act in horizontal adduction, and therefore do not support the theory that the anterior cornual cells have the power of grouping muscles together for a functional purpose.]

§ 19. Against the view that each root of the plexus—and therefore presumably the segment of the cord from which it comes—when stimulated produces a well co-ordinated movement by groups of muscles acting synergically is the statement of Herringham* that although both pronators must act together in one movement the pronator quadratus is supplied by one root and the pronator teres by a different root. Also the cells supplying a single muscle

* 'Proc. Roy. Soc.,' 1886, vol. xli.

in the limbs extend over two or more segments. Further, no segmental grouping of any of the cell columns of the spinal cord has been detected by Kaiser, or by V. Argatinski,* and this conclusion stands in harmony with the results of the examination of the relation of the reflex movements to spinal segments.

§ 20. On the whole the evidence, it seems to me, is against the cells of the anterior cornua being arranged physiologically for a functional purpose.

§ 21. But although the anterior cornual cells may probably not be arranged for functional purposes it does not follow that there is no power of co-ordination in the spinal cord. This is proved by the various complicated reflex actions which are performed when the spinal cord is cut off from the cerebral influence, reflex actions which, as in the plantar reflex, are made up of contractions of several joints in the limb. It has been found by Page May † and by Sherrington ‡ that electrical stimulation of each posterior root produces a definite movement which acts reflexly through the anterior cornual cells. Sherrington also states that the group of cells discharged by spinal reflex action innervate synergic and not antagonist muscles. May's experiments were made on the lumbar enlargement of the monkey, and Sherrington's on the brachial enlargement. May's observations were also made by direct excitation of the spinal cord along its postero-external column. He says: "The movements resulting from excitation of a segment of the spinal cord in the lumbo-sacral region, and those from excitation of the corresponding posterior root are similar, but are never quite identical. In each case flexion is the predominant effect, but in the former case (spinal cord) the resulting movements are always stronger than in the latter (posterior root), and frequently movements in other parts (tail, perineum, etc.) are added." The stimulation of one posterior root causes impulses to pass out along many anterior roots, and while stimulation of the posterior roots always produced flexion, that of the anterior roots produced extension.

Sherrington gives a list of the movements obtained by stimulation of all the posterior roots in the monkey, but as his results in the lumbo-sacral cord correspond very closely with those of May, I refer chiefly to his observations on the brachial part of the cord only. The resulting movements obtained by Sherrington from

* 'Schäfer's Text-book of Physiology,' vol. ii, p. 795.

† 'Phil. Trans. Roy. Soc.,' 1897, vol. 188 B.

‡ *Loc. cit.*, 1898, vol. 190 B.

stimulating a posterior root are synergic and not antagonistic, which, as he remarks, is against the theory of the action of the antagonists, a matter which we have already discussed.

As an example of the results obtained by May we may take the third lumbar posterior root, excitation of which gave the following movements :—" Flexion of side, flexion and adduction of hip, dorsal flexion of ankle, flexion of toes and tail," and, as an example of the results obtained by Sherrington, excitation of the eighth cervical posterior root produced the following movements :—" Adduction and flexion of thumb, flexion of other digits, flexion, more often extension, of wrist, sometimes with drawing to ulnar side ; drawing in and down of shoulder, retraction of upper arm, with occasional contraction in part of triceps going from humerus to scapula ; at elbow rarely extension, sometimes flexion."

§ 22. Besides the movements obtained by stimulating a posterior spinal root are the results obtained by Sherrington * on the isolated length of the brachial enlargement on stimulating the skin of the palm of the hand ; the reflex movements obtained were as follows :

Thumb, flexion—adduction.
Shoulder, retraction, later protraction.
Wrist, extension.
Elbow, flexion.
Fingers, flexion.

It is therefore evident that even in the highest animals, as the monkey, it is possible to evoke such highly co-ordinated movements as the above.

§ 23. The mechanism by which this is effected is by the afferent fibres of the posterior root, which either sends branches forwards in the grey matter of the spinal cord to the neighbourhood of the cells of the anterior cornua, or the cells of the posterior cornua are interposed between the posterior root fibres and the anterior cornual cells. Whether for the purposes of producing such co-ordinated movements as those obtained by stimulating the palmar surface, the two-cell system is sufficient, it is difficult to say, but it has been suggested † that the two cells are probably connected by the help of a mediate system of cells. The time at my disposal will not permit me to go into this question, but there is evidently in the cord itself a nervous organisation which can produce co-ordinated movements reflexly on stimulating the skin or the posterior spinal roots, but

* 'Schäfer's Text-book of Physiology,' p. 816.
† 'Schäfer's Text-book,' vol. ii, p. 804.

whether the co-ordination is the same as that occurring in voluntary movements it is difficult to say. I should mention that Prof. Gad* was the first to ascribe to the posterior cornual ganglion cells in the frog the function of connecting together the cells for the flexors of the ankle, knee, and hip.

Representation of Single Movements in the Cortex Cerebri.

§ 24. The representation of movements in the excitable area of the cortex cerebri next claim our attention. Time will not permit me to enumerate the various observers, from the pioneers Hitzig and Ferrier to the present day, nor is it my intention to discuss the much-vexed question whether the so-called motor or, as it is better to call them, the excitable areas of the cortex, are motor, sensori-motor, or sensory. But that they depend on sensory impressions for the power of exciting movements is shown by the remarkable observations of Mott and Sherrington,† who found that after dividing all the posterior spinal roots of the brachial enlargement of the cord, the voluntary movement of grasping by the hand was permanently lost, while movements of the limb could be elicited with apparently normal facility by electrical stimulation of the part of the cortex where the movements of the upper limb are represented.

§ 25. I wish particularly to refer to the results obtained by Sir Victor Horsley and myself on stimulation of the excitable cortex in the monkey,‡ and the orang.§ In the monkey we examined every two square millimetres of the excitable cortex, and we found in certain squares where the upper limb was represented, that the co-ordinated movements of flexion of the fingers and thumb, extension of the wrist, and flexion of the elbow was obtained, and though flexion of the fingers and flexion of the wrist were also obtained in other parts of the cortex, flexion of the thumb and fingers with extension of the wrist were much more frequently the rule. Another co-ordinated movement which was obtained was that of opening the eyes and simultaneous turning of the head and eyes to the opposite side, a combination described previously by Dr. Ferrier.

§ 26. The results obtained from stimulating the excitable area of the cortex were always co-ordinated movements, and never the con-

* 'Festschrift der Med. Facult.,' Würzburg, 1882.

† 'Proc. Roy. Soc.,' 1895, vol. 57.

‡ 'Phil. Trans.,' vol. 178 B, 1887; vol. 179 B, 1888.

§ *Loc. cit.*, vol. 181 B, 1890.

traction of a single muscle, unless a movement was performed entirely by a single muscle. The frequent association of the extensors of the wrist with the flexors of the fingers and thumb was sufficiently frequent to warrant the opinion that a synergic association existed between those two sets of muscles.

§ 27. The results which Sir Victor Horsley and myself obtained from our experiment of stimulating electrically the cortex in the orang thirteen years ago have been in the main confirmed by the more extensive researches of Sherrington and Grünbaum,* who have added to the number of movements which we had found to be represented in the excitable cortex. In the one case which we examined, the representation of movements was found chiefly in the ascending frontal convolution, but we also obtained movements of the index finger, of the thumb, of the orbicularis oris, of elevation of the upper lip, and of pouting of both lips from stimulation of the ascending parietal convolution. Sherrington and Grünbaum, however, failed to get any evidence that any movement was represented in the ascending parietal convolution. In the orang, the movements that we obtained were nearly always single movements, such as flexion of the elbow, flexion or extension of thumb, and they differed from those obtained in the monkey in that the sequence of movements occurring from stimulating one spot, which Dr. Hughlings Jackson has termed the "march," was rarely obtained. The best example of this sequence of movements which we obtained in the orang was the movement of opening the eyes, followed by that of turning the eyes to the opposite side, and ending with the movement of turning the head to that side. Professor Sherrington has been good enough to inform me that they did obtain in their experiments sequence of movements including the combination of flexion of the fingers and thumb with extension of the wrist, and though they agree with us that the representation of the movements in the excitable cortex of the anthropoid apes is much more differentiated than in that of the monkey, they did obtain evidence of the representation there of such co-ordinated movements as that of grasping.

Representation of Single Movements in the Internal Capsule.

§ 28. The co-ordinated representation of muscles for a definite movement which was found to exist in the excitable cortex of the

* 'Proc. Roy. Soc.,' vol. 69.

monkey is also found in the internal capsule according to the investigations by Sir Victor Horsley and myself.*

In these experiments the internal capsule was cut across horizontally, and every square millimetre of its fibres was stimulated electrically. In almost every one of the experiments—which were forty-five in number—we obtained from one of these squares the movements of flexion of the thumb and fingers and extension of the wrist, and frequently flexion of the elbow and adduction of the shoulder.

The association between the flexion of the thumb and fingers and the extension of the wrist was most marked and occurred so often that the association must be for a synergic purpose.

§ 29. The association between the flexors of the fingers and the extensors of the wrist has been well shown by some interesting experiments by Hering,† who stimulated electrically the cortex in the monkey about one millimetre above the angle of the precentral sulcus, where Ferrier, and Horsley and Schäfer had produced the movements of closing the hand into a fist, and where Sir Victor Horsley and myself ‡ had found flexion of the fingers and extension of the wrist. Hering first stimulated this part and produced the characteristic closure of the fist. He then cut through the tendons of the extensores carpi radialis longus et brevis, and he then obtained not only flexion of the fingers but also flexion of the wrist owing to the absence of the synergic action of the extensores carpi radiales. Also, when in place of dividing the tendons of the extensors of the wrist, he divided the tendons of the flexors of the fingers, the wrist was extended but the fingers were not flexed when the same part of the cortex was stimulated. Hering also performed the same experiment and got the same results by stimulation on the horizontally cut surface of the internal capsule, the fibres which we had found to give flexion of the fingers and thumb and extension of the wrist. These experiments are very strong evidence that co-ordination of synergic movements takes place in the excitable area of the cortex.

* 'Phil. Trans. Roy. Soc.,' 1890.

† 'Archiv für Physiologie,' 1898.

‡ 'Phil. Trans. Roy. Soc.,' 1887.

Relation between the Representation of a Single Movement in the Spinal Cord and in the Excitable Cortex.

§ 30. What, then, is the relation between these two parts of the nervous system? We have seen that there is in the grey matter of the spinal cord a mechanism by which, on stimulation of the posterior root fibres, a series of co-ordinated movements are produced, and that it is also possible by excitation of the cerebral cortex to produce co-ordinated synergic movements.

The questions before us are:

(1) Does the co-ordination of a simple voluntary movement take place in the spinal cord? Or

(2) Does the co-ordination of a simple voluntary movement take place only in the excitable cerebral cortex?

From a consideration of these two main questions the following subsidiary questions arise:

(*a*) If this co-ordination take place in the cord is there a mechanism (by this I mean an arrangement of cells) which is put into action by an impulse travelling down the pyramidal tract from the excitable cortex?

(*b*) If there be a mechanism in the spinal cord for receiving cortical impulses is it identical with the mechanism for receiving impulses from the skin for the production of reflex actions?

(*c*) If all co-ordination take place in the cortex, so that there is no intermediate co-ordinating station between the cortex and the muscle, then is the mechanism in the spinal cord used only for reflex actions?

§ 31. In speaking of the relation between the representation of simple movements in the cord and in the cortex I would ask: Can all the reflex movements which are elicited by stimulation of the posterior roots or of the skin be reproduced voluntarily? It is well known that certain reflexes, such as coughing, can be performed voluntarily, and can be inhibited and prevented from taking place. while others, like sneezing and the sexual reflex, cannot be voluntarily performed and cannot be inhibited, but with regard to the skin reflexes I do not know that the question has been raised, and it occurred to me to try and reproduce them voluntarily. The plantar reflex can, I think, be reproduced voluntarily, though I am not sure that the order in which the muscles contract can be exactly imitated. The cremasteric certainly cannot be reproduced voluntarily. The abdominal and epigastric reflexes are those in which the middle line of the abdomen is drawn to one side reflexly by scratching with a quill pen along the side of the abdomen. I was rather surprised to find that it was quite impossible to reproduce voluntarily the epigastric or abdominal reflex, and I have not yet met with a person who could voluntarily draw the umbilicus to the right or left of the middle line.

My time is too short to go into the question whether some of these superficial reflexes are spinal or cerebral * in origin, and to discuss why they are frequently lost in hemiplegia, but assuming that they are spinal, we have co-ordinated movements produced reflexly by stimulating the skin, but which cannot ordinarily be reproduced by voluntary effort. The fact, that an ordinary individual is not able to reproduce voluntarily the particular co-ordination which can be elicited as a cutaneous reflex, would mean, either that this particular co-ordination was represented in the cord but was not represented also in the excitable cortex, or that, if the movements obtained by exciting the cortex were also represented in the spinal cord, the mechanism by which these movements were co-ordinated was not the same as that by which the cutaneous reflexes were brought about.

At present I do not think that we are in the position to decide whether these reflexes are of cerebral or of spinal origin, and in view of the inability to reproduce voluntarily all the cutaneous reflexes, and on the supposition that the movements obtained by stimulating the cortex are also co-ordinated in the spinal cord, the question will have to be worked out whether the mechanism in the cord used for cortical impulses is identical with that used for co-ordinating the movements obtained reflexly by irritating the skin.

§ 32. I will now pass to the relation of the excitable cortex to the co-ordination of simple movements.

The relation of the excitable cortex to the co-ordination of simple movements has been discussed by various authors (Kölliker, Waldeyer, Mann, Förster), but the time at my disposal will not allow me to go into the history of the subject. As some authors have raised the question whether single muscles can be put into action by a cortical pyramidal cell, I may say at once that this is a condition which I believe never occurs, except there be a movement in which only one muscle takes part. The

* Schiff, 'Archiv für Exp. Path. u. Pharm.,' Bd. iii, 1874.

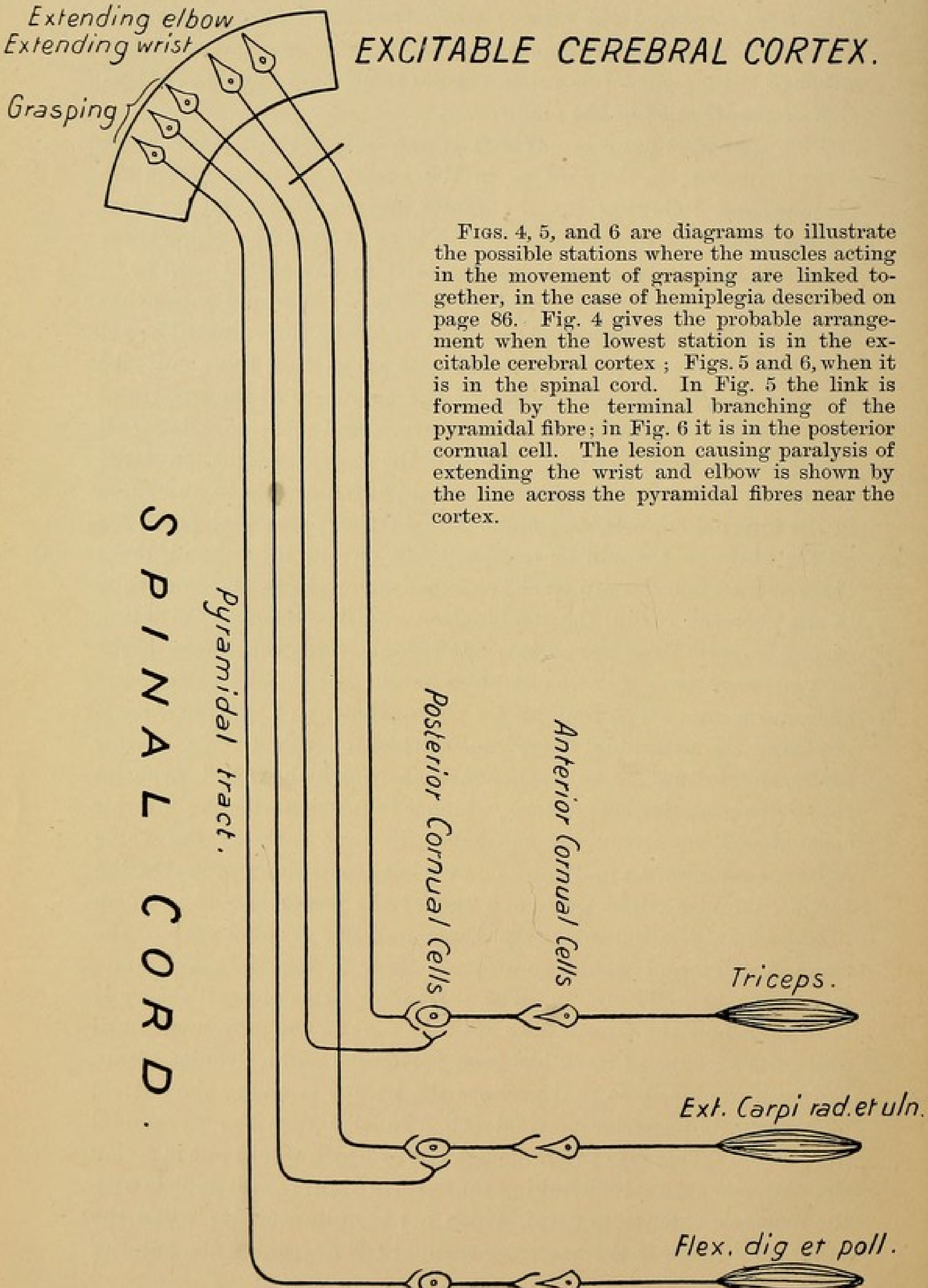
results obtained by stimulation experiments and also by clinical observation of epileptic attacks and of hemiplegia, due to lesions of the cortex or of the internal capsule, are all in favour of the view that movements and not single muscles are represented in the arrangement of the cortical cells and of the fibres forming the internal capsule. This is the doctrine taught by Dr. Hughlings Jackson.

§ 33. As I therefore consider that only co-ordinated movements are represented in the excitable cortex, I will give in illustration of this view a case which I have lately seen at the Marylebone Infirmary through the kindness of Mr. Lunn. It was that of a man with recent hemiplegia—and here in passing I would remark that I do not think much can be learnt with regard to co-ordination from old cases of hemiplegia who have recovered one or two movements, but in whom there are probably secondary changes in the spinal cord. In describing this case I would remind you of what I said in a previous lecture (p. 70), that in strong movements of closing the fist in grasping, the prime movers are the flexors of the thumb and fingers, the synergic muscles are the extensors of the carpus, and the fixation muscles are the triceps followed by the biceps.

The case was that of a patient suffering from hemiplegia, in whom contrary to the usual course the return of power had commenced in the hand, and he could perform the movement of grasping, but he had no power to extend the wrist or to flex or extend the elbow. On getting this patient to grasp with his full strength I noted that in addition to the contraction of the flexors of the thumb and fingers, there was a contraction of the synergic muscles of extending the carpus and also of the fixation muscle, the triceps; and, further, that the action of the triceps was not felt to contract till a certain strength of grasp was reached. The important point is that the patient had not the slightest power to contract the extensors of the carpus, when he was told to perform the movement of extending the wrist, or of the triceps when he was told to extend the elbow. In this case, therefore, where the lesion was probably in the internal capsule, the only fibres which were available for impulses emanating from the so-called "arm-centre" of the cortex were those coming from that part where the movements of grasping were co-ordinated, whereas the fibres conducting impulses emanating from the part of the cortex where extension of the wrist and extension of the elbow were represented were unable to pass. In other words the patient could put into action the extensores carpi and the triceps when they acted as synergic and fixing muscles in the movement of grasping, but he could not make either of them contract as prime movers in the movements of extension of the wrist or of the elbow.

§ 34. The next point is: Where is the link between these three sets of muscles; in the cord or in the cortex? Starting from the muscles and following up the motor nerves, where is the first station where the arrangement of cells is to be found by which these three sets of muscles work together; is it in the spinal cord or in the cortex? If it be in the cortex (see Fig. 4) it would mean that there must be three sets of cells which would be co-ordinated to act together for this purpose; it would also mean that there must be separate cells for the movements of the extensors of the wrist and the elbow for their action as prime movers, and separate cells for all the different combinations. Though the cortex might be large enough to contain all these cells it would be impossible to find room in the internal capsule, and much less in the pyramidal tract, for all the fibres that would be required. If, on the other hand, these three sets of muscles are joined together under the guidance of cells in the posterior cornu, the combination would be thrown into action by one impulse from the cortex. It is conceivable that there might be two ways in which the impulse might act on the cells of the posterior cornu. The impulse for the movement of grasping, passing down the pyramidal fibre, might, when it reached the posterior cornu, divide into three branches, each of which would arborise round the posterior cornual cell, which is in relation with the anterior cornual cell supplying the muscular fibre of each of the three different muscles, as in Figure 5; or what seems more probable, the cortical impulse might go to one cell of the posterior cornu, which would be in relation with the three anterior cornual cells of the three muscles, and would co-ordinate their actions into a definite movement, as in Figure 6. The difficulty of this one-cell theory is to explain how the triceps does not take part in the movement until a definite amount of work has been performed and a definite strain has been produced, so that perhaps the triceps is under the control of a separate posterior cornual cell. In this case the pyramidal fibre would divide into two branches, one of which would put in action the posterior cornual cell linking the flexores digitorum et pollicis with the synergic extensores carpi, which act simultaneously; while the other would pass to the posterior cornual cell governing the anterior

Fig. 4.



Figs. 4, 5, and 6 are diagrams to illustrate the possible stations where the muscles acting in the movement of grasping are linked together, in the case of hemiplegia described on page 86. Fig. 4 gives the probable arrangement when the lowest station is in the excitable cerebral cortex; Figs. 5 and 6, when it is in the spinal cord. In Fig. 5 the link is formed by the terminal branching of the pyramidal fibre; in Fig. 6 it is in the posterior cornual cell. The lesion causing paralysis of extending the wrist and elbow is shown by the line across the pyramidal fibres near the cortex.

Fig. 5.

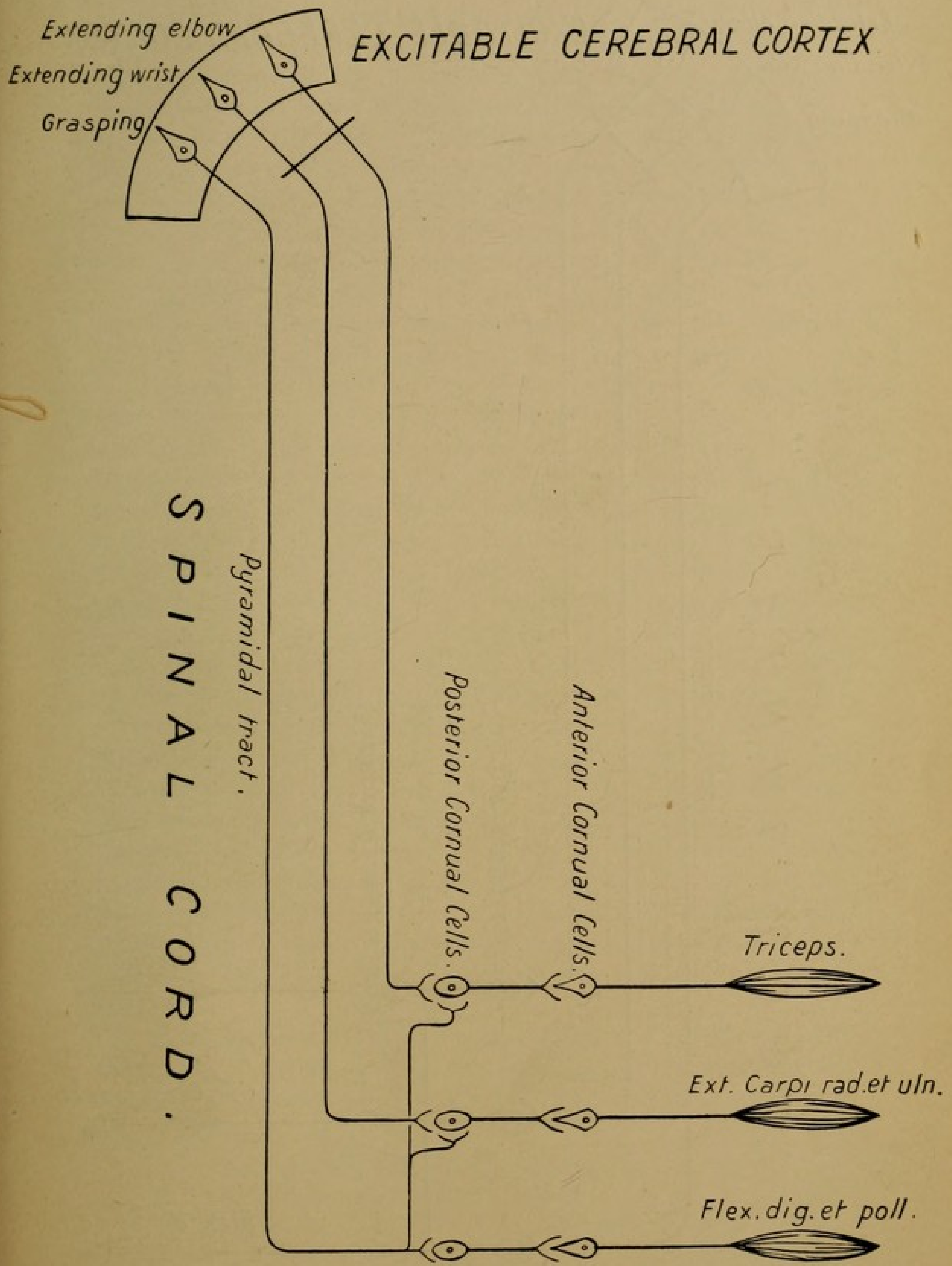
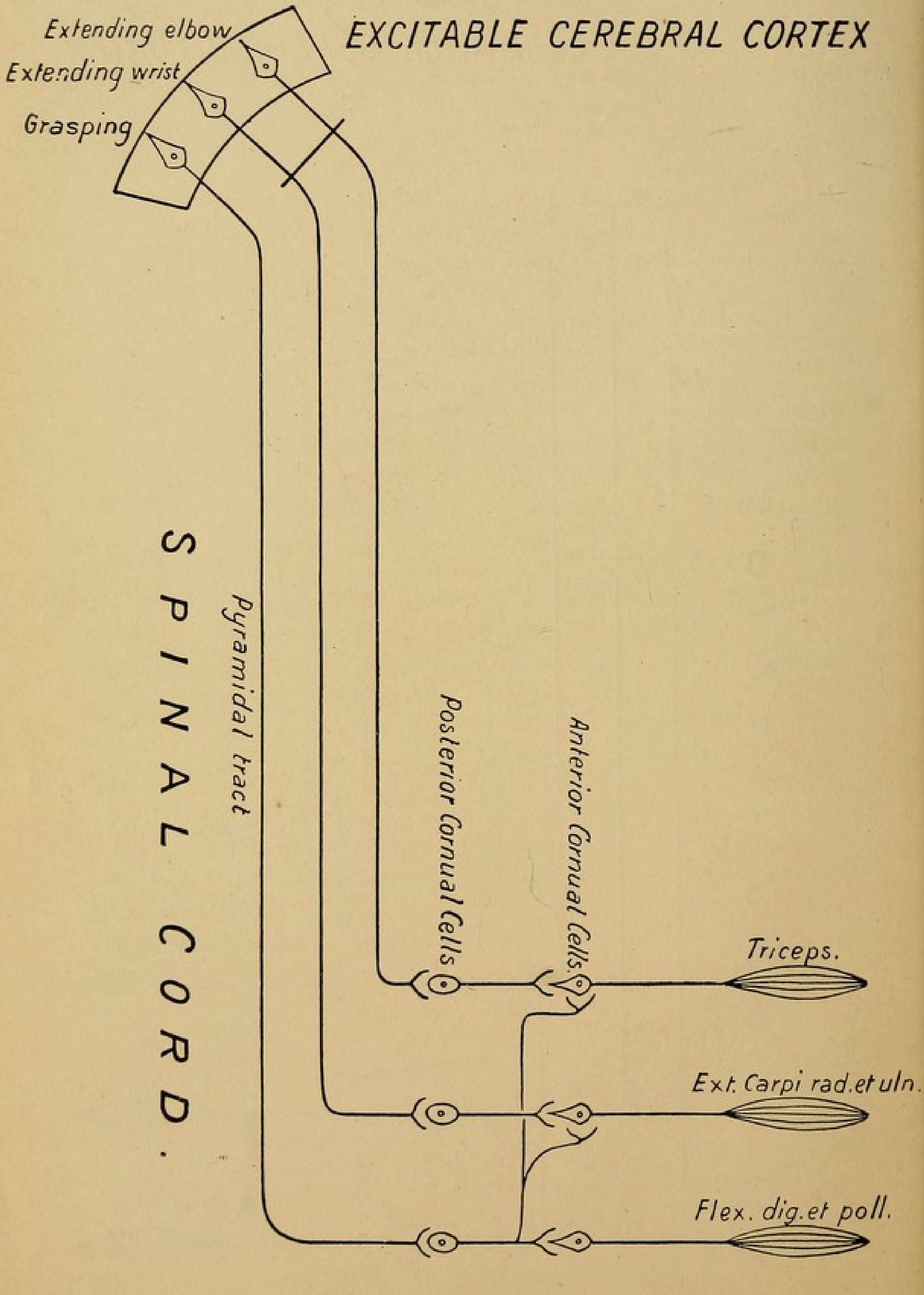

Extending elbow
Extending wrist
Grasping
EXCITABLE CEREBRAL CORTEX
SPINAL CORD.
Pyramidal tract.
Posterior Cornual Cells.
Anterior Cornual Cells.
Triceps.
Ext. Carpi rad. et uln.
Flex. dig. et poll.

Fig. 6.


Extending elbow
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EXCITABLE CEREBRAL CORTEX
SPINAL CORD.
Pyramidal tract
Posterior Cornual Cells
Anterior Cornual Cells.
Triceps.
Ext. Carpi rad. et uln.
Flex. dig. et poll.

cornual cell of the triceps, which muscle would not then come into action until a certain force had been exerted.

§ 35. I think that the question is best approached by examining what takes place in the movement of lateral deviation of the eyes. If the part of the cortex in the angle of the precentral sulcus of—let us say—the left side be stimulated in the monkey, both eyes move conjugately to the right, and if the particular fibres of the left internal capsule be stimulated the same effect is produced. Conversely, if the left cortex or the left capsule be paralysed, either as the result of a gross lesion of this particular part of the cortex or capsule, or as a temporary result following an epileptic fit, as I showed to occur,* the eyes deviate to the left. These fibres passing through the left internal capsule and the left crus cerebri cross to the opposite side to the nucleus of the right sixth nerve, from whence fibres pass over to the part of the left third nucleus, or third nerve, which presides over the left rectus internus oculi muscle. In this case the link between the right external rectus and the left internal rectus takes place in the medulla in the sixth nucleus, as suggested by Foville. The proof of this is that, in lesions of the right sixth nucleus without involving the third nuclei or the pyramidal tract, the same conjugate paralysis of the eyes with deviation to the left is produced as from a lesion of the left cortex.

Now, although these two muscles, the external and internal recti, are on opposite sides of the body, this conjugate movement of the eyes is as much a unilateral movement † as that of closing the fist, for the reason that on stimulation of the left cortex the two eyes turn always to the right and not to the left. I think, therefore, that we are justified in inferring that the principle which underlies the simple movement of turning the eyes to the right can also be applied to the simple movement of closing the fist, and that the link between the three sets of muscles, the flexors of the fingers and thumb, the extensors of the carpus, and the triceps, takes place somewhere below the internal capsule, and by analogy in the spinal cord.

§ 36. It has been shown by von Monakow ‡ and by Schäfer § that the ending of the fibres of the pyramidal tract is in the neighbourhood of the posterior horns and not in the anterior horns, as was

* 'Brain,' 1882.

† See 'Phil. Trans. Roy. Soc.,' 1890, B, p. 73.

‡ 'Archiv für Psych.,' 1895, Bd. xxvii.

§ "Proc. Phys. Soc.," 'Journ. of Phys.,' 1899, vol. xxiv.

formerly thought to be the case. Monakow also thinks that there are intermediate cells between the anterior cornual cell and the ending of the pyramidal fibre, and that this cell has the power to bring out associated movements.

§ 37. It therefore seems probable that the co-ordination or the link between the muscles entering into a simple movement takes place in the cells of the posterior cornua, which are put into action by impulses coming down the pyramidal tract from the excitable cortex, where these movements are also represented. Whether the same co-ordinating mechanism in the spinal cord is used alike for reflex actions as well as for cortical impulses, or whether there is a separate mechanism for each, I do not think, as I said before, that we can give a certain answer.

§ 38. Now as the most complicated and intricate muscular performances are only an arrangement of simple movements in some particular order, it is probable that in learning some new combination of movements, such as playing the violin, fencing, or golfing, the simple movements represented in the excitable cortex are in response to visual or auditory impressions brought into action in their proper combination and sequence. Later on the combination learnt with difficulty becomes by frequent practice automatic. But as these learnt combinations, or even such an elementary combination as walking, become automatic, there does not seem to me to be sufficient evidence that their seat of co-ordination is transferred from the brain to the spinal cord, for the reason that if there ensue a lesion of the cortex or of the internal capsule, all these so-called automatic movements are lost.

With regard to the above-mentioned complicated performances, I would like to mention that driving at golf differs from most muscular exercises in that the exact action of striking the ball has to be accomplished by the co-ordination of the large coarse muscles of the spine and the shoulders acting at the end of a flexible club some five or six feet distant from the shoulder. As these large muscles are not in the habit of being called upon to perform fine work, the beginner naturally tends to use the muscles of the wrist which are accustomed to fine movements, and in so doing he commits the error of "pressing."

Representation in the Cortex of Homolateral Movements.

§ 39. In conclusion, I would like to make some remarks about the question of representation in the cortex of movements of the body on the same side as the cortex stimulated, or in other words if the—let us say—left cortex is stimulated what movements, if any, are produced in the left arm and leg. I do not propose to go into the question of the representation in one hemisphere of such bilateral movements as pouting of the lips, mastication, and adduction of the vocal cords. Sir Victor Horsley and myself discussed this question in our paper on the "Internal Capsule,"* and the matter has been exhaustively dealt with by Sir Victor Horsley and Professor Gotch in their Croonian lecture before the Royal Society.† The question is rather to find out what single movements, if any, are produced on the same side as the cortex stimulated and the strength of current which is required to evoke these movements.

§ 40. The subject has been referred to by various authors. Hitzig ‡ in his first memoir remarked that if the currents were feeble, their action was localised on the muscles of the opposite side of the body, but if stronger, the muscles on the same side of the body were put into action.

François-Franck,§ experimenting on cats and dogs, found that weak currents produced movements of the opposite anterior limb, and if the current be stronger, movements of the anterior limb of the same side were produced, but after those of the opposite side. He also found that the movements persisted on the two sides in spite of removal of the opposite cerebral cortex, section of the white matter of the centrum ovale, division of the corpus callosum, median section of the bulb, or after section of one half of the cord on the same side as the cortex stimulated. He therefore considered that the movements are not caused by impulses conveyed from one hemisphere to the other, and he came to the conclusion that the association between the two sides can only take place in the spinal cord by the transverse commissures.

According to Unverricht || in dogs when the motor cortex of one side—let us say the left—was stimulated, epilepsy was produced on the right side and also on the left side. He also obtained convulsions on both sides when unilateral cortical extirpation or hemisection of the cord was performed, and this is, he considers, a proof that the convulsions on the same side only arise by centri-

* 'Phil. Trans. Roy. Soc.,' B, 1890.

† 'Phil. Trans. Roy. Soc.,' B, 1891.

‡ 'Du-Bois Reymond's Archiv,' 1870.

§ 'Lecons sur les Fonctions Motrices du Cerveau,' Paris, 1887.

|| 'Volkmann's Klin. Vortr-Innere Medicin,' Nr. 55—78, 1897—1900.

fugal excitation in the spinal cord itself. But after double-sided cortical extirpation it is not possible to produce clonic contractions.

§ 41. As I believe that no researches of this nature have been made on monkeys, I have made some observations with Sir Victor Horsley, whom I have to thank for performing the operation of electrically stimulating under ether the motor cortex in monkeys. Four experiments have been done, and the general results that we obtained were as follows:

1. On stimulating the cortical "arm centre" by faradisation with the bipolar method when the current was of the strength of 16–8 centimetres between the coils, the first movement was in the arm of the opposite side.

2. On increasing the current by diminishing the distance between the coils to about 6 cm., movement was obtained in the arm on the same side as that stimulated.

3. The character of the movement on the same side was usually identical with that evoked on the opposite side, but in one case where the movement began with extension of the fingers, it was followed on the same side by adduction of the shoulder.

4. When the cortical "leg centre" was stimulated, the movements on the same side appeared rather sooner than in the case of the arm and in some cases as weak a current as 12 cm. between the coils produced movements in the leg of the same side.

5. Epilepsy was obtained in all the cases in the arm of the opposite side, in three cases it was not obtained in the arm of the same side, even with the coils at 4 cm. apart, and in two out of the three cases that it was looked for in the lower limb, epilepsy occurred on the same side as that stimulated.

The first movement of the epilepsy on the same side was the same as that obtained on the opposite side.

6. After excising the excitable cortex from the opposite hemisphere, on stimulating the cortex of the intact hemisphere in two of the cases no movements were obtained on the same side as that of the cortex stimulated. In the third case, where movements of interosseal flexion of the fingers, flexion of the wrist and pronation were obtained on the opposite side, the most frequent movement on the same side was slow flexion of the fingers under deep narcosis, but under slighter narcosis the movements were the same as on the opposite side. In the fourth experiment the only movement obtained on the same side was slow flexion of the elbow, whether the stimulation was applied to the "arm centre" or to the "leg centre."

In this animal, when the internal capsule was exposed and stimulated, very slow flexion of the elbow was obtained on the same side, when extension of the wrist and flexion of the fingers were obtained on the side opposite to the stimulated capsule: also very slight extension of the hip and knee were obtained on the same side, when marked extension of the toes and flexion of the thigh and knee were obtained on the opposite side.

7. No epilepsy was obtained on the same side as the cortex stimulated, when the opposite cortex was removed.

The above experiments are hardly sufficient in number to prove for certain whether the movements occurring on the same side of the body as the cortex stimulated are evoked from the opposite cortex by means of the corpus callosum or from the endings of the pyramidal tract through the commissural fibres of the spinal cord.

In two of the cases after removing the left motor cortex there was no movement at all in the right arm on stimulating the right cortex, although there was marked movement in the whole of the left side, and even in one case epilepsy. In the third case the same movement—slow flexion of the elbow—was produced on the same side irrespective of the place stimulated, and in only one case, the fourth, was there any correspondence of movement between the two sides.

§ 42. On the whole the experiments, as far as they go, are in favour of the theory that in the monkey the movements obtained on the same side as the cortex stimulated are produced from the opposite cortex through the corpus callosum rather than through the commissural fibres of the spinal cord, and that epilepsy is not obtained in the same side of the body as the cortex stimulated if the opposite cortex be removed.

Table of Muscles for movements of the upper limbs.

Joints.	Movements.	Prime movers.	Synergic muscles.
Fingers: 1st phal. . .	Flexion	Flex. subl. et prof. dig. Interossei et lumbricales	Ext. carpi rad. longior et brev. Ext. carpi ulnaris.
,, ,, . .	Extension	Ext. com. dig.	Flex. carpi rad. et ulnaris. Palmaris longus.
2nd & 3rd phal.	Flexion	Flex. subl. et prof. dig.	Ext. com. dig.
,, ,, .	Extension	Ext. com. dig. Interossei et lumbricales	
Finger index .	Abduction	Abductor indicis	Ext. metacarp. pollicis. Ext. brevis pollicis.
,, fourth .	Abduction	Abduct. min. dig.	Flex. carpi ulnaris. Ext. metacarpi poll.
Thumb: Distal phal. .	Flexion	Flex. long. pollicis	Ext. brevis poll. et ossis metacarpi.
,, ,, .	Extension	Ext. long. pollicis Abd. et add. pollicis Flex. brevis pollicis	
Proximal phal.	Flexion	Flex. long. et brev. poll. Abd. et add. poll.	
,, ,, .	Extension	Extens. brev. poll.	
Metacarpal .	Flexion	Abd. et add. poll. Opponens poll. Flex. brevis poll. Flex. long. pollicis	Extens. brevis pollicis.
,, .	Extension	Ext. ossis metacarpi poll. Ext. brevis poll.	Extensor carpi ulnaris. Flexor carpi ulnaris.
,, .	Abduction	Abd. et oppon. poll. Flex. brevis poll. Ext. metacarpi poll. Ext. brevis poll.	Extensor carpi radialis brevior. Extensor carpi ulnaris.
,, .	Adduction	Adductores poll. Extens. long. poll.	? Palmaris longus. ? Flexor carpi ulnaris.
,, .	Opposition	Abd. et oppon. poll. Flex. brevis poll. Adductores poll.	
Thumb & fingers	Flexion	Flexores pollicis Flexores digitorum Inteross. et lumbric.	Extensor carpi radialis. Extensor carpi ulnaris.

Table of Muscles for movements of the upper limbs—continued.

Joints.	Movements.	Prime movers.	Synergic muscles.
Wrist . . .	Flexion	Flexor carpi radialis Palmaris longus Flexor carpi ulnaris Ext. metacarpi poll. Flex. dig. (sometimes)	
,, . . .	Extension	Extensores carpiradiales Extensor carpi ulnaris Ext. long. pollicis Ext. digit. (sometimes)	
,, . . .	Abduction	Flexor carpi radialis Extensores pollicis (3) Ext. carpi radialis	Thenar muscles.
,, . . .	Adduction	Flex. carpi ulnaris Ext. carpi ulnaris	

Joints.	Movements.	Prime movers.	Synergic muscles.	Fixation muscles (essential).
Radio-ulnar .	Pronation	Pronat. teres Pronat. quadratus Flexor carpi radialis (sometimes) Palmaris longus (sometimes)	Triceps	Abductors of shoulder.
,, .	Supination	Supinator brevis Biceps Extensores carpi radiales (sometimes) Extensor carpi ulnaris (sometimes)	Triceps (ext. and int. heads)	Adductors of shoulder.
Elbow . .	Flexion	Biceps Brachialis anticus Brachio-radialis (supinator longus) Pronator radii teres Flexores carpi (sometimes)	Extensores carpi	Muscles of shoulder.
,, . .	Extension	Triceps Anconeus		Muscles of shoulder.
Shoulder .	Advancing to horizontal line	Deltoid (anterior) Pectoralis major (clavicular) Biceps Coraco-brachialis(?)	Triceps (ext. and int. heads)	Trapezius (acromial). Trapezius (inferior). Erectores spinæ [*positional*].

Table of Muscles for movements of the upper limbs—continued.

Joints.	Movements.	Prime movers.	Synergic muscles.	Fixation muscles (essential).
Shoulder .	Advancing above horizontal line	Serratus magnus Trapezius (acromial) Trapezius (inferior)		
,,	Abduction to horizon	Deltoid (middle) Supra-spinatus Biceps	Triceps (ext. and int. heads	Trapezius (acromial). Trapezius (inferior). Opposite rectus abd. [*positional*]. Opposite erector spinæ [*positional*].
,, .	Abduction above horizon	Serratus magnus Trapezius (acromial) Trapezius (inferior)		
,, .	Depression	Pectoralis major (sternal) Latissimus dorsi Teretes major et minor Infra-spinatus Triceps (long head) Subscapularis (?)	Biceps and brachio-radialis	Trapezius (inferior). Rhomboidei. Pectoralis minor. { Recti abdominis. { Obliqui externi.
,, .	Retraction	Latissimus dorsi Teretes Infra-spinatus Deltoid (posterior half)		Trapezius (inferior). Rhomboidei. Pectoralis minor.
,, .	Adduction	Pectoralis major (all) Latissimus dorsi Teretes major et minor Infra-spinatus Subscapularis (?) Deltoid (posterior one-third)		Trapezius (inferior). Rhomboidei. Pectoralis minor. { Rectus abdominis. { Erector spinæ.
,, .	Horizontal adduction	Coraco-brachialis Pectoralis major (sternal)		Recti abdominis.
,, .	Horizontal abduction	Deltoid (middle) Deltoid (posterior) Latissimus dorsi		Trapezius (except clavicular). Erector spinæ (of same side).

Table of Muscles for movements of the upper limbs—continued.

Joints.	Movements.	Prime movers.	Synergic muscles.	Fixation muscles (essential).
Shoulder .	Horizontal abduction (*continued*)	Teretes major et minor Infra-spinatus Subscapularis (?)		
„ .	Rotators in	Pectoralis major (both parts) Deltoid (anterior) Teres major Latissimus dorsi Subscapularis		Rhomboideus major (when humerus horizontal).
„ .	Rotators out	Teres minor Infra-spinatus Deltoid posterior		Trapezius (inferior)

Muscles for movements of head.

Joints.	Movements.	Prime movers.	Fixation.
Head (Occipito-atloid)	Flexion	Sterno-mastoids Platysmata Omo-hyoids Sterno-hyoids Sterno-thyroids Mylo-hyoids Recti capitis antici	Recti abdominis. Obliqui externi.
„	Extension	Trapezii (clavicular) Complexi Splenii capitis Trachelo-mastoids (?) Recti capitis postici Obliqui inferiores (?)	
Head (Atlanto-axial)	Rotation (face to right)	Left sterno-mastoid Left trapezius (clavicular) Right splenius capitis Right trachelo mastoid (?) Right platysma Right omo-hyoid Right obliquus inferior (?) Right rectus capitis major (?)	
Head (Atlanto-axial)	Adduction (to left shoulder)	Left sterno-mastoid Left trapezius (clavicular) Left splenius capitis Left omo-hyoid Left platysma Left obliquus superior (?) Left rectus capitis lateralis (?)	

Extraordinary muscles of respiration.

	Movements.	Prime movers.	Fixation.
Extraordinary Respiratory	Inspiration	Sterno-mastoids Pectorales minores Scaleni ? Latiss. dorsi Serrati magni Pectoralis major at end of forced inspiration	Extensores capitis.
	Expiratory	Latissimi dorsi Abdominal muscles	

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