A LECTURE ON THE THEORY OF CONSTRUCTION OF THE NERVOUS SYSTEM.

Delivered at a Conversation at the West Riding Asylum, Wakefield.

By W. IL. BROADBENT, M.D., F.R.C.P.,
Physician to St. Mary's Hospital.

GENTLEMEN,—The shortness of the time at my disposal saves me trouble in one respect, by rendering impossible any introductory remarks. I enter, therefore, at once upon the subject announced: the Theory of Construction of the Nervous System. The word theory is not altogether free from objection, as here employed; but, as the facts of structure have to be interpreted by experiment, the conclusions reached, however definite and certain they may ultimately become, can scarcely be other than a theory.

We must begin as usual with the spinal cord, which is not only the instrument of the brain and the medium of communication between it and the outer world, but offers, in its plan of construction, a key to the more complex structure of the higher centres. The spinal cord, as is well known, is at the same time an independent centre for reflex action, and the channel by which sensory impressions are transmitted upwards from the surface to the brain, and motor impulses downwards from the brain to the muscles. In the anterior grey cornua are seen large irregular multipolar cells, in the branching processes of which all the fibres of the anterior or motor nerve-roots find their origin. The groups of cells here found are, therefore, called the motor nerve-nuclei; only in the cord the individual nuclei are not separate and distinct, but joined into a continuous column extending the whole length of the cord—the anterior grey column. In the posterior grey cornua, again, are found cells smaller and different in shape, in which some at least, and probably all, the fibres of the posterior or sensory nerve-roots end. These groups of cells constitute the sensory nerve-nuclei. It is impossible to demonstrate the complete termination of the posterior nerve-roots in the cells of the posterior grey columns, because many fibres turn upwards, and some downwards, before they enter the grey matter; but all the sets of fibres have by different observers been followed to cells; and when the nerve-nuclei are no longer fused together, but distinct, as in the medulla oblongata, we see the entire nerve-roots go straight to them. Physiological reasons for the conclusion will also be given.

The mechanism for simple reflex action, then, will consist of a sensory nerve-nucleus in the posterior grey column, with its afferent nerve-root; a motor nerve-nucleus in the anterior grey column, with its nerve-fibres passing to muscles; and fibres or cell-processes connecting the two. Now, the first proposition respecting them is as follows.

PROPOSITION I. *The same cell-and-fibre apparatus which serves for reflex action serves also for the transmission upwards of sensory impressions, and downwards of voluntary motor impulses.* We have not, in fact, in each posterior nerve-root, one set of fibres ending in cells in the cord for reflex action, and another which passes up to the cerebrum conveying sensation; and, again, in each anterior nerve-root, one set of fibres arising in the anterior nerve-nucleus for reflex impulses, and another set continuous with fibres in the cord which have come down from the brain to conduct volitional movements; but the very same fibres and cells in the posterior nerve-roots and nuclei receive impressions which, transmitted forwards to motor nerve-nuclei, give rise to reflex action, and upwards to the brain, give rise to sensation. The same cells also in the motor nerve-nuclei are called into action at one time by posterior nerve-nuclei in the cord, when the movements are reflex; at another, by the centres in the brain, when they are volitional. The double or multiple relation of groups of nerve cells here indicated is a fact of great importance, and prevails throughout the nervous system. The accompanying diagrams, 1 and 2, will make this more clear.

It has long been recognised that movements require what has been called a *guiding sensation*. The structural aspect of this fact is presented by a comparison between the anterior and posterior nerve-roots and nuclei. The anterior or motor nerve-cells are large, and have numerous processes, which branch frequently in all directions. The cells of the posterior or sensory nerve-nuclei are more numerous,

smaller, and have fewer processes, thus permitting more definite grouping and combination. The larger size of the posterior nerve-root, and the fact that some of its fibres pass upwards and others downwards, suggest the same conclusion: namely, that definite arrangements of receptive or sensory nerve-cells exist, which govern or

Fig. 1 and 2.—PR and AR represent the posterior and anterior root-nuclei. PN and AN their respective nerves. PR and AR are characterized by processes for reflex action. From PR passes upwards the sensory tract S. To AR descends the motor tract M. There is not, as in Dzierżynski's theory, a distinct apparatus for reflex action separate from the motor and sensory channels.

direct the motor manifestations. The predominance of the sensory side of the nervous apparatus over the motor is worthy to be borne in mind.

The channel of voluntary motor impulses in the cord is found by experiment to run in the antero-lateral white column, and the decussation of the entire motor tracts of the cord proper takes place in the medulla oblongata. The sensory channel in the cord lies within the grey matter; and the decussation takes place, not at one spot for the entire cord, but for each sensory nerve-nucleus separately just above the nucleus.

The second proposition respecting the spinal cord is the following.

PROPOSITION II. *The spinal cord is capable of co-ordinating—i.e., of combining—for orderly, purposive, or adapted action, all movements guided by cutaneous impressions.* The word co-ordination has been a kind of bugbear. From expressing a simple fact of observation, it has come to mean or imply with many some special power or property analogous to volition or involving intelligence. It may be well, therefore, to explain that co-ordination simply means the *connecting together by fibres or cell-processes of cells, or nerve-nuclei, or ganglia, or the like may be, for co-operation in action.* It should be added, however, that the connection involved in co-ordination is peculiarly intimate.

There are three chief modes of co-ordination exemplified in the human spinal cord: 1. That by which the balancing of the body in the erect position and in the act of walking is effected; 2. The bilateral association of the nerve-nuclei of muscles bilaterally associated in their action; 3. The crossed association of the anterior extremity of one side with the posterior extremity of the other side, and of different segments of the trunk.

In man, the chief spinal co-ordination is that concerned in the maintenance of the erect position and in the movements of walking. The balance of the body on the narrow base afforded by the feet is kept for us automatically by the spinal cord. We see how much better this is done than by our own conscious effort if we attempt to walk a plank thrown across an abyss. Under these circumstances, we cannot trust the cord, but must try ourselves, by the aid of vision and strict attention to our steps, to steer a right course and maintain a just poise. The result needs no description. Safety is endangered by the effort to secure it, and we go tottering and hesitating along the plank, which we should walk without the least difficulty were it lying on the ground. In this unconscious balancing action, almost all the muscles of the lower limbs and trunk take part. We tend towards one side or the other; a little extra pressure is made on the corresponding part of the feet; the impression travels up to the cord, and at once calls into action the muscles, which will correct the departure from the upright position. This involves the co-operation of many surrounding nerve-nuclei almost along the entire length of the cord, and such co-operation implies connection by fibres or cell-processes. The pathology of locomotor ataxia has, moreover, shown us that the fibres which effect the required co-ordination run in the posterior white columns; and they pass, no doubt, in loops, some short, some longer, from one segment of the cord to another.

The spinal cord of the frog is generally spoken of as affording the most remarkable instance of co-ordinated or purposive reflex action. As is well known, a decapitated frog, when it has recovered from the

shock of the operation, sits in a natural attitude; turns over when placed on its back; pushes away with both hind legs a straw used to irritate the cloaca, and leaps if the irritation be persistent; wipes off with the corresponding hind leg acetic acid applied to the side of the body, and, this leg being amputated, employs the other for the purpose. It has been considered that the co-ordination here seen is higher in degree than, if not different in kind from, any effected by the human spinal cord; and that, in fact, functions are delegated to the spinal cord in the frog which are exercised by the brain or sensori-motor ganglia in man. I do not accept this view. These movements in the frog are simply

Fig. 3 illustrates Spinal Co-ordination. PR to PR₃ is a series of posterior nerve-root-nuclei, with looped co-ordinating fibres (CC) of posterior columns. AR to AR₃, motor nerve-nuclei. S, sensory; M, motor channel. In locomotor ataxy, the fibres (CC) being atrophied, the co-operation of different segments is prevented.

responses to cutaneous impressions, and far less complex and delicate than those which balance the human body. It would be much easier to construct an automaton frog performing these actions than an automatically self-balancing human figure. In my opinion, the mechanism for any movements effected through the spinal system of the frog exists potentially in the spinal cord of man; but it is superseded by co-ordinations of higher centres, and is never called into operation; and I repudiate the idea, with all the conclusions based upon it, that there is anything higher in degree or different in kind in the endowments of the spinal cord of the lower animals.

The phenomena of locomotor ataxy are too well known to require description; and the loss of the power of standing erect, or of walking with the eyes shut, is at once understood by reference to the damage of the automatic apparatus. But there are other features of this condition besides the mere loss of balancing power which require explanation. Why are the legs jerked out so extravagantly and irregularly in walking? There is loss of control, it is said. But this is no answer; it is merely stating the fact in other words. We shall understand it by referring to the mechanism of the cord, as described in the first proposition. The motor impulses for the successive stages in the act of walking come down the antero-lateral columns to the nerve-nuclei of the lumbar enlargement. Normally, they would be distributed along many segments of the cord by the co-ordinating fibres in the posterior white columns; but, this dispersion of energy being prevented by damage of the tracts along which it would have travelled, the energy is concentrated on the nerve-nuclei of the lower limbs, and provokes inordinate action in them.

The precise converse of this sometimes occurs. For example, in a case under my care, there was great loss of sensation in the lower extremities, so much so that the patient, when admitted into the hospital, had large blisters on the soles of both feet, produced by a hot bottle which he had not felt. The muscles were well nourished, exceedingly powerful, and well under command while lying in bed; but the man walked with difficulty. He stood and walked, however, equally well with the eyes shut or open (a proof, by the way, were any now needed, that ataxy is not due to loss of sensation). When on his feet and attempting to walk, the muscles of the calves and thighs were found to become as hard as iron, and it was this contraction which impeded locomotion; but the most striking fact was that, if made to stand *bare-foot*, the reflex action in the lower limbs was so violent as to throw him off his feet, and walking was absolutely out of the question. After putting on thick stockings and boots, he would stand and walk fairly well. Here, of course, the voluntary movements were interfered with by excessive reflex action, especially when this was intensified by contact of the naked feet with the ground; and the explanation is simple. The upward channel of sensation in the cord being damaged, impres-

sions reaching the posterior nerve-nuclei, which normally are divided between the anterior nerve-nuclei, where they excite reflex movements, and this sensory tract, were here concentrated on the former, with the result described. (See Diagram 3.)

I know no other explanation capable of being expressed in terms of cells and fibres, except that afforded by the mechanism I have described, which can be applied to the phenomena of ataxy and of the case just mentioned, or to the facts of inhibition, or to the exaggeration of reflex action after section of the cord.

The second mode or kind of co-ordination effected by structural arrangements in the spinal cord, or its prolongation upwards as the medulla oblongata and pons, is that known as the bilateral association of nerve-nuclei. I should have been glad, had time permitted, to discuss this fully. I enunciated the hypothesis some years ago (*British and Foreign Medico-Chirurgical Review*, April 1866). It has been of service in the elucidation of the physiology of the nervous system, and has not yet come to the end of its applications. To explain it, I must refer to the facts of the ordinary form of hemiplegia caused by damage of the corpus striatum. In a severe case, it is observed that, while the paralysis of the arm and leg is complete, there is only partial paralysis in the face and tongue; and in the ocular muscles, the muscles of the neck, back, and abdomen, no paralysis at all can be detected. The conclusion was, that the corpus striatum could not be the motor ganglion for the entire opposite half of the body, but only for the limbs; and endless confusion arose therefrom. But it will be seen that another interpretation is possible. When the paralysed parts in hemiplegia are compared with those not paralysed, it is found that the paralysis is complete in those muscles which are entirely independent of any muscles in the other half of the body, as is the case in the limbs. Paralysis is entirely absent, on the other hand, in muscles which never act, and cannot be made to act, without the corresponding (or some other) muscles of the opposite side. We cannot, for instance, look with one eye in one direction and the other in another, or hold one still while the other is carried round the field of vision. Now, when muscles thus constantly act together, and are incapable of acting independently, it is a physiological necessity that their nerve nuclei in the two halves of the cord should be associated by commissural fibres, so as to become, to all intents and purposes, one nucleus. But this common nucleus will be in communication with both corpora striata; and, when one corpus striatum is damaged, it can still receive impulses from the other, so that no paralysis is produced. This will, perhaps, be better understood by reference to a simple diagram (Diagram 4). The chains of cells B B' represent the nerve-nuclei of the

Fig. 4.

right and left brachial plexuses, not connected together by commissural fibres; B B' and B' S', the motor channels from the corpora striata, decussating in the medulla; O and O' represent the oculo-motor nuclei in close apposition, and intimately connected by fibres; O S and O' S', the

motor channels from the corpora striata, decussating at once, as is the case, above the common decussation of the anterior pyramids. If, now, the corpus striatum *s* be destroyed, the brachial nucleus *B* is cut off from all volitional impulses, and is paralysed; but the oculo-motor nucleus *o*, though it receives no impulse from *s*, is reached by impulses from *s*' through the fibres *o' o* which join it with *o*, and exhibits no paralysis.

It has been put forward, as an explanation of the immunity from paralysis in hemiplegia of the muscles which escape, that their action is automatic. If this were true, it would afford none but a verbal explanation; but it is not true. No actions can be less automatic than the rotation of the head and the movements of the eyes.

It will be found that throughout the body the paralysis is proportionate to the independence of the muscles of the two halves. In the face and tongue, where, as already stated, the paralysis is partial, the movements are habitually symmetrical, and independent movements, though possible, are extremely rare and exceptional. A minute analysis of this partial paralysis would further illustrate the general law, were there time for it. I will only mention the fact that, while a hemiplegic man can close both eyes together, he cannot, however accomplished in the trick previously, wink the eye of the paralysed side alone.

I should have been glad, again, to dwell on some of the interesting explanations afforded by the association of nerve-nuclei. One of these is of the lateral or conjugate deviation of the eyes and head observed in some cases of hemiplegia, which is usually set down as a phenomenon of irritation. The face and eyes are persistently turned away from the paralysed side, and cannot be directed towards the sound side, or brought beyond the median line. (The patient has been humorously said to be trying to look at his lesion.) The deviation is only temporary as a rule, and is due to difficulty in the establishment of the communication between the associated nuclei in a reverse direction. Sometimes, in disease of the pons, lateral deviation of the eyes is persistent.

The association of nerve-nuclei, again, affords the only explanation of the origin of the spinal division of the spinal accessory nerve so low down the cervical cord. The sterno-mastoid muscle which it supplies co-operates with the opposite inferior oblique and other muscles of the neck in the rotation of the head; and by the filaments arising from successive segments of the cord the necessary association of the spinal accessory nucleus with the various nuclei with which it acts is accomplished.

A fact in connection with the association of nerve-nuclei, which may be said to have established the hypothesis, is that, in hemichorea and other forms of unilateral convulsive affections, the commissural connection of the nerve-nuclei, which prevents the paralysis of bilaterally associated muscles in hemiplegia, permits their being reached by the irregular impulses issuing from the affected corpus striatum; so that hemichorea becomes bilateral exactly at those parts where in hemiplegia there is no paralysis. Referring again to the Diagram 4, if *s*, instead of being destroyed, be discharging irregular impulses, they will reach *B*, but not *B'*; while they will reach *o* through the associated nucleus *o*. I was on the look out for this corollary from the moment of my enunciation of the proposition, but was anticipated in the publication of observations by Dr. Hughlings Jackson, to whose enthusiastic adoption of the hypothesis of this association of nerve-nuclei it is, indeed, greatly indebted for acceptance. We may legitimately push our inferences further, and say that the correspondence between hemichorea and hemiplegia throws light on the pathology of chorea, and affords a strong presumption that chorea is due to an affection of the corpora striata; and other evidence in the same direction is that, in hemiplegia with spasmodic rigidity, the contraction of the paralysed muscles ceases during sleep, as do the movements of chorea, the limbs becoming flaccid, falling into natural attitudes.

The third form of spinal co-ordination I have mentioned: the crossed association of the anterior extremity of one side with the posterior extremity of the other. This is more prominent in some of the lower animals than in man; but we see it illustrated in the swinging of the arms in walking, or especially in running. A crossed association between muscles at different heights of the two halves of the body prevails more or less, however, along the entire trunk; and I am inclined to think that this is what is represented by the decussation seen in the anterior white commissure of the cord, in which fibres from the anterior white column cross over to the opposite anterior grey cornu. I refer to this crossed association, however, chiefly to show how confusion is introduced into the study of nervous physiology by the conflicting results of experiments. In the dog, which trots, the association of action is between one fore-leg and the opposite hind-leg; in the rabbit, which leaps, and never trots, the association is between the two fore-legs and the two hind-legs; and these associations are represented by commissural fibres, as seen in the two diagrams (5 and 6), in which *B* and *L* represent the brachial and lumbar nuclei.

An experimenter on dogs obtains certain results; an experimenter on rabbits obtains results which differ, and at once considers himself authorised to contradict his predecessor, forgetting that the different

Fig. 5.

Fig. 6.

modes of locomotion in the two animals implies a totally different mechanism in the spinal cord.

The crossed association of the anterior and posterior extremities, and of different segments of the body, explains why an injury which in man would cause hemiplegia, in dogs usually gives rise to the *mouvement de manège*, the dog usually going round and round, as if running after his tail. Prevost of Geneva has shown that the conjugate deviation of the head and eyes in man is exactly analogous to the *mouvement de manège*; and it is interesting to note that the muscles concerned in this conjugate deviation have an oblique rather than direct association with each other; the external rectus of one eye supplied by the sixth nerve with the internal rectus supplied by the third of the other, and, as has been already mentioned, the sterno-mastoid of one side with the inferior oblique or axo-atloid of the other.

The fibres, again, effecting the association under consideration are, no doubt, those which throw the hind leg into action in general convulsions, in spite of its paralysis from section of the corresponding half of the cord: a phenomenon which led Brown-Séquard to conclude that a special tract of fibres exists in the cord for convulsive purposes!

This brings up the question of multiple conducting channels in the cord, to which no reference has yet been made. It has been considered that a separate and distinct channel was necessary for every kind of sensibility and each form of motor activity: for tactile sensibility, for pain, for sensations of heat and cold, for tickling, for the muscular sense. Altogether, I think, eleven different channels are said to be required, and, to my distress, a new complication has been suggested by my friend Dr. Lauder Brunton, who postulates a chain of special inhibitory ganglia all down the cord. I do not believe a word of all this, and, were it desirable, could give reasons for my rejection of the idea. If, in a telegraphic wire, two messages can be transmitted at the same time, it would be strange if impressions so different from each other as those enumerated could not be discriminated by differences in the molecular movement excited in the nerve-fibres and cells. We are all a little like the profane Yankee who acknowledged that man was a smart piece of work, but thought that, if he had been present at the making of him, he could have suggested "a wrinkle or two". A distinguished medical authority would make him without tonsils, and a great anatomist thinks the vermiform appendix an useless source of danger. I will not in like manner impute clumsiness to Nature in requiring a different tract and apparatus for each modification of sensation; I think it is the interpretation which is clumsy.

While, however, we need not permit ourselves to be perplexed by the complications introduced into the spinal mechanism by the hypothesis of multiple channels for the various sensations, there is a complication which should not be lost sight of. The spinal cord is a nerve-centre for the sympathetic as well as for the cerebro-spinal system. The chain of ganglia along the bodies of the vertebrae does not constitute the spinal cord of the sympathetic system. In the early stage of development, the rudimentary cord gives off its nerves to the two primary layers of the embryo, serous and mucous alike; but, the serous layer evolving the great mass of the body, while the mucous forms only the viscera, the nerves of the latter remain small in proportion, and are represented by the inconspicuous tracts which form the roots of the sympathetic issuing with the spinal nerves from each intervertebral foramen. The reactions between the sympathetic and spinal systems, which are numerous and important, are represented by a mechanism of cells and fibres in the cord, blending with that I have just crudely sketched; but of this we know little.

[To be continued.]