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Address

THE COORDINATION OF SINGLE MUSCULAR MOVEMENTS IN THE CENTRAL NERVOUS SYSTEM.*

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It is with a deep sense of the great honor which has been bestowed on me that I come before you, and I can assure you that I appreciate very much the invitation which your chairman sent me to give an address before the Section on Nervous and Mental Diseases of the American Medical Association. I must confess to feeling somewhat disconcerted at the imposing names of professors who have preceded me, and I must crave your indulgence if I fail to attain the high standard which they have set.

In choosing a subject it seemed to me that the great value of international meetings or of the custom of inviting members of another country to give addresses consists largely in the opportunity it offers of bringing forward subjects which may not have engaged the attention of the members of the profession over here and may thus be the means of directing their thoughts into fresh channels. For this reason I have chosen the subject of the coordination of muscular movements in the central nervous system, as it is one of great importance from a practical as well as from a theoretical point of view and one which perhaps has not received the amount of attention which it merits.

First, it will be necessary to state what is meant by a muscular movement, what the different classes of muscles are which take part in any particular movement.

By the term muscular movement I mean the single movement of one joint, such as flexion of the thumb, or of several similar joints, such as flexion of all the fingers and the thumb as in grasping; I do not refer at present to such a combination of movements as are involved in the act of walking. Now what are the different classes of muscles which may take part in any particular movement, such as that of flexion of the fingers and thumb in the act of grasping? We have first the muscles which do the work, viz., the flexors of the fingers and thumb and which are called the prime or principal movers. We also have the antagonists to the movement, i. e., those muscles which produce the movement which is the opposite to the one we wish to perform, viz., the extensors of the fingers and thumb. Furthermore, we have to notice that the prime movers, the flexors of the fingers and thumb in their course from their origin in the forearm to their insertion into the phalanges pass over the wrist joint, and it will be evident that after these muscles have flexed the thumb and fingers they will also tend to flex the wrist.

This movement of flexion of the wrist, however, is not wanted, and it would be very awkward if, whenever we grasped an object firmly, the wrist would persist in flexing. How is this difficulty to be overcome? It is done by bringing other muscles into action which will prevent the wrist being flexed, and the muscles which can do this are the extensors of the wrist; so that whenever we perform the movement of grasping, the extensors of the wrist contract and their tendons on the dorsum of the wrist can be seen and felt to become tight. These muscles are called synergic muscles because they work with the prime movers whenever these muscles pass over two joints, and they neutralize the action of the muscles which is not required.

Other muscles which take part in simple movements are those which we may call fixation muscles, as they fix and prevent any movement in the joints intervening between the joint, in which the movement required is being performed, and the trunk. Taking the movements of the fingers as an example, it is found that in flexing the fingers against resistance, when the forearm is in the position of supination, the tendency of the resistance, if strong, is to overcome and extend the wrist and the elbow, and in order to counteract this tendency the flexors of the wrist and the flexors of the elbow—the biceps, supinator longus and other muscles —contract to fix the wrist and elbow joints. We have, therefore, the following classes of muscles which may take part in a movement: 1. Prime or principal movers. 2. Synergic muscles. 3. Fixation muscles. 4. Antagonists.

PRIME OR PRINCIPAL MUSCLES OF MOTION.

Taking first the prime or principal movers, we have to take into account in performing a movement whether muscles forming the prime movers all contract together, or whether there is any sequence, and whether the same sequence is always preserved. It is not easy to find a group of muscles in which it can be ascertained which particular muscle is contracting first. But in supinating the forearm the two chief muscles are the supinator brevis and the biceps, and if no work is being done it is possible to supinate the forearm without producing any contraction of the biceps.

Another example of this is shown in flexing the elbow. If this joint be flexed lifting only the weight of the forearm, the biceps is seen and felt to contract without any action of the supinator longus, and the joint can thus be kept in a position of flexion with the forearm at right angles to the vertical humerus.

Another group of muscles which I have lately observed is that of the flexors of the hip. Some of the

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muscles such as the psoas and iliacus, are too deep and can not be seen or felt to contract; but there are two, the sartorius and the rectus femoris, which are easily seen and felt. Besides flexing the thigh on the trunk, they will also flex the trunk on the thigh, if the latter be the fixed point, and it is in this movement that a differentiation can best be made out.

To show this the person should stand erect on one leg and have the other resting on a chair, with the knee and thigh flexed. The person should incline slightly forward, so as to bring the center of gravity in front of the foot on which he is standing. On then inclining backward, so as to shift the center of gravity behind the foot, the flexors of the hip of the leg resting on the chair will contract to prevent the trunk falling backward, and the only muscle which will be seen to contract is the sartorius. If then the person incline still further back the rectus femoris will be seen to act but without the vasti externus and internus. This, by the way, illustrates the point that one part of an anatomic muscle can take part in a movement and not the rest of it.

The important point is that we have no power to make the rectus contract before the sartorius. The same thing can be shown by flexing the hip when in the position of sitting down, but it is then more difficult to differentiate the muscles, as merely raising the weight of the limb is sufficient to bring out both muscles. Why the sartorius should contract first it is difficult to say, unless it be that, as it arises from the anterior superior iliac spine instead of from the anterior inferior iliac spine, it can exercise more leverage and so is more capable of fine adjustment.

These examples show that in every movement the prime movers contract in a regular orderly sequence and that the muscles successively come into action, adding to their number according to the amount of work that is required to be done.

In describing the mode of action of the prime movers which take part in any movement I raised the question some years ago[1] whether a muscle acting on a rotatory or a ball and socket joint ever takes part as a prime mover in two movements, which are diametrically opposed to each other.

To illustrate this point I will take, first, the action of the supinator longus as a pronator and a supinator of the radio-ulnar articulations; next the action of the upper or clavicular fibers of the pectoralis major, which were stated by Duchenne from electrical stimulation to be both elevators and depressors of the humerus; then the posterior fibers of the deltoid, which were stated by Duchenne also from electric stimulation to be both adductors and abductors of the hanging humerus; and, last, the action of the two sternomastoids in flexing and also extending the head and neck in the position of extreme extension.

As to the first of these examples, the supinator longus, I still consider that it does not take part in both supination and pronation—in fact, I do not think it takes part in either. The opinion which I expressed regarding the clavicular fibers of the pectoralis major as being elevators and never depressors of the humerus I am glad to find has received the approval of Merkel.[2] Next, the posterior fibers of the deltoid I consider to be adductors and never abductors of the humerus—an action about which opinions differ—and, last, the sternomastoids also are, in my opinion, never extensors of the head and neck. The muscle which might act in two opposite ways is the latissimus dorsi, the large flat muscle which extends from the iliac crest and lower half of the spine to the humerus. This muscle has always been described in the text-books as an extraordinary muscle of inspiration, but as I showed ten years ago[3] it is evidently a muscle of expiration, as any one can prove for himself by putting the fingers on the posterior fold of the axilla and giving a good cough, or, if one prefers, indulging in immoderate laughter; and it is evidently one of the muscles which are affected in Milton's line from *L'Allegro:*

> Sport that wrinkled care derides
> Laughter holding both his sides.

With regard to inspiration, I have found that this muscle does not take part in such severe dyspnea as occurs in pneumothorax or pneumonia, though it does act in the emotional movement of sobbing and yawning. With the exception of the latissimus dorsi, whose action as an inspiratory muscle I think is doubtful, I do not know of any muscle in the body which takes part as a prime mover in two actions diametrically opposed to each other.

SYNERGIC MUSCLES.

Taking next the synergic muscles, of which I have already given one example, I would say that another example is seen in the movement of extending the thumb; here the extensors of the thumb pass over the wrist joint and would abduct this joint, but to prevent this movement, which is not wanted, the ulnar adductors, the flexor carpi ulnaris and the extensor carpi ulnaris contract and thus fix the wrist joint; so that in extending the thumb we contract at the same time the ulnar carpal muscles. Another example is that of the extension of the fingers, where the principal movers are the extensors of the fingers, and the synergic muscles are the flexors of the wrist.

In the movement of supination we have also a good example. The chief supinator is the biceps, but this muscle is also a powerful flexor of the elbow, and yet it is perfectly easy to supinate strongly without flexing the elbow. The explanation is that the biceps takes part in two movements by passing over two joints, viz., flexion of the elbow and supination of the forearm, and if only supination is required the triceps contracts as a synergic muscle and counteracts the flexion of the elbow by the biceps; so that whenever we perform strong supination only, the triceps contracts.

I have recently been examining the action of the synergic muscles in the movements of the leg, which has not, I believe, been previously observed. In flexion of the hip the sartorius acts when the movement is slight and the rectus femoris comes in when the movement becomes stronger. But the sartorius also is a flexor and a rotator in of the knee joint, and the rectus femoris is an extensor of the knee and a more powerful muscle than the sartorius. Therefore, in strong flexion of the hip when the knee is bent, the knee would tend to be extended and also to be rotated in. On carefully examining the muscles at the back of the thigh I find that in this movement the biceps contracts; this muscle, it will be remembered, is the hamstring, which arises by two heads from the femur and from the ischial tuberosity and is inserted into the head of the fibula. The in-

1. Brain, 1891, p. 51.
2. Ergebnisse der Anatomie, 1905.
3. Brit. Med. Jour., Oct. 1, 1898.

teresting point is that although its tendon becomes tense in this movement, its long head arising from the ischial tuberosity can not be felt to contract. The only actions which are here required of this muscle are flexion and rotation out of the knee, to counteract the extension of the knee by the rectus and the rotation in by the sartorius; the long head does not contract presumably because extension of the hip is not required, as it would be antagonistic to the movement we wish to perform, viz., flexion of the hip.

Again, extension of the hip is performed by the hamstrings, i. e., the biceps, semimembranosus and semitendinosus, but these muscles also flex the knee, and if the latter movement is not required, as in extending the hanging lower limb against resistance applied to the back of the thigh, the vasti contract to prevent flexion of the knee, but not the rectus femoris, as this last would also tend to flex the hip, a movement which is antagonistic to the one required.

The relation between the prime movers and the synergic muscles is very close, and it seems impossible to contract one without the other. For instance, it is not possible to extend the thumb in the slightest degree without causing a contraction of the extensor and flexor carpi ulnares, and if the prime mover be paralyzed by a lesion of the peripheral nerves the synergic muscles go on contracting and produce movements which are not intended.

As Duchenne pointed out, if the extensors of the fingers be paralyzed or weakened by a peripheral neuritis and the patient be asked to extend the fingers, the only effect is to flex the wrist by the synergic muscles, the flexors of the wrist, which go on contracting as though nothing had happened. The brain sends down a message to the two sets of muscles, and if one set—the prime movers—happens to be weak, the other set—the synergics—get their full amount and produce a movement—flexion of the wrist—which is quite different to extension of the fingers, which was required.

Apparently the brain has no power to moderate the impulse sent to the synergics to make them act proportionately to the weak prime movers. The close relation is also well shown by performing the movement of clenching the fist tightly and at the same time flexing the wrist. In the first movement the flexors of the fingers and thumb contract and also the extensors of the wrist to prevent the wrist being flexed; in the other movement the flexors of the wrist contract strongly. We have, therefore, two different movements to be carried out, and I have found that in the first movement the synergics—the extensors of the wrist—are so closely connected with the prime movers that they will continue acting and will oppose and antagonize the flexors of the wrist, the prime movers in the other movement. This opposition is the cause of the strained effort which is experienced when these two movements are performed at the same time.

The intimate relation is also shown by the fact that the synergic muscles act in all positions of the joint. Duchenne thought that the function of the synergics was to put the muscles of the prime movers in the greatest elongation in order to augument their dynamic power, but this I think can not be their true use, as is shown by the following procedure: If the thumb be extended the synergic muscles, the extensor and flexor carpi ulnares contract to prevent the wrist being abducted; if, however, the wrist be first passively abducted to the radial side, and then the thumb be extended, the synergic muscles will still contract without, however, improving the position of the joint and enabling the extensors of the wrist to work at a greater advantage.

FIXATION MUSCLES.

I have already mentioned the fixation muscles of the flexors of the finger, and I now wish to refer to the extensors of the fingers and their fixation muscles. If the wrist be in the position of pronation, and the fingers be extended against resistance, this resistance if strong enough will tend to overcome the wrist and cause it to flex. So to prevent the wrist from being flexed the extensors of the wrist take part in the movement, and to prevent the elbow being extended by the pressure the biceps contracts. It is to be observed that the extensors of the wrist and the biceps as fixation muscles do not come into action at once, but that a certain amount of resistance has first to be experienced; it seems, however, that as soon as the joints begin to be displaced by the extra pressure then the fixation muscles contract.

In the action of the extensors of the wrist as fixation muscles in the movement of extension of the fingers, an interesting clinical fact has long been observed in lead paralysis. In some cases of lead paralysis we see the following well-known condition: The patient has paralysis of the extensors of the fingers, but not of the extensors of the wrist, and if he be told to extend the wrist in the ordinary way with the fingers flexed he can do so and the tendons of the extensors of the carpus can be felt and be seen to stand out at the wrist. When, however, the patient is told to extend the wrist with the fingers straight, he gets the phalangeal joints straight by means of the interossei and lumbricales muscles which extend those joints, but he is unable to extend the metacarpo-phalangeal joints owing to paralysis of the extensors of the fingers, and the only thing which takes place, as Duchenne pointed out, is that the wrist is flexed owing to the synergic action of the flexors of the wrist, for, as I have already pointed out, whenever we wish to extend the fingers the flexors of the wrist contract to prevent the wrist being extended.

But the most interesting point is that the patient has absolutely no power to make his extensors of the wrist, which are not paralyzed, contract so long as he is trying to extend his wrist with the fingers kept straight, and no tightening of the tendons of the extensors of the wrist can be felt. This condition has been known for some time but had not been explained, and a few years ago I made some observations to see what occur in health. Such observations anyone who wishes can readily make on himself.

Put the left thumb on the back of the right wrist over the tendon of the extensor carpi radialis, and the left first finger over the right flexor carpi ulnaris just above the pisiform bone; let the right fingers remain flexed and extend the wrist, and at once the tendon of the carpi radialis can be felt to contract. If now one starts again and extends the right fingers fully one feels at once the tendon of the synergic muscle, the flexor carpi ulnaris, to contract. If the wrist be now extended, keeping the fingers extended, the flexor carpi ulnaris tendon is still taut, but the thumb does not feel any contraction on the tendon of the extensor carpi radialis, showing that all the work is done by the extensors of the fingers. But if the wrist be now extended, with the fingers extended, against resistance, it can be done by pressing the back of the fingers upward against the under surface of a table, what will happen? After the pressure has reached a certain point the thumb will feel the extensor carpi radialis contracting, which shows that the extensors of the wrist are now assisting the extensors of the fingers to overcome the resistance which would otherwise cause the wrist to flex. The important point is that if the fingers be kept fully extended, the extensors of the wrist will not take part in the movement until the pressure to be overcome is considerable; in my own case it was as much as three or four pounds.

The fact that in health the extensors of the wrist will not take part in the movement of extending the wrist, until there is a fear that the resistance of the wrist will be overcome, places these muscles in the category of fixation muscles, which, as I have already mentioned, do not take part in a movement until there is a certain amount of stress on the joint. In lead paralysis the patient tries to extend his fingers and manages to extend the phalangeal joints by the interossei and lumbricales, but he has no power to contract the paralyzed extensors of the fingers and to produce the tension of three pounds which is necessary to bring into the movement the action of the extensors of the wrist.

The interesting point is that the patient has no power to make the extensors of the wrist contract so long as they are in a secondary position as fixation muscles, but they can do so at once as prime movers.

Another instance of fixation muscles is the contraction of the muscles of the upper arm, which occurs when the fingers and thumb flex in the movement of grasping an object. The flexors of the fingers, arising as they do from the internal condyle of the humerus, have a slight action of flexing the elbow and, especially when the elbow is at a right angle, to prevent this flexion and to steady the elbow joint the triceps contracts, but, like other fixation muscles, it does not contract until a certain amount of displacement takes place. In my own case I can not feel the triceps contract until the dynamometer has registered a grasp of from six to ten pound (3-5 kgs.).

In describing the action of the prime movers I have made mention of the muscles which produce exactly the opposite movement, viz., their antagonists.

For instance, in the movement of flexion of the fingers the antagonists are the extensors of the fingers (but not the extensors of the wrist which are synergic muscles), and in the movement of flexion of the elbow the antagonists are the triceps and anconeus. I do not propose to give you the history of the action of the antagonists and the antagonism which they have given rise to among authors. I would merely say that I think Galen was right and that Winslow and Duchenne were wrong in their ideas of the subject.

Beaunis[4] and Demeny,[5] by means of Marey's myographs, showed that the antagonists relax when any resistance is made to a movement, but that in natural movements (when there is no resistance) and which are at a slow and uniform rate, there occurs a simultaneous action of the antagonists. According to Winslow, who thought that "to move any part . . . all the muscles belonging to it must cooperate," the want of action of the antagonists is in many cases supplied by the weight of the part to which they are fixed or by additional weight. This would mean that when gravity is acting on a limb or a weight is being lifted the antagonists do not act. Therefore, the only time that the antagonists might act is in unopposed movements when gravity is not acting. I have pointed out in a previous communication[6] that the movements of rotation of the head in the erect position are particularly adapted to determine this point, as they are unopposed and not acted on by gravity, and that in rotation of the head by one sternomastoid no contraction can be felt or seen in its antagonist, the other sternomastoid.

In some unopposed movements, which are required to be suddenly stopped, the antagonists certainly do act, but not in opposed movements, as every one experiences when he makes a great effort to lift an empty can which he thinks is full of water, with the result that he lifts it suddenly much higher than was intended.

Professor Sherrington[7] has shown by numerous experiments that electric stimulation of the excitable cerebral cortex not only produces a definite movement by causing contraction of the muscles directly taking part in the movement, but also produces corresponding relaxation of the antagonists by inhibiting their tone, and this occurs with even minimal stimulation.

But perhaps some may say, what does it matter whether the antagonists contract or relax, and does any practical use come from the knowledge? Apart from the dictum that every observation which is correct is worth recording, I do consider that this question of the relaxation of the antagonists is even of practical use to us. It is sometimes very difficult to get a patient to relax certain muscles which we wish to examine, as, for instance, the deltoid muscle—an abductor of the shoulder—when we may wish to know whether the patient is able to abduct the humerus or not, or whether the inability to move the shoulder is due to a rheumatic joint. For this purpose it is only necessary to ask the patient to put the adductor muscles into action, and to strongly adduct the humerus against resistance, when the deltoid will be relaxed. The muscle can then be freely moved between the finger and thumb, and on then telling the patient to abduct his humerus it will be possible to tell at once whether the muscle is capable of contraction or not.

Another use of this knowledge of the relaxation of the antagonists is that in a certain class of cases this relaxation of the antagonists which should normally occur does not do so. About five years ago I described the following condition which occurred in a case of functional paralysis in a girl: She had partial hemiplegia, and when she was told to extend the affected elbow against resistance, in place of the extensor muscles contracting, and the antagonists—biceps, brachialis anticus and supinator longus—relaxing, the antagonists actually contracted first, and the first movement took place in the biceps and supinator longus. This was followed by contraction of the triceps and again by the biceps, giving rise to the to-and-fro hesitating movement which is so characteristic of attempted movements in functional cases.

Since seeing this first case I have come across many cases of functional paralysis showing the same inability to inhibit the antagonists. This condition can also be well seen in the knee; for this purpose the patient lies with the face downward and the leg is put at right angles to the thigh and the patient is directed to extend the knee against resistance. Normally the hamstrings

4. Arch. de Physiol., 5th series, I, 1889.
5. Arch. de Physiol., 5th series, II, 1890
6. Croonian Lectures, 1904, p. 54.
7. Proc. Roy. Soc., vol. lxxvi, B., 1905.

should be relaxed at once, but in these cases these muscles can be seen and felt to contract along with the extensors.

In the ankle joint the same thing can be seen, by telling the patient to dorso-flex the ankle against resistance. In a normal person the antagonists—the calf muscles—would be relaxed, but in these cases the Achilles tendon can be felt to tighten in place of being relaxed. In all these cases it is necessary for the observer to fix the limb and prevent it moving; otherwise, as the joint is extended or flexed, the antagonists may be passively drawn on and give the impression that their muscles are actively contracting.

What, then, is the significance of this action of the antagonists? The first time that I observed this contraction of the antagonists was seven years ago, in the case to which I have already referred, and which I considered to be hysterical or functional and in which there were no signs of organic disease of the nervous system. It has been considered by some observers, notably by Buzzard, that some of these cases of functional paralysis may be the first stages of disseminated sclerosis, and I have been waiting to see if any of these cases should eventually shows signs of this disease. I have lately had the opportunity of seeing again my first patient, and I find that she does not show after seven years any symptom of sclerosis. There is no nystagmus, no intention tremor, no increase of the deep reflexes and the plantar reflex is of the flexor type.

As I have never seen this condition in disseminated sclerosis or in any other organic disease of the nervous system I consider it to be a symptom of functional disease as opposed to organic. Moreover, I look on this condition as probably the first stage of what is known as hysterical contracture. In hysterical contracture all the muscles—the flexors as well as the extensors—are in a state of tonic contraction, so that the limb is rigid and resists any movement either by flexion or extension. It seems probable that if this intermittent contraction of the prime movers and the antagonists were to become permanent we should have the condition of tonic contraction of all the muscles which goes to produce a general contracture. I have observed that under appropriate treatment, isolation and faradization, this undue action of the antagonists gradually passes off and the muscles return to their natural condition with relaxation of the antagonists when any voluntary movement is performed.

In relation to this condition of the contraction of the antagonists I would call attention to some observations of Sherrington,[8] who, as I stated above, has found that when any particular movement, such as flexion of the elbow, is produced by electrical stimulation of the motor area in the cortex of the monkey, the antagonists are not only relaxed, but their tone is diminished. Recently, however, he has found that under the action of strychnin or of tetanus toxin the antagonists are not relaxed, but, on the contrary, the inhibition which usually takes place is converted into an excitation. We thus have synchronous excitation of antagonistic muscles, and this explains the simultaneous contraction of large inharmonious groups of muscles in strychnin convulsions.

Another point of interest is that in both strychnin and tetanus-toxin poisoning, and as also in functional conditions, the character of the convulsive attacks which are liable to occur is that of overaction of the extensors producing the well-known symptom of opisthotonus and forming in the latter condition the hysterical *arc en cercle* of Charcot and his school. I do not wish to push the analogy too far, but I would merely point out that it is curious that the two conditions in which we obtain the absence of the inhibition of the antagonists and also the presence of convulsive attacks in which the extensors of the spine are strongly involved, are obtained in functional (i. e., hysterical) cases, and also in poisoning by tetanus toxin and strychnin. I suppose that in each case the cause is a loss of control.

According to Sherrington, tetanus and strychnin poisoning "work havoc with the coordinating mechanisms of the central nervous system because in regard to certain great groups of musculature they change the reciprocal inhibitions, normally assured by the central nervous mechanism, into excitations." Sherrington thinks that the reactions elicitable from the cortex cerebri under strychnin are due not to the action of this agent on the cortex but by alterations produced in the spinal and bulbar centers on which the cortex acts. He also states that in other fields of action, as in the arcs of purely sensual and perceptual level, one cortical element may inhibit another cortical element. It seems more probable that in so-called hysterical paralysis the loss of control takes place in the cerebral cortex rather than in the spinal cord and that this loss of control transforms the inhibition of the antagonists into excitation of these muscles.

We have now to sum up the various muscles taking part in a movement and to consider where in the nervous system these muscles are linked together.

We may have, therefore, in any single movement such as the closure of the hand the following classes of muscles taking part: The prime or principal movers, the flexors of the fingers and thumb; the synergic muscles, the extensors of the wrist; and the fixation muscles, the triceps and biceps. The principal movers frequently consist of two or more muscles, and these muscles, as in the case of the flexors of the elbow and of the extensors of the hip, come into action in a definite order according to the amount of work required to be performed, and, further, it seems that the will has no power to alter this order or to make a muscle act out of its turn (except perhaps by trained exercises). Again, in those muscles which have two or more movements by passing over two or more joints, the synergic muscles come into action at the same time as the principal movers, and here again the will has no power to prevent these muscles acting or to leave them out of the list. Lastly we have the fixation muscles, which fix the joint or joints intervening between the joint under examination and the trunk and which do not come into action until a certain pressure and displacement has been brought to bear on the joint.

The question which we have now to consider is in what part of the nervous system are these groups of muscles linked together as to form a movement? There are two places where this may take place—in the spinal cord and in the motor cortex. Now, if we start from the muscles and follow up the motor nerves, where in the nervous system is the first station where such an arrangement of cells exists by which the ultimate component muscles can be combined to form one movement?

It has been shown by the experiments of Sherrington and of May that in the spinal cord coordinated movements can be obtained reflexly in the monkey by stimu-

8. Proc. Roy. Soc., 1905, vol. B., 76.

lating the posterior roots, or the different areas of skin supplied by these roots. According to Sherrington,[7] the inhibition of the antagonists which occurs on stimulation of a peripheral nerve or by excitation of the cortex cerebri, appears in both cases with some likelihood to lie in an internuncial mechanism—synapse or neurone—between the afferent and efferent neurones. He, therefore, thinks with Exner[9] that in the cortical movements the inhibitory phenomena have their chief seat in the spinal mechanisms though elicited from the cortex. Sherrington and Hering also found on stimulating the cut across the internal capsule that the spot where the triceps was inhibited corresponded exactly to the place where the biceps was stimulated to contract.

In favor of the lowest station for cortical movements being in the spinal cord and not in the cortex are the following considerations: There is a mechanism in the cord by which muscles can be coordinated to produce definite movements and by which their antagonists can be inhibited. Coordinated movements with inhibition of the antagonists can be obtained from stimulating the internal capsule similar to those from the cortex cerebri. It is not possible to produce contraction of single muscles by stimulation of the cortex or internal capsule.

Also in a previous communication[10] I have described a case of hemiplegia in which the patient had the power of grasping but had no power to extend the wrist or to extend the elbow in prime movements. When, however, he grasped an object the extensors of the wrist and the extensor of the elbow were put into action, as synergic and fixation muscles, although they could not be made to contract as prime movers. In this case all the muscles taking part in the movement of grasping, even the fixation muscles, were coordinated into action, but these same muscles were paralyzed, when they took part in another movement, where they were prime movers. This showed that these muscles were coordinated at some point below the internal apex.

Further it was found by Ferrier that the coordinated movement of clenching the fist, in which the flexors of the fingers and thumb and the extensors of the wrist took part, could be obtained from stimulation of the motor cortex in the monkey, and Sir Victor Horsley and myself also found the same movement from stimulation of the internal capsule in the monkey.

It hase been considered by some observers—among others by O. Foerster—that this linkage of the ultimate components of a movement takes place in the motor cerebral cortex and that single muscles and not movements are represented in the cortex. This is a doctrine with which I can not agree, as I hold fast to the opinions of John Hunter and Duchenne and particularly of Hughlings Jackson, that "nervous centers know nothing of muscles; they only know of movements."

If the motor cortex were the lowest station, where these muscles are linked together to produce one movement, it would hardly be possible to get the simultaneous action of the flexors of the thumb and fingers together with the synergic action of the extensors of the wrist from stimulation of the internal capsule; and if every combination between different muscles had to be arranged in the cortex and impulses had to be sent from the cortex to each separate muscle the number of fibers required to transmit the various combinations would be much more than is provided for by the internal capsule and the pyramidal tracts.

It seems to me that all the evidence is in favor of the linkage of the ultimate constituents of a movement being in the spinal cord. It has been shown by von Monakow[11] and by Schafer[12] that the pyramidal fibers end in the gray matter at the base of the posterior horns and not in the anterior horns, as was formerly thought, and that probably there exist intermediate cells between the ending of the pyramidal fiber and the anterior cornual cell, and that these have the power to bring about associated movements. A clinical fact which throws light on this subject is mentioned by Foerster[13] as occurring in locomotor ataxia, and it is a condition which I can corroborate. In cases in which there is loss of the sense of position in the upper limbs, if the patient be asked to clench the fist with the eyes open he can do so in a normal manner, but if he tries to do it with the eyes closed the wrist will be flexed at the same time, owing to the want of action of the synergic extensors of the wrist. The reason of this seems to be that the proper combination of the principal movers and of the synergic muscles can not take place if the posterior cornua are affected as they are in some cases of tabes, and the faulty position has to be rectified when the patient has his eyes open by a voluntary extension of the wrist. This, I think, is evidence that the lowest station where these muscles are linked together for a voluntary movement is in the spinal cord. Whether the mechanism by which these voluntary movements are produced is identical with that used for reflex movements is, I think, uncertain.

It therefore seems probable that the mechanism by which the muscles taking part in a single movement are linked together, is situated in the cells of the posterior cornua of the spinal cord, which cells are acted on by impulses from the excitable cerebral cortex. Take, for instance, the action of supination of the foramen. If only a weak action is required as in simply moving the limb, the impulse coming to the posterior cornual cells is weak, and these cells send a message to the anterior cornual cells of the supinator brevis only. If stronger action is required, a stronger impulse is sent to the posterior cornual cells which stimulate the anterior cornual cells of the biceps, and at the same time those of the triceps which act synergically to prevent the elbow from being flexed by the biceps. If a stronger movement still is required the fixation muscles, viz.: the adductors of the shoulder are brought into action by the posterior cornual cells to prevent the humerus being drawn away from the trunk by the very strong pressure to be overcome.

A very good simile is that of an engine room on board an ocean liner. The captain on the bridge sends down messages to the engine room and his orders are put into action by the engineer, but the captain has nothing to do with the mechanism of turning on the particular steam cocks, etc. The captain also gives messages to the man at the wheel, who puts in action the steam steering gear. The captain on the bridge represents the cerebral mechanism, including the motor area, and the engineer represents the posterior cornual cells and turns on the proper amount of steam. The captain does not know what is going on in the engine room, except by his orders being properly carried out,

9. Pflüger's Arch., xxviii.
10. Croonian Lectures, 1903.
11. Arch. für Psych., 1895, Bd. xxvii.
12. Proc. Physiol. Soc., Jour. of Phys., 1899, xxiv.
13. Die Physiologie und Pathologie der Coordination, 1902.

and likewise the brain knows nothing about how the movements are done. If the ship have twin-screws and be driven by turbines, then the engines for going astern will constitute the antagonists to the prime movers for going ahead. The rudder will represent the synergic muscles, and if it be required to turn the ship to the right the rudder will be used to counteract the action of the right screw, which is not required. If the rudder does not act the ship performs a movement, which the captain did not intend, and if the synergic muscle be paralyzed the movement, which the brain ordered, is wrongly carried out, and neither the captain nor the brain knows that it will happen, as the block takes place either in the engine room or at the periphery from the breaking of a screw shaft, i. e., in the anterior horns or in peripheral nerves.

On the other hand, if the mechanism for coordinating the muscles took place entirely in the brain, it would mean that the captain would have to manage all the machinery of the engine room—which would have to be on deck—and would himself have to turn on the necessary steam cocks, and at the same time he would have to steer the ship himself.

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DISCUSSION.

Dr. Charles K. Mills, Philadelphia: Dr. Beevor's illustration of the manner in which movements occur and are coordinated is an appealing one, but at the same time (as in all our efforts to illustrate problems of philosophy or biology) by comparison there may be present some little source of fallacy. The cerebral cortex, I think, at least takes part in the regulation of the manner in which the movements which are coordinated and are arranged for outward expression in the spinal cord occur. Dr. Beevor has by his presentation of the subject of the non-relaxation, or action contrary to intention, of antagonistic muscles in hysterical subjects, given us a valuable addition to our methods of making a diagnosis of hysteria from organic disease.

Dr. F. X. Dercum, Philadelphia: While familiar in a way with Sherrington's results, I was not prepared for the beautiful exposition of muscular movements to which we have just listened. The fact that in a hysterical palsy or hysterical contracture the opponent muscles do not relax is of great practical value—a sign which, like the Babinski sign, will prove useful in differentiating between functional and organic palsies. In regard to the localization of the co-ordinating function. I am inclined to accept Dr. Beevor's view, that the cortex represents the motion only and has nothing to do with the muscles.

What rôle does Dr. Beevor assign to the cerebellum in this beautiful play of action between the cortex and the associations in the spinal cord?

Dr. Hugh T. Patrick, Chicago: There is one muscular sign which Dr. Beevor was the first to observe and describe, that is, the excursion upward of the umbilicus in some cases of paraplegia. Within a week I have had opportunity to observe it in two cases. In one case the sign was not particularly useful because the sensory symptoms made the spinal localization easy; but in the other case there were no sensory symptoms, and the only means of ascertaining the level of the cord where this lesion was, causing complete paraplegia, was what, I believe, Dr. Beevor calls the umbilicus sign. In a severe lesion of the cord at about the tenth dorsal segment, of course the muscles of the abdomen above that level are not paralyzed, and those below that level are. Consequently, with the patient recumbent, if the arms are folded across the chest, and the patient raises the head off the pillow, or perhaps a little better attempts to raise the shoulders, the recti muscles above the umbilicus contract, the recti muscles below can not contract and the umbilicus moves upward one-half an inch, three-fourths of an inch, even an inch. In a case in which the sensory symptoms are not so distinct as to make the level apparent, this sign practically settles the localization. For instance, in a case of spinal tumor with sufficient pressure on the cord to cause paraplegia, with no marked anesthesia, but with imminent danger of destruction of the cord, and with no deformity whatsoever, this Beevor's umbilicus sign tells us just where the tumor is, where the incision should be made, which laminæ are to be removed to expose the tumor.

Dr. Morton Prince, Boston: I recall a number of facts of which Dr. Beevor has not spoken, which are entirely in accord with his main proposition, that is, that this linking together, this association at least, of these movements, is to be found in the spinal cord rather than in the brain. This association, this co-ordination of movements in a certain part of the nervous system, reduced to its simplest terms, is in the final analysis memory.

Since the great classical work of Herring we all know that memory is not simply a conscious attribute, but an attribute of all living matter, of a cell, and the spinal cord as well as of the brain; and therefore, when Dr. Beevor points out that this linking together may be in the spinal cord in such a way as to be reproduced on a certain stimulus from the brain, all he means to say, of course, is that the spinal cord possesses memory, which is well known. The memory of these primary movements and these synergic movements, and of these movements which are a part of all organic matter, is particularly within the function of the spinal cord. Witness the classical experiment of the movements obtained by stimuli applied to a decapitated frog, which is nothing more than the reproduction of these primary and synergic movements; also the experiments of Charington and another on the brainless dog, in which they obtained movements of running, jumping and leaping, all representing these movements which Dr. Beevor has explained, and which, therefore, must be organized and linked together as memories in the spinal cord or in other ganglia. We have a mechanism by which this all can take place in the center below that of the brain; and this fact seems in harmony with the fact that so very few fibers coming down through the foraminal tract can produce this vast variety of movements which we know emanates from below, from the cord. Dr. Beevor's theory of that particular phenomenon which he found in hysteria, namely, the contraction of the antagonistic muscle from lack of inhibition of that antagonistic muscle in hysteria, is entirely in accord with the entire lack of inhibition observed in hysteria.

Dr. William G. Spiller, Philadelphia: I think that in associated movements in another sense, conclusions confirming Dr. Beevor's findings might be drawn. Where, for example, the left upper limb is paralyzed and the man has little control of it, yet there is occasionally seen an associated movement of the right and left upper limbs; as, for example, when the patient closes the right hand, the left closes involuntarily. It is reasonable to believe that associated movements, especially those of a reflex character, at least in part, depend on centers below the cortex, as it is produced even when the right side is cut off from the brain. Goltz's dog ran after the cerebrum was removed. Babinski has stated that it is common in hysteria for the antagonistic muscles to be contracted. Does Dr. Beevor regard that contraction of the antagonistic muscles which he says occurs in hysteria, as the result of suggestion? Babinski holds that all hysterical phenomena are produced by suggestion.

Dr. D. I. Wolfstein, Cincinnati: I once saw Oppenheim differentiate a case of multiple sclerosis from hysteria by the suspected ankle clonus which resulted. The other physicians had considered the movements that they got on the plantar portion of the foot as a distinct dorsal ankle clonus, whereas Oppenheim showed that the movement was upward instead of downward. It would be interesting to know whether that has anything to do with the innervation from the cortex. It seems to me that we must invest the cortex cerebri with an intelligent controlling influence.

In the case of the decapitated frog, when we take a piece of paper and wet it with acid and put it on the back, and see the frog make apparently intelligent motions—just as intelligent probably as if it had a cortex left—what we do see is that there is an excess of somewhat uncontrolled motion resulting in the frog's efforts to liberate itself from the irritation; and it seems to me that the rôle of the cerebrum would be the proper gradation of the exact amount of movement, and the exact amount of force, that is required in stimulating the antagonists and protagonists to produce the proper action.

DR. H. A. TOMLINSON, St. Peter: In my study of the reflexes in newborn babies, I made some observations that tend to confirm the conclusions of Dr. Beevor. In the newborn child the muscles of prehension and locomotion are flexed, and the extremities are flexed and adducted, while the trunk muscles are relaxed. Combinations of reflexes are begun by bringing into play the synergic muscles, then the fixation muscles, and finally the extension or antagonistic muscles. In all coordinate combinations of the reflexes it is fixation and extension that accomplish the movement; so that what I have described as the sequence in the building up of a compound reflex, Dr. Beevor has observed as the sequence in the carrying out of single muscular movements in the adult.

DR. M. ALLEN STARR, New York: I consider the matter of differentiation between the organic and the functional type of movement a very valuable point in connection with Dr. Beevor's observation. Possibly his observations have a tendency to confirm a position advanced in 1904 by Lapinsky in the *Deutsche Zeitschrift für Nervenheilkunde.* We have always been taught that each group of cells in the cord is related to a muscle, and that when that muscle moves that one group of cels is called into play. Lapinsky took the position that each group of cells in the spinal cord is not related to a muscle, but to a movement; and that therefore, when I flex my fist I do so by sending a cortical impulse down through the pyramidal tract to a group of cells, which group of cells is thrown into activity and innervates the various muscles; and he substantiated this position by citing the well-known fact that a single group of cells sends out its motor neurons to the anterior motor nerve roots: those motor nerve roots split up in the various plexuses, consequently a given group of cells of the spinal cord sends out impulses to a great number of different muscles. I have seen no reference to this interesting theory, opposed, as you see, to all our doctrines of the relations of spinal functions, and the relations of groups of cells to groups of muscles; but it seems to me important in connection with these observations of Dr. Beevor, for it supplies us immediately with the spinal mechanism which will explain the action of these various muscles without forming a connection between the pyramidal tract and the group of cells in the cord—a hypothetical group of cells in the posterior horns of the cord which he brings in—hypothetical, because we do not know of groups of cells in that portion of the tract. Therefore, this theory of Lapinsky would substantiate in that way Dr. Beevor's conclusion, giving us a physico-anatomic basis for the findings that Dr. Beevor has made from the physiologic side.

DR. CHARLES K. MILLS, Philadelphia: Taking Dr. Beevor's illustration of the captain and the engineer and the machinery; has not a given region of the cerebral cortex the power, so to speak, to elect that a simple movement, a movement less simple, a complicated and a more and more complicated movement, shall be performed by the machinery, whatever it is, in the lower levels of the nervous system; and if this be the case in the sense in which we ordinarily use our words in describing cerebral localization, do not given regions of the cerebral cortex even represent the prime and synergic and antagonistic and all of these coordinated movements? That seems to me the crucial question in this discussion.

DR. JULIUS GRINKER, Chicago: Has Dr. Beevor included in his beautiful experiments the involuntary contractions of single muscles and the disorders of associated movements which are regular phenomena of Sydenham's chorea? Most writers on chorea place the disease either in the cerebellar cortex or in the cerebrum. Otto Foerster, who has made an extensive study of the motor phenomena of chorea, places the disorder in the cerebellum. He says that whenever a movement is conceived in the cortex, two impulses are sent out, one through the pyramidal tract (this neuron arborizes around the anterior horn of the cell) and another impulse is sent by way of the cerebellum, to which organ he assigns the rôle of coordinating the movement conceived in the motor cortex. Both movements reach the same cell, one from the cortex of the cerebral motor area, the other somewhere from the frontal lobe by way of the cerebellum and into the anterolateral region, eventually arborizing around the motor cell. He explains chorea as a disorder of the cerebellum which frustrates the plans of the voluntary impulse by either producing a useless movement, namely, contracting the antagonists rather than the so-called agonists or the synergists; the result being just exactly the opposite of what was intended; or, he thinks possibly, the impulse is side-tracked and some other muscles than those intended, contract. Of course he is unable to substantiate the opinion by pathologic proof.

DR. ARCHIBALD CHURCH, Chicago: I believe that the so-called spurious foot clonus of hysteria may bear on the conclusions in Dr. Beevor's paper. In such cases there is always a contraction of muscles on the front of the leg when developing the clonus. In organic clonus, as from a spinal or cerebral lesion, I have failed to see the participation of the muscles on the front of the leg; and Dr. Beevor's exposition seems to substantiate my observation as to the participation of antagonists in this particular hysterical condition. I have noticed that the primary attempt of children in grasping an object is one of extension of the wrist, and I have thought this a reversionary element, that extension must precede prehension, but Dr. Beevor's wonderfully lucid and clear exposition would indicate another application of this idea of the orderly arrangement of muscular action in the simplest movement.

DR. ALBERT E. STERNE, Indianapolis: We have always been, I believe rightly, accustomed to consider the cerebral cortical centers as those which originate impulses. The centers lower down in the spinal axis are in their functions probably wholly inhibitive and guiding. We must not forget that in the scale of evolution the centers high up are those which gain in dignity, and that the centers which we commonly look on as being the lower centers are those which in the lower type of animals come into greater prominence. It seems to me that it is but natural in the process of evolution that much of the function which is present in lower animals (practically an automatic function) should exist to a very great degree in human beings. I believe that the theory and the application of the theory which Dr. Beevor has placed before us may well embrace the mass of known facts that we have before us, and I feel as nearly sure as possible, that most known phenomena will fit in with the ideas presented in Dr. Beevor's most interesting and remarkable paper.

DR. CHARLES E. BEEVOR: I do not want to bring in the subject of cerebral movements, but to consider exclusively one single movement; therefore, I have not taken up the consideration of the combination or coordination of several movements, such for instance, as we find in the act of walking. Considering one movement only, the question is where the muscles are joined together and combined to form this movement, whether it is in the spinal cord, or whether it is in the cortex. I always considered it in the spinal cord until I read that matter up and found that some people think it might be in the brain. If it is in the brain or cortex you ought to get a single movement of the single muscle by itself, that is a movement of the biceps without the movement of any other muscle; but I have never seen that occur.

Then the question is with reference to a single movement. Messages are sent down from the cortex. I agree with Dr. Mills that the cortex has the power of combining movements; but it seems to me that in a single movement like extension of the thumb, the muscles are all combined together in the spinal cord, and especially in the posterior horns, and that a message sent down is not sent to every individual muscle, but to a set of the cells of the posterior horn, which has the power of bringing in muscles one after another, according to the amount of stimulation sent down; but any combination of movements would necessarily take place in the cortex to start with. It would otherwise be necessary to send down a vast multitude of fibers; you would want to send down a fiber to the flexors of the finger, and another to the extensors to the wrist and to the fixation muscles; if you consider the various combinations, a pyramidal tract and internal capsule of immense size would really be necessary. The captain sends down one message, "Go ahead;" he does not tell the engineer how much steam power to use, nor does he attend to any of the details; and all the details are attended to in the engine-room and elsewhere.

Of course I have not taken the cerebellum into account, because I have only taken a single muscle and not a combination. The cerebellum is the center where movements of balance take place, but you can not balance with only one muscle.

I do not know anything about the corpus striatum. As to whether it is excitable or not, people differ. In some work I did with Victor Horsley some years ago, we stimulated the corpus striatum with negative results. We found that if we got near to the internal capsule we got movements, and the movements were precisely the same as we got from the internal capsule only less in degree, and weaker and weaker the further from the internal capsule we got.

Therefore we concluded that there is no evidence that the corpus is excitable, and the result was really due to the stimulation of the internal capsule. Dr. Prince and I agree that it may be a question of memory. I agree also that want of inhibition is the great point in hysteria.

At a meeting in Berne I saw a dog without any cerebrum running about, but that can not occur with a monkey. Goltz used a dog and Fourier used a monkey, and of course they could not agree. I think the monkey is nearer to man than he is to the dog. I think that want of control not suggestion is concerned with hysteria. The movements of the frog trying to rub off an irritating substance is a matter of the co-ordination of several muscles—a matter which I have not been considering.

I studied a number of newborn children to see whether in the youngest child coordination took place—that is, whether when the child grasps, the hand goes round or not, and I think in about half the cases the arm muscle went around, and in the other half it did not. Dr. Robinson showed years ago that you can hang up a newborn child by the hands and it will hold on to a rail.

I once thought that coordination of muscular movement takes place in the anterior horns, but I have come to the conclusion that probably it takes place in the posterior horns.

In regard to chorea I have not induced the antagonist to act in the same way. But there again it is a question of combined movements and not one single movement. No doubt the patient performs the wrong movement, but it is a wrong movement as a rule, and not an antagonistic movement.

I have observed that the muscles in front of the leg contract in ankle clonus, as Dr. Church observes.

Serum Sickness from Antitoxin Treatment of Tetanus.—Savariaud reports in the *Tribune Médicale*, June 13, the case of a girl of 8 who scraped her knee in falling on the gravel and three days later began to limp and was brought to him. Besides rest and simple local measures he advised an injection of antitetanus serum, assuring the family that it was absolutely harmless. Five days after a second injection, at the tenth day, severe pains developed in the joints and the child could scarcely move her neck and limbs, while especially on the forearms and in the inguinal and axillary regions erythematous patches suggested an eruptive disease. The eruption subsided in fifteen hours, but fever persisted for six days and the pains in the joints for four or five. He cites a few cases of similar disturbances from serum treatment, observed in France, remarking that these accidents are neither frequent nor serious, but that their possibility must be borne in mind.

Original Articles

INSANITIES CAUSED BY ACUTE AND CHRONIC INTOXICATIONS WITH OPIUM AND COCAIN.

A STUDY OF 171 CASES. SUGGESTIONS FOR LEGISLATIVE AND OTHER MEASURES. THE QUESTION OF RESPONSIBILITY.*

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During the last seven years I have been collecting cases of intoxication with morphin and cocain. The majority are cases observed in hospitals. Confining myself to the effect of the drugs on the cerebral functions, and especially on the mentality, I am able to divide the 171 cases into two groups, viz.: 80 of acute and 91 of chronic poisoning. The first group comprises 60 cases of morphin, 15 of cocain and 5 of mixed intoxication. The second group is composed of 70 morphin habitués, 10 cocain habitués and 11 patients with mixed intoxication.

The permanent effect of the poison did not depend altogether on the mode of its administration or amount absorbed. For a normal adult 6 or 7 cgm. hypodermically constitute a toxic dose, but individual susceptibility should be taken into consideration. Cases of recovery have been reported even with doses of 75 cgm. of morphin.

Habit is very rapidly established.

FIRST GROUP.—A. ACUTE INTOXICATION WITH OPIUM OR MORPHIN (SIXTY CASES).

In this category are placed patients who showed signs of intoxication even after one dose of the drug. When the dose is not immediately fatal, there is at first some agitation without delirium. The patient is loquacious. The mental faculties are stimulated. There is a feeling of beatitude, of euphoria. Soon heaviness of the head and vertigo make their appearance. The latter is followed by somnolence. The general sensations and special sensorium become obtunded, the patient enters into a profound sleep during which death may ensue. In grave cases the respiration is slow, viz., five or six respiratory movements a minute. The pulse is small, irregular; the face is congested, the temperature is lowered. Urine decreases in quantity. Convulsions occur during the last period. In five cases somnolence was absent and the agitation of the first period persisted and was accompanied by a delirium with terrifying hallucinations of sight and hearing.

In seven cases the terminal coma gradually disappeared. The patients regained consciousness and apparently recovered, when at the end of 12, 24 and 36 hours a new attack of coma supervened with rapid death. It is probable that a new absorption of the poison occurred which during a number of hours remained inactive in some portion of the digestive tract.

Recovery may follow even after long hours of coma. During convalescence are observed vertigo, mental hebetude, temporary aphasia or blindness, and many

* Read in the Section on Nervous and Mental Diseases of the American Medical Association, at the Fifty-ninth Annual Session, held at Chicago, June, 1908.