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PHYSIOLOGY

OF THE

NERVOUS SYSTEM.

BY

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NERVOUS SYSTEM, PHYSIOLOGY OF THE.—In inquiring into the physiology of the nervous system, the first step is to determine the vital endowments of nerves and of nervous centres.

When a nerve is laid bare in a living animal, and a mechanical or electrical stimulus is applied to it, we do not find as in muscle that a *visible* change in the nerve takes place; on the contrary, the nerve seems to be uninfluenced by the applied stimulus, and the evidence we have to the contrary is derived from the contraction of certain muscles, if the nerve be muscular, or from indications of pain, if it be a nerve of common sensation.

We infer, then, from the contraction of the muscle in the one case, or from the affection of the mind in the other, that the application of the stimulus has wrought a change in the nerve, which, however, is of such a nature as not to be discerned by any means of observation within our reach. We get, however, excellent proof of the excitation of the change in the nerve, from the fact that when a ligature is applied to a nerve sufficiently tight to produce a solution of continuity in the nerve fibres, the propagation of the influence of the stimulus beyond the ligature is checked. No kind nor degree of stimulation of a muscular nerve above a ligature so applied is capable of exciting muscular contraction.

The most remarkable feature which we notice in the experiment of stimulating a muscular nerve, is *the instantaneousness* with which the muscular contraction takes place. Although the muscles may be at a considerable distance from the point of the nerve to which the stimulus is applied, there seems no appreciable interval of time between the application of the stimulus and the contraction of the muscle. And the cessation of the muscular contraction, instantly upon the removal of the stimulus, is equally conspicuous.

It would appear, then, that the change in the nerve is produced and is propagated along the nerve to distant parts, as it were at one and the same moment. This rapidity of the production, and the instantaneousness of propagation of the change in the nerve, denote that the nerve fibres must be the seat of a molecular change rapidly propagated along the nerve, from molecule to molecule, from the point of application of the stimulus. The change is obviously analogous to that which takes place in the particles of a piece of soft iron, in virtue of which the iron acquires the properties of a magnet, so long as it is maintained in a certain relation to a galvanic current; the magnetic power being instantly communicated when the circuit is completed, and as rapidly removed when it is interrupted.

The action of the stimulus, then, excites a *state of polarity* of the particles of the nerve stimulated; and this polar state may be induced in other particles, whether muscular or nervous, with which the nerve stimulated may be in organic connexion. Just as the polar state of the electrical apparatus is capable of being communicated to the piece of soft iron, which thereby acquires the well-known magnetic properties during the continuance of the excited polarity.

Thus, then, we learn that such is the nature of the nerve fibre, that under the application of a stimulus, mechanical, chemical, or galvanic, it is capable of generating a polar force analogous in many particulars to that of muscle; this force we call the nervous force, *vis nervosa*, or *nervous polarity*.*

And if we examine the ordinary mode of the development of the nervous force, in the usual actions of the frame, we find that under the influence of a mental stimulus, the will, it is propagated from the nervous centre along the nerves to muscles, or under the influence of a physical stimulus it is propagated along the nerves to the centres, where it is capable of exciting either a sensation or muscular motion in a secondary manner, or both.

But the application of a physical stimulus to a nervous centre may cause the development of nervous force, which may be conducted away from it by nerves which are implanted in it. And thus we learn that the same polar condition which may be produced in nerves is equally capable of being excited in nervous centres. The polar condition of the nerve fibre may be propagated to the nervous centre, or that of the nervous centre to the nerve fibre.

In some of the nervous centres, however, no *visible* change of any kind takes place upon the irritation of the nervous matter, nor does the animal seem to suffer pain. Such is the case when the hemispheres of the brain are the subject of experiment. We are not to infer from this that the nervous force is not developed in these centres, but that they have no direct connexion with the muscular system, nor have they that peculiar organization which would enable them when irritated to excite painful sensations.

There are certain nerves which when stimulated excite neither muscular motion nor common sensation or pain, but a sensation peculiar to themselves. Thus, if the optic nerve be stimulated by a mechanical or galvanic stimulus, a sensation of light is produced; if the auditory nerve be stimulated in like manner, a sensation of sound is produced.

These facts prove not only that a peculiar force is generated by the nervous matter, but they also show that the nerve fibres in the centres, as well as in the nerves, possess special endowments depending, in all probability, upon their central as well as upon their peripheral connexions. Thus nerve fibres connected with muscles are capable of exciting muscular contraction, and are therefore called *motor* or *muscular* nerves. Nerve fibres, which are distributed to a sentient surface, as the skin or mucous membrane, and have a certain relation with that part of the nervous centre which constitutes the centre of sensation, are when stimulated capable of exciting a feeling which may be agreeable or painful, according to the degree of stimulation. These are called *sensitive nerves*, or *nerves of common sensation*. To the class of sensitive nerves belong those which, owing no doubt to a peculiarity in their connexion with the centre, as well as to their relation to a special apparatus at their periphery, develope peculiar sensations, as the nerves of sight, hearing, taste, &c., and they have been distinguished as *nerves of special sensation*.

Very many sentient nerves are implanted in the nervous centre near to certain motor nerves, so that a stimulus applied to the former is capable of reacting upon the latter, and of exciting motion through their connexion with the muscles. Dr. M. Hall, however, ingeniously supposes that this power resides only in a particular class of nerve fibres (and not in the ordinary sentient nerves through their closeness of relation with the ordinary motor nerves). A nerve of this kind would constitute an arc, consisting of an *incident* and a *reflex* portion, which are united at the nervous centre. The stimulus is conveyed to the centre by the incident portion, and is then reflected into the reflex or motor portion. Such nerves, Dr. Hall designates *excito-motor*. We shall examine further on the grounds of this hypothesis.

It is an important fact, which Sir C. Bell was the first clearly to prove, that nerve-fibres of different endowments may be bound together in one sheath, forming, in anatomical language, one nerve. Thus a nerve may contain sentient and motor fibres, as the median nerve in the arm, or if we admitted Dr. Hall's hypothesis, it might contain sentient, motor, and excito-motor fibres. And most nerves in the different regions of the body are of this description, i. e. *compound* nerves, made up of sentient and motor fibres bound together in the same sheath, in very different proportions. In many of these nerves, as in the spinal nerves, and the fifth pair, the separation of the fibres of motion from those of sensation exists at the implantation in the centre, and there the fibres of each endowment are collected into a separate bundle, which possesses the endowment proper to its constituent fibres. These are the roots of these nerves, of which one has been satisfactorily proved to be sentient, the other motor, the former being generally the larger, and having the peculiar feature of a ganglion being formed upon it.

There is scarcely a nerve in the body, which, in strictness, ought not to be regarded as a compound one; the physiological character of each nerve must depend on the endowment of the majority of its fibres, and the nerve will be called *sensitive* or *motor*, according to the pre-

* I have been in the habit of taking this view of the nervous force in my lectures for the last four or five years, and of using the term, *nervous polarity*, as expressive of the nature of the nervous force. This term has likewise been adopted by Mr. Bowman and myself in our work on the Physiological Anatomy and Physiology of Man, vol. i. p. 56, and in the chapters on the Nervous System, *passim*.

dominance of motor or sensitive fibres in it. For example, the facial nerve, or *portio dura* of the seventh pair, is called *motor*, because it is almost wholly composed of motor fibres; but it contains, besides, in very much smaller number, some sensitive filaments which it derives from anastomoses with neighbouring nerves. The third, fourth, and sixth nerves are of similar constitution to the facial. In the ramifications of the fifth nerve, on the other hand, the filaments of sensation are predominant; those of motion being much fewer, and confined to the ramifications of its inferior maxillary division.

There is no difference between a motor and a sensitive nerve as regards structure. Ehrenberg, indeed, endeavoured to establish that the varicose character of the fibre belonged to nerves of special sense; but subsequent observation showed this to be incorrect. We can attribute the difference of endowment of the fibres to no other cause, but to the nature of their peripheral and central connections. The same nervous force is propagated by the fibres of each kind, but whether that force is to excite motion or sensation must depend on the connection of the fibres with muscles in the one case, and with the centre of sensation in the other.

The terms *afferent* and *efferent* have been used in expressing the function of different fibres, and they are convenient terms to a certain extent. But the use of them tends to convey erroneous ideas respecting the change which takes place in a nerve when stimulated, as if that change took place only in one direction. It is true that, in a motor nerve, the stimulus ordinarily acts from the centre, and the nervous force is propagated peripherad; and on the other hand, in the sentient nerve, the stimulus is usually applied at the periphery, and the nervous force proceeds centrad. It is the place at which the stimulus is applied which usually determines the *direction* in which the nervous force travels. But there are no good grounds for supposing that the molecular change consequent upon the stimulation of a nerve is limited to that part of the nerve-fibre which is included between the point stimulated, and the centre or the muscles, where the effect of the stimulation appears; on the contrary, it is not improbable that, at whatever point the stimulus be applied, the whole length of the nerve-fibre participates in the change. This is not unlikely in the case of *motor* nerves. For a continued or violent irritation of a motor nerve, in some part of its course, causing spasm or convulsive movement of the muscles it supplies, may be propagated along its whole length to the centre, and may there give rise to irritation of neighbouring fibres, whether motor or sensitive, exciting more convulsion and pain. The phenomena of many cases of epilepsy, in which the fit begins with irritation of a few muscles, may be referred to in illustration of this position.* And it is also very probable as regards *sensitive* nerves. If the ulnar nerve be irritated when it passes behind the internal condyle, a sensation of tingling is excited, which is referred to the sentient surface of the ring and little fingers; and if the irritation is kept up, the skin of those fingers becomes tender to the touch, its sensibility being very much exalted. This fact cannot be explained unless upon the supposition that the molecular change in the nerve-fibres, produced by the irritation, extended to the periphery as well as to the centre, exalting the excitability of their distal extremities.

It is a highly interesting physiological fact, which has an important practical bearing, that at whatever part of their course sentient nerve-fibres be irritated, the same sensation will be produced, whether the seat of the irritation be the centre, the periphery, or the middle of their course, provided only the same fibres are irritated in the same degree. Thus it frequently happens that sensations are referred to the extremities of a nerve when the existing irritation is situated at its point of implantation in the centre. The sensation of tingling or formication, in the hand or foot, arm or leg, is frequently an indication of cerebral or spinal disease; but the practitioner should not forget that precisely the same sensation may be caused by an irritation taking place in the course of the nerve. I have frequent occasion to estimate the importance of this fact in the treatment of cases of Sciatica. This disease generally consists in an irritated state of the nerve in some part of its course by a gouty matter, and it may be treated with the best effects by blisters applied over the nerve. As, however, the morbid impregnation may have taken place at any part of the course of the nerve, it is a very useful practice, when a single application fails, to apply the blisters over different parts in succession, instead of confining the vesication to one region.

This law of action of sensitive nerves gives the clue to the explanation of the extraordinary but well-attested fact, that persons who have suffered amputation will continue to feel a consciousness of the presence of the amputated limb, immediately after, and often for a long time, or even always, after its removal. I have met with two cases, in one of which the arm, in the other the leg, was amputated so long before as forty years; yet each person declared that he had the sensation of his fingers or toes as distinctly as before the operation. And not only does the consciousness above referred to exist, but likewise, when the principal nerve of the limb is irritated, the patient complains of pains or tingling, which he refers to the fingers or toes.* In such cases the central segments

* I am aware that these phenomena admit of another explanation, but there is no reason why they might not likewise originate, in many cases, in irritation of a few motor fibres.

* Müller records several instances in his Physiology, vol. i. p. 746. (*Eng. edition.*)
There is a man now in King's College Hospital who suffered amputation at the upper third of the arm, and whose entire scapula, with the shoulder

of the amputated nerve-fibres remain; if they retain their healthy condition, they continue to represent in the sensorium the various points on the surface of the amputated limb, and likewise the muscles which they were destined to supply. If, however, the integrity of the nerve-fibres has been impaired in consequence of any morbid action which may have followed the operation, then the sensation exists imperfectly or not at all.

It may be stated in connection with this subject, and in confirmation of the view above taken, that in many cases of complete paralysis of a limb from cerebral disease, the patient, although perfectly clear in his general mental perceptions, is not conscious of the presence of the paralysed member, and really feels as if it did not exist. I have known instances in which this unconsciousness has been so great that the patient has actually mistaken the paralysed part for the limb of some other person coming in contact with him, or for some entirely foreign substance. One man fancied that his paralysed arm was his wife's, and called to her to take it away. In such cases the morbid state of the brain prohibits the developement of that affection of the centre of sensation upon which the feeling of the connection of the limbs depends.*

The same law of action applies to nerves of special, as to those of common sensation. Thus, whilst ordinarily they propagate to the centre impressions made at the periphery, we find nevertheless that irritation of the nervous trunk at any part of its course may give rise to its peculiar sensation; and if the brain be stimulated at the part in which the nerve is implanted, similar sensations may be produced. The phenomena of vision and hearing which are excited in these ways are called "*subjective;*" they are familiarly known to medical men as not unfrequent precursors of more serious symptoms of cerebral disease. Muscæ volitantes, ocular spectra, and tinnitus aurium, are the most common instances of these phenomena. Pressure on the eyeball, a galvanic current passed through it or very near it, rotation of the body, are capable of giving rise to similar phenomena, by exciting the retina or the central connections of the optic nerve, or by disturbing the circulation of the blood in them. A sense of giddiness, similar to that produced by the means last-named, is also a very common symptom of cerebral affection arising from a disturbed circulation, or from the blood being deficient in one or more of its staminal principles, or vitiated by some morbid element.

The stimuli of nerves. — Nervous action is ordinarily provoked by stimuli of two kinds, *mental* and *physical*. Mental stimuli are those resulting from the exercise of the will, or from thought. Physical are due to some external excitant; light, heat, sound, mechanical stimulation, chemical substances, as acids or alkalis, or electricity.

In all voluntary movements an act of the mind is the excitant of the nerve. Sensations are caused generally by the influence of physical agents upon the peripheral extremities of nerves, which communicate with the *sensorium commune*. The change thus produced in the nerve gives rise, through the medium of this communication, to a corresponding affection of the mind. A mental stimulus, however, may affect a nerve of sensation. Such stimulus would originate in that part of the brain which is the seat of the changes connected with the intellectual actions, and affecting the centre of sensation, would excite in certain sentient nerves a change similar to that which a physical stimulus applied to their peripheral extremities is capable of producing. In this way the mind is capable of exciting pain in any part. When the attention has been long directed to any particular situation, whether it has been previously the seat of pain or not, painful sensations may be excited there. Of this we have many instances in practice. In the treatment of cases of hysteria it is of great importance, on this account, to direct the attention of the patient as much as possible away from any local affection.

Motor nerves are never *immediately* excited by a physical stimulus in the ordinary actions of the body. A physical stimulus acts upon a motor nerve always through a sensitive nerve; the actions thus produced are, commonly, called *reflex actions* from the apparent reflexion of the change excited by the afferent or sensitive nerve in the nervous centre into the motor or efferent nerve. This class of actions was first pointed out and described by Prochaska, who viewed them as consisting "in reflexione impressionum sensoriarum in motorias." The contact of a foreign substance, pressure, titillation, are the ordinary physical means by which such actions may be excited. As a good example of this may be quoted the act of deglutition at the isthmus faucium.

Physical stimuli of other kinds, however, may excite motor nerves. The pressure of a morbid growth of any kind may irritate such nerves and create spasm of the muscles they supply. Any virulent fluid applied to a motor nerve will irritate in a similar way—hot water—liquor potassæ—a mineral acid—a solution of strychnine, &c. And for the same reason certain morbid matters in the blood may irritate nerves whether sensitive or motor, causing the so-called neuralgic pain in the one case, and cramp or spasm in the other.

Effects of the galvanic stimulus.—The most perfect and powerful physical stimulus of motor

joint and great part of the clavicle, was removed by Mr. Fergusson within the last two months. This man still feels his fingers.

* Valentin states that persons who are the subjects of congenital imperfections, or absence of the extremities, have nevertheless the internal sensations of such limbs in their perfect state. According to the view above taken this could not be, unless the primitive nervous fibres are present in their full number in the trunks of the nerves destined for the limb. Repertorium fur Anat. und Phys. 1836, p 330, and note to Baly's translation of Müller's Physiol. vol. i. p. 747.

nerves, and that which most nearly imitates the natural mental stimulus, is the galvanic current. That the nerve should be duly excited by the galvanic current it is necessary that the current should pass *along* its fibres for however short a distance. If it pass *across* the fibre, and *at right angles* to it, it will produce no effect upon the muscles; but if it travel *along* it, even for the twentieth or a smaller portion of an inch, it will effectually excite the nerve and its muscles, just as when the will stimulates it to action.

The influence of the galvanic current upon nerves is so remarkable that it deserves the careful study of physiologists and of practitioners in medicine who often have recourse to the galvanic stimulus with the hope of rousing the dormant energies of nerves. It is to the Italian school of *Physiciens* that we owe the highly interesting series of facts which have been collected upon the influence of the galvanic current upon nerves, to Galvani, Valli, Volta, Marianini, Nobili, and, although last not least, to my distinguished friend, Professor Matteucci, of Pisa, by whose well-devised experiments and researches a flood of light has been thrown upon this hitherto obscure and difficult subject.

I shall content myself here with briefly noticing the points most deserving of attention as bearing upon the laws of action of the nerves.

1. When a galvanic current is passed for however short a distance along a nerve which contains motor fibres, muscular contractions will be excited at the moment of completing as well at that of breaking the circuit, but not while the current is passing. These phenomena take place whatever be the direction in which the current be passed, whether from the nervous centre towards the periphery, (when the current is distinguished as *the direct current,*) or from the periphery towards the centre (when the current is styled *the inverse current*).

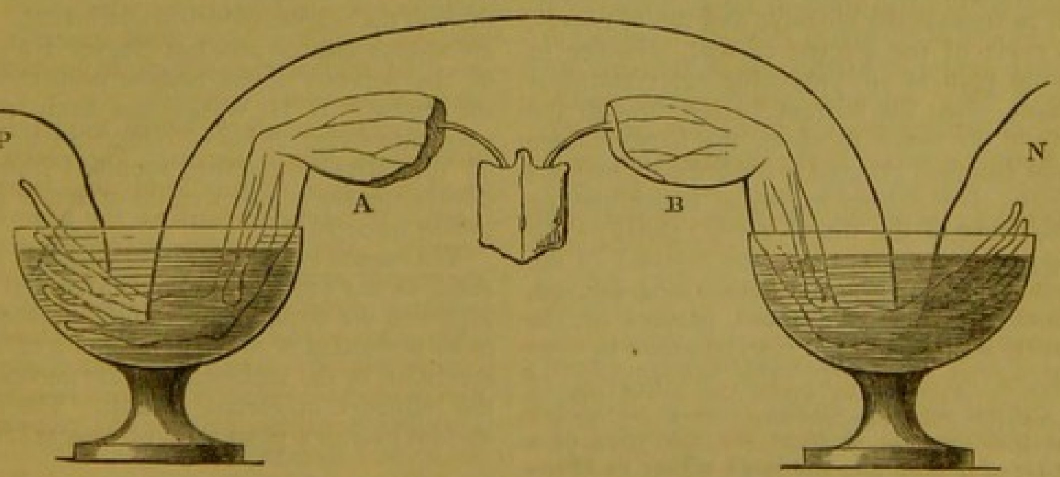
These effects may be produced in warm as well as in cold-blooded animals. In the former, however, the physical conditions necessary for the display of the vital forces continue for so brief a period that cold-blooded animals should be selected for the experiments. On this account, as well as because of their peculiar susceptibility to the galvanic current, frogs are generally employed for this purpose. The most striking way of exhibiting the influence of the current, direct and inverse, upon the nerves is illustrated by the annexed woodcut. It represents a frog prepared in the manner adopted by Galvani. The integuments have been removed from the lower extremities, which have been separated from the trunk by the division of the lumbar region of the spine. The lumbar nerves are carefully raised from the muscles on which they lie, but are suffered to retain their connection with the spinal cord and with the thighs. The pelvic bones, however, are removed so as to admit of the more free separation of the extremities, as well as to isolate the nerves more completely. Each leg is immersed in a glass or cup of water, and the current is made to pass through the limbs by immersing each wire of the battery in the water of the cups. It is obvious that in one limb the current is direct, whilst in the other it is inverse.

The advantage of this arrangement is that it affords great facility in making and breaking the current without bringing the conducting wire of the battery into actual contact with either limb. One wire may be left constantly in the water, while the other can be alternately introduced or removed from it as we wish to observe the effects of completing or of breaking the current.

2. If the current be allowed to pass for a short time through the nerves of a frog, prepared as before-mentioned, contractions will no longer take place in both limbs at the same time, but only in one upon completing the circuit, in the other on breaking. And we shall always find that the contractions occur on making in the limb in which the current is direct, on breaking in the limb in which the current is inverse. I find it useful to adopt the following formula to impress this fact upon the memory; MD, BI, making direct, breaking inverse.

3. If the current continue to pass for some time longer, these phenomena cease completely

Fig. 1.



Lower extremities of the prepared Frog.

P, positive wire of the battery; N, negative ditto. In the limb A the current will be inverse; in B it will be direct.

and no contractions are produced. They may, however, be reproduced by inverting the direction of the current by transposing the conducting wires of the battery. The current will now be inverse in B, and direct in A, *fig.* 1. Or the fact may be illustrated by another disposition of the legs of the frog. Let both feet be immersed in one vessel and the pelvis in the other. The direct current may now be passed along the nerves in both limbs at the same time, until the phenomena of contraction on making or breaking cease. Inverse the current, and the contraction will again become manifest. This fact was first discovered by Volta, and this mode of exhibiting it has been described under the title *Alternatives Voltianes.* If the inverted current continue some time, exhaustion will be produced; but on inverting it again or restoring it to its former course, the actions will recommence.

4. These effects cannot be produced unless the nerves be in a state of integrity. If a ligature be tightly applied to the nerve of either limb close to the muscles, the contractions in that limb will no longer take place. Or to give a more striking illustration of this important fact, if a drop or two of pure sulphuric ether be applied to a point of either nerve, the contractions in the limb of that side will be suspended until the effects of the ether pass off. These experiments unequivocally shew that the nerves are not merely conductors of the electrical current, but that the passage of the current through them developes in them a change which influences the contractile force of the muscles.

5. The influence of the galvanic current affords the most striking results when *motor* nerves are made the subject of the experiments, but Matteucci has shown that sensitive nerves are affected in an analogous way by the inverse and direct current. In a living rabbit the sciatic nerves were exposed, and one nerve was devoted to the direct current, the other to the inverse. Opening and closing both currents were accompanied with marked signs of pain, which, however, were greatest at the closure of the inverse current. After a short time, the signs of pain are manifested only on opening the direct current and closing the inverse.

The reader will scarcely fail to observe that both as regards the sensitive and motor nerves, the effect of the electric current, whether in causing pain or in producing contractions, is greatest when the current passes through the nerve in the course in which the nervous force would naturally proceed in the ordinary nervous actions. It is further worthy of notice that the continuance of the direct current exhausts the power of the nerve, while the reversal of the direction of the current, if not too long delayed, restores it. The continuous passage of the current, however, is not marked either by contractions or by pain. The interruption of the current by any means at once developes these phenomena; or even the diversion of a portion of it produces the same effect, as Marianini showed long ago. If, for instance, the two vessels in which the frog's paws are immersed be connected by a conductor, as an arc of copper or silver wire, contractions will take place on making or breaking the connection; or if the wires of the battery be connected by a third wire of the same material before they dip into the cups, the same effects will be produced.

The continued transmission of an inverse current through a nerve increases to a remarkable extent its excitability. This is shewn by the following experiments: let the limbs of a frog be placed in two vessels of water and the current be passed through them in the manner above described, and let this be continued for a few minutes. After the lapse of this period, if the circuit be broken by taking one of the wires out of the water, the limb in which the current was inverse will be thrown into a state of tonic or tetanoid spasm for a few seconds, the tetanus ceasing with a clonic convulsion on the renewed completion of the circuit.*

That these phenomena are due to a *change developed in the nerve* (not to any affection of the muscles) by the passage of the galvanic current, is clearly demonstrated by applying the galvanic current to a muscle directly, having first removed as much nerve out of it as possible. The muscle will contract equally on making and breaking the circuit, whatever be the direction of the current; nor is it possible to produce tetanic spasm, however long the current may have been continued through it. The following experiment, suggested by Matteucci, also strongly confirms this view. Let the current be passed through the limbs of a frog in the ordinary way. After the current has passed for 25 or 30 minutes, cut the nerve traversed by the inverse current, at the point where it plunges into the thigh, and there will instantly ensue a violent contraction of that limb, which ceases very quickly. If, however, instead of this the nerve be cut where it issues from the spinal cord, *so as to leave a certain* length of the nerve attached to the thigh, there will be a violent contraction of the muscles, which will be followed by others, and the limb will remain in a tetanic state for 10 or 15 seconds or longer.†

The tetanoid contractions of the muscles may be produced by a rapid series of currents passed through the nerve alternately in the inverse and direct course, as by the electro-magnetic or the magneto-electric instrument. These are always greatest and last longest if a portion of the nervous centre remain connected with the limbs. E. H. Weber has lately made a very interesting series of researches by means of the magneto-electric rotation instrument developing the peculiar mode of action of particular muscles.‡

We cannot explain these remarkable phenomena on any other principle than on that which supposes the developement of the nervous force to be associated with the assumption of a polar condition by the molecules of the nerves under the influence of certain stimuli. The inverse current excites a polar state of greater intensity

* Matteucci, Phil. Trans. 1846.

† Comptes Rendus, March 15, 1847.

‡ Wagner, Worterbuch. Art. Muskelbewegung.

and of longer duration than the direct current: hence the tetanic contractions which remain after the interruption of the current.

It is sufficiently obvious why a contraction should occur at the moment of completing the circuit in a nerve. But why the same phenomenon should occur on breaking the circuit is not easily explained. Marianini supposed that during the passage of a direct current through a nerve a part of the electricity accumulated in it, and on the interception of the current discharged itself, traversing the nerve in an opposite direction, and thus giving rise to contractions. It is not, however, likely that such an accumulation would take place, when the conducting power of muscle is so much better than that of nerve. And further, it is evident that this will not explain the absence of contractions in the direct limb after a time on breaking the circuit.

The truth is, that when a continuous current has been passed through the limb of a frog for some time a different state of excitability is established in the nerve of each limb according to the direction which the current had taken. That in which the direct current passes becomes exhausted in its powers, while that in which the inverse current passes has its excitability augmented. In the quiescent state a nerve maintains a certain state of tension: the application of a stimulus modifies this tension and causes the nerve to assume a new polar state, which displays itself in the contraction of muscles or the excitation of a sensation or of pain. The electric current is a powerful stimulus of the nervous force, and the greatest disturbance of the quiescent state of tension is produced by making the direct current. Upon this current beginning to pass, a new state of tension is established, which is disturbed by breaking the circuit: but if the current have continued to pass too long, the maintenance of the state of unnatural tension exhausts the nervous power, and the nerve ceases to respond to any stimulus. Whilst, however, the nerve of the direct limb has assumed one condition, that of the inverse limb has taken on a different one, in which the molecules of the nerve may be conceived to have a disposition the opposite to that which the direct current would produce. Hence only two electric stimuli would restore the particles of the inverse nerve, and so disturb the state of tension into which it had been thrown, namely, making a direct current through the nerve, or simply breaking the inverse.

The tetanoid state which results from the continued passage of the inverse current through a nerve is a phenomenon resulting from the extreme augmentation of its polarity. This state is never produced by the direct current; and the instantaneousness with which it is removed by resuming the current, thereby restoring the state of tension which had been disturbed by breaking the circuit, is highly favourable to this supposition. Anything which weakens the force of the current, or diverts a portion of it from the nerve, as the contact of muscles with the nerve, or of much moisture, or the occasional reversal of the current making it direct where it had been inverse, will materially retard and diminish, or altogether prevent the developement of this phenomenon.

The rapidity with which the changes in the nerves, however they may have been excited, are propagated, and the precision with which they are perceived by the mind in the case of sentient nerves, or produced by it in the case of motor nerves, are well calculated to excite our admiration. If the communication between the nerve and the centre be cut off, the will can exert no influence upon the muscles supplied by the nerve below the section; nor will the mind perceive any stimulus applied to parts which derive their nerves from below the separation. And this for an obvious reason; because the solution of continuity of the nerve interrupts the propagation of the change which the mental or physical stimulus excites in it. In the case of the voluntary nerves, the effects of the mental stimulus are propagated no further *peripherad* than the point of section; and in that of the sensitive nerve, the change travels no further *centrad* than the same point. That this interruption is caused solely by the solution of continuity, and not by any alteration in the properties of the nerve, is proved by the fact that the lower segment of the motor nerve will still continue to respond to a physical stimulus. Mechanical or chemical irritation, or the passage of an electric current along it, will cause its muscles to contract. Such a degree of injury to a nerve as will break the continuity of the nervous matter within the tubular fibres is likewise sufficient to destroy its power as a propagator of nervous change. This effect may be produced by tying a ligature very tightly round a nerve, or by pressing it with great force between the blades of a forceps. The paralysis, which results from the compression of a nerve by a tumour or in any other way, is, no doubt, due to a similar solution of continuity in the nervous matter.

These facts strongly denote the important principle in nervous physiology, that, in propagating the influence of a stimulus, either from periphery to centre, or vice versâ, the whole extent of the nerve-fibre between the point stimulated and its peripheral or central connection is the seat of change; and that the power of developing the nervous force is inherent in the nerve-fibre itself is shown by the fact that the stimulation of a muscular nerve, which has been separated from the centre, below the point of section is capable of exciting muscular action. The conducting power of a nerve, then, results from its proneness to undergo certain changes, physical or chemical, under the influence of stimuli.

We may perceive, then, how important it must be to the healthy action of nerves to preserve them in a sound physical condition. A morbid fluid impregnating a nerve at any point may irritate it, or may suspend or destroy its inherent property by modifying its nutrition or impairing its physical condition. Thus we may paralyse nerves by soaking them in a solution of opium, or of belladonna, aconite, or tobacco, in sulphuric ether, or other sedative or narcotic substances; or, on the other hand, we may unduly excite them by applying a strong solution of strychnia. The contact of a solid body with a nerve may irritate and keep up a continual state of excitement, if it do not destroy its properties. A spiculum of bone, in contact with nervous fibres, is often the cause of the severest forms of neuralgia; inflammation may produce like effects. Various physical agents may produce similar consequences. The benumbing influence of cold is explained in this way. Exposure to a continuous draught of cold air is a frequent cause of facial paralysis. The giving way of a carious tooth will immediately occasion toothache by exposing the nerves of its pulp to the irritating influence of the air, or of the fluids of the mouth. And undue heat is likewise injurious to the physical constitution, and, therefore, to the action of nerves. These facts are of great interest in reference to the pathology of nervous diseases, and suggest that the attraction of a morbid material in the blood to a nerve or set of nerves, or to that part of the nervous centre in which such nerves may be implanted, may afford satisfactory explanation of many obscure phenomena of nerves of sensation.

The organic change, whatever be its intrinsic nature, which stimuli, whether mental or physical, produce in a nerve, developes that wonderful power long known to physiologists by the name *vis nervosa*, the nervous force. This force is more or less engaged in all the functions of the body, whether organic or animal. In the former its office is to regulate, control, and harmonize; in the latter it is the mainspring of action without which none of the phenomena can take place. It is the natural excitant of muscular motion, and the display of that wondrous power depends upon its energy; without vigour in the developement and application of the nervous force, a well-formed muscular system would be of little use, for it would quickly suffer in its nutrition if deprived of that exercise which is essential to it.

In the various combinations of thought which take place in the exercise of the intellect, there can be no doubt that the nervous force is called into play in the hemispheres of the brain. Here the stimulus is mental; the independent operations of the mind excite the action of the appropriate fibres of the brain, and the developement of the nervous force in the brain immediately succeeds the intellectual workings. It is thus that we explain the bodily exhaustion which mental labour induces; and thus, too, we can understand the giving way of the brain—the inducement of cerebral disease—under the incessant wear and tear to which men of great intellectual powers expose it. On the other hand, physical changes in the brain, of a kind different from those which are normal to it, the circulation of too much, or too little, or of a morbid blood, may excite mental phenomena in an irregular way and give rise to delirium or mania.

Of the conditions necessary for the maintenance of the power of developing the nervous force.—From what has been already stated, it is manifest that a healthy physical state of the nervous matter, whether in the nerves or in the nervous centres, constitutes the main condition necessary for preserving in them the power of developing the nervous force. And as nerves will not maintain their healthy nutrition unless they be in union with the nervous centres, this union becomes an important condition for the maintenance of this power in nerves. In the nervous centres the nerves form a connexion with the vesicular matter. We therefore infer that this connexion of the fibrous and vesicular matter is necessary for the exercise of the peculiar power of nerves, because we know of no instance, either in the human economy or in that of the inferior creatures, in which the nervous power is developed without this union.

It is true that if a motor nerve be separated from the nervous centre, its peripheral segment will evince a susceptibility to stimuli, or, in other words, it will retain the power of generating the nervous force for some time after the separation. This is, however, only for a short period, as the experiments of Longet distinctly show. Longet cut out a portion of the sciatic nerve in dogs, and irritated the lower segment of the nerve on each succeeding day by means of galvanism from a pile of twenty couples, and by mechanical irritation. The nerve ceased to be excitable *on and after the fourth day*, ("des le quatrieme jour.")* These results, although they appear to differ from those obtained by Müller and Sticker, and Steinruch, are not really inconsistent with them. These observers, instead of examining and irritating the lower segment of the nerve each succeeding day after the section, allowed it to remain for an arbitrary period untouched, and then reopened the wound to try the effect of stimulating the nerve. Thus Müller and Sticker waited eleven weeks in one rabbit, five weeks in a second, and two months and a half in a dog, and in all the cases found the nerve inexcitable; and Steinruch waited four weeks, at which time he found that the power of the nerve had disappeared. It is obvious that there was nothing in any of these experiments to cast a doubt on the possibility of the nerve having lost its excitability at a much earlier period after the section, and that the selection of five or eight or eleven weeks, as the period when to inquire whether the nerve retained its excitability or not, was entirely arbitrary on the part of the experimenters.

The rapidity with which a nerve loses its power after it has been separated from the nervous centres clearly denotes that connection with the centre is a necessary condition for the nutritive activity of nerves, and is, therefore, a necessary condition for their functional activity, or, in other words, for the full developement of the nervous force under its appropriate stimuli. There are, however, other facts which, inasmuch as they enhance the importance of the vesicular matter in the manifestation of nervous phenomena, give great weight to the proposition under consideration. These are—

* Longet, Recherches Experimentales sur l'Irritabilité Musculaire: l'Examinateur Med. Dec. 1841.

1. That there is invariably an accumulation of vesicular matter around the points of implantation of nerves in the centres, as already referred to. This is true of all nerves in the vertebrata and the higher invertebrata, and we know of no reason to doubt it in the lower invertebrata. 2. The quantity of the vesicular matter around the point of implantation of a nerve is in the direct ratio of its size and of the activity of its function. Under particular circumstances the quantity of vesicular matter becomes so large as to cause a special ganglionic enlargement of the portion of the centre in which the nerve or nerves may be implanted. The cervical and lumbar enlargements of the spinal cord are due to this cause: the gangliform swellings on the upper part of the spinal cord in the gurnard *(trigla lyra)* are connected with the exalted functions of the nerves of touch distributed to the feelers, and contain a large quantity of vesicular matter. A remarkable instance of the developement of vesicular nervous matter under similar circumstances is to be found in the electric lobes of the Torpedo, in which are implanted the nerves distributed to the electrical organ. These lobes are of very considerable size, much exceeding that of any other part of the brain, and they contain vesicular matter in large quantity. The nerves implanted in them are of great size.*

Such facts as those cited in the preceding paragraph denote clearly that the developement of the nervous force is to a certain extent connected with the vesicular nervous matter, and to such a degree as to justify the opinion that this element of the nervous centres may be viewed as the dynamic matter, the originator of the force. At the same time it must be borne in mind that this form of nervous matter never occurs alone, and that probably the union of the two is necessary for the developement of nervous power. Just as the union of two metals in the galvanic battery is necessary for the developement of the current, while one of them, that, namely, which possesses the greatest affinity for the fluid interposed between them, seems to originate the current, and is on that account called the *generating* plate, whilst the other is called the *conducting* plate.

Of the nature of the nervous force.—All that we have said respecting the mode of developement and the laws of the nervous force denotes its polar character.

We can no more detect by our senses any physical change in the piece of soft iron which is rendered *magnetic* by the galvanic current, than we can discover a change in the particles of a nerve stimulated to action by the same current. That both the iron and the nervous matter are thrown into an analogous state by the same agent seems highly probable. In the case of the iron the indication of the assumption and of the maintenance of the polar state is afforded by its power of attracting particles of iron; while in a muscular nerve the assumption and maintenance of the polar state are shown by the active contraction of certain muscles, or a more tonic state of passive contraction. While the current is passing through a motor nerve there is no active contraction of the muscles; but that these organs are in a more excited state than the ordinary one of passive contraction seems evident enough, from the readiness with which they assume a tetanic condition upon the cessation of the passage of an inverse current which had been allowed to pass through their nerves for some time. And the fact demonstrated by Marianini and Matteucci, that the passage of a continuous current through a nerve will after a time exhaust its excitability, although not so quickly as a current frequently interrupted, denotes that the nerve is in an excited state during the actual passage of the galvanic current.

Is the nervous force electricity?—There is so much resemblance, as regards their mode of developement and propagation, between the nervous force and electricity, that many physiologists have been led to regard these forces as identical. The nervous force, however, presents striking points of difference from electricity, which render it highly improbable that it is identical with that force, and which show that if it be so it must be an electricity of extremely low tension.

1. The ordinary tests for electricity fail to detect the existence of a galvanic current in the nerves, whether during their quiescent or their active state. The most delicate galvanometers have been employed for this purpose, in vain, by Prevost and Dumas, who were themselves advocates of the electrical theory of nervous action, by Person, by Müller, by Matteucci, and by myself. Person connected the wires of a galvanometer with the surfaces of the spinal cord in kittens and rabbits, in which spasmodic action of the muscles had been excited by the influence of nux vomica, and was unable to discover any evidence of electrical action. It had been affirmed that needles introduced into the nerves or muscles of living animals became magnetic during nervous and muscular action, so as to attract iron filings, but neither Müller nor Matteucci has succeeded in obtaining such a result from their experiments. Matteucci took the precaution of employing astatic needles for the purpose, but could detect no signs of magnetization. He also introduced the prepared limbs of a frog into the interior of a spiral covered on its inside with varnish; the extremities of this spiral were united to those of another smaller spiral, into which he introduced a wire of soft iron. The nerves of the frog were irritated to excite muscular action, and at the same time Matteucci sought to ascertain if an induced current would traverse the spirals and magnetize the wire, but to no purpose.

2. Were it to be admitted that the nervous force and electricity were identical, it cannot be doubted that the provision made for propagating the latter force in the nerves is very inadequate. The nerves are very imperfect conductors of electricity; Matteucci assigns to them a conducting power four times less than that of muscle; Weber states that they are very

* Savi, Etudes Anat. sur le Système Nerveux et sur l'Organe Electrique de la Torpille.

inferior to the metals as conductors. And from experiments made on this subject in 1845 by Dr. Miller, Mr. Bowman, and myself, we were led to conclude that nerve was infinitely a worse conductor than copper. The provision for insulation, however perfect for the nervous force, seems most insufficient for electricity, unless, perhaps, for a current of very feeble intensity. Yet we know that the nerve fibres convey the mandates of the will with the nicest precision to the muscles, and propagate the effects of physical stimuli applied to the periphery with the greatest exactness to the centre. This could scarcely be if the force so propagated were an imperfectly insulated electric current, for it is evident that in such a bundle of fibres as a nervous trunk disturbances would continually be taking place, from the secondary currents induced in neighbouring fibres by the electricity passing through those in action.

3. The firm application of a ligature to a nerve stops the propagation of the *nervous power* along that nerve below the point of application; the passage of electricity, however, is not interrupted by these means. The nervous trunk, indeed, is as good a conductor of electricity after the application of the ligature as before it, provided it do not become dry at the point of ligature.

4. If a small piece be cut out of the trunk of a nerve, and its place supplied by an electric conductor, electricity will still pass along the nerve and along the conductor; but the nervous force, excited by a stimulus applied above the section, will not be propagated through the conductor to the parts below.

5. The existence of an organ in certain animals capable of generating electricity is unfavourable to the electric nature of the nervous force. The best examples of this organ are found in the Torpedo and the Gymnotus; and experiment has placed it beyond doubt that the organ generates electricity, which is capable of giving a shock similar to that from a Leyden jar; which developes a spark during the discharge, and can effect electrolysis; by which, likewise, the galvanometer may be disturbed, and needles rendered magnetic.*

The electrical organs have no resemblance, in point of structure, to nerves; they, however, present a remarkable analogy in that respect, as well as in their physiological action, to the striped variety of muscles. They are composed of a number of prisms, each of which consists of a membrane closed at both extremities, and containing a soft albuminous substance, but subdivided by transverse very delicate septa into a multitude of small compartments. The bloodvessels and nerves are distributed upon the enclosing membrane and upon the septa, but do not penetrate the albuminous material. On these septa, according to Savi, the nerves form a network, in which the disposition of their terminal fibres differs from that in muscle in there being a true anastomosis or fusion of the primitive tubules. The analogy of the structure of the electrical prisms with that of muscular fibres is sufficiently obvious, the latter being prismatic columns of fibrine, enclosed by a membrane, the sarcolemma, and separable into discs, the nerves and vessels being distributed upon the sarcolemma, and not penetrating the contained sarcous elements. In both these textures the anatomical disposition has evident resemblance to the artificial arrangements for generating electricity, and accordingly in one (the electric organ) true electricity is generated; in the other, as we shall see further on, either electricity, or a force in close relation to electricity, is developed. In both cases the generation of the force is independent of the nervous system; its exercise and application, however, are under the influence of that system.

The arrangement of the nerves and nervous centres is essentially different from that of muscle or of the electric organ, and so far would suggest a decided difference in the character of the force which they can develope from that produced by the latter textures.

6. A comparison of the muscular with the nervous force throws some light on the nature of the latter, and upon its true relation to electricity.

Matteucci has established beyond a shadow of doubt that electricity of feeble tension is generated in the ordinary nutrition of the muscles of all animals, and by a particular arrangement this may be made to assume the current form, passing from the interior to the exterior of the muscle. The source of this electricity is no doubt to be found in the chemical action which accompanies the nutrition of the muscular tissue, "principally that which takes place in the contact of the arterial blood with the muscular fibre."* The intensity of this current increases in proportion to the activity of muscular nutrition, and in proportion to the rank the animals occupy in the scale of beings. It requires a particular artificial arrangement to accumulate the electricity in such a manner as that it shall affect the galvanometer; "during life the two electric states evolved in the muscle neutralize each other at the same points from which they are evolved;" but in the arrangement of a muscular pile as devised by Matteucci, "a portion of this electricity is put in circulation just as it would be in a pile composed of acid and alkali, separated from each other by a simply conducting body."

During the *active contraction* of a muscle, however, a force is developed which has resemblance to electricity, and in his early experiments was regarded in that light by Matteucci. This power is capable of affecting the nerve of the frog in the same manner as electricity. The following experiment displays this:—Take the lower extremity of a frog and skin it; dissect out the sciatic nerve from among the muscles on the posterior part of the thigh, and then separate the thigh by cutting it across just above the knee-joint, leaving the nerve connected with the knee and leg; this preparation is the *galvanoscopic frog*, so called by Matteucci from the readiness with which it indicates an electric current; next prepare the lower extremities of a frog according to Galvani's method:

* See ELECTRICITY, ANIMAL.

* Phil. Trans. 1845, p. 294.

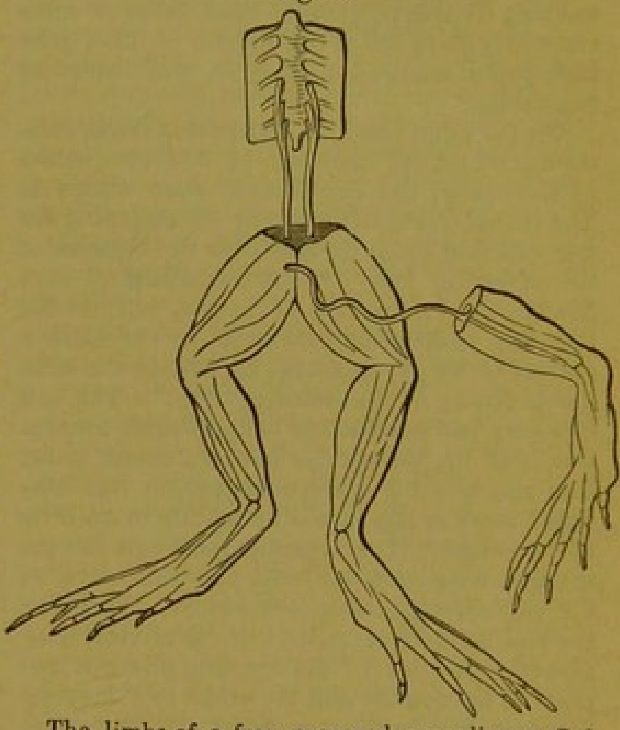
the nerve of the leg is to be laid upon the muscles of either thigh, and if these muscles be excited to contraction by mechanically stimulating the lumbar nerves, or the spinal cord, or by passing a galvanic current through the nerves or the cord, the muscles of the galvanoscopic leg will be simultaneously contracted. If a second and a third galvanoscopic leg be prepared, and the nerve of the second be laid on the muscles of the first, and that of the third be laid upon the muscles of the second, contractions will take place in all three whenever the muscles of the prepared thighs are thrown into contraction. Matteucci, to whom we owe the discovery of this important fact (which he terms *induced contraction**) has failed to cause a fourth leg to be thus affected.

If the galvanoscopic nerve be laid on the muscles of a frog's thigh in which tetanoid convulsions have been produced by the cessation of a long continued inverse current, the induced contractions will be likewise tetanic.†

The annexed woodcuts (*figs.* 2 & 3) will serve to show the manner in which these experiments may be performed.

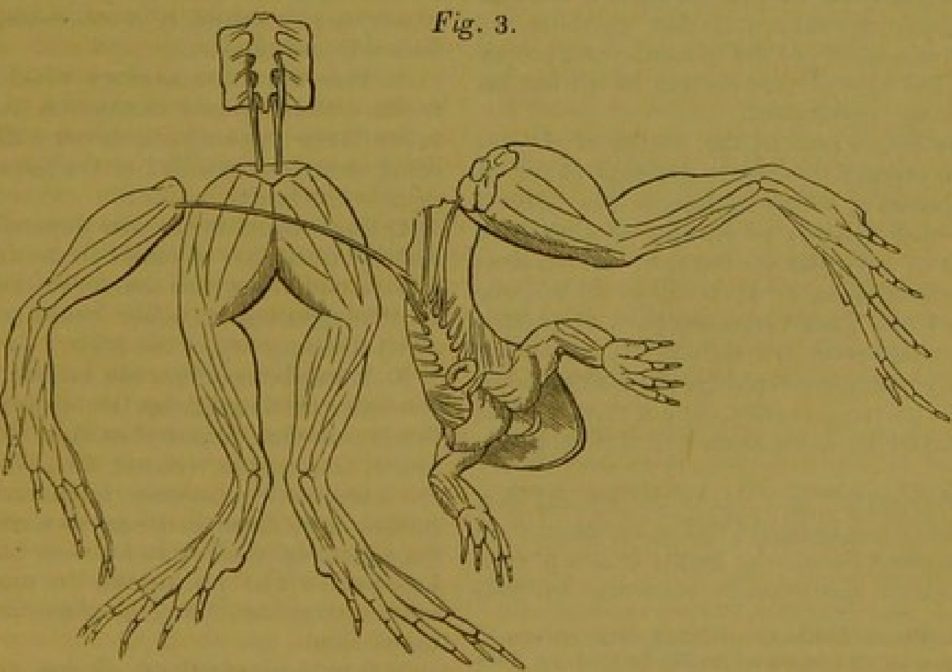
It is plain, then, that during the contraction of muscles, whatever be the means used to stimulate them, a force is evolved capable of exciting a nerve laid upon the exterior of the contracting muscle to such a degree as to cause contraction of the muscles it supplies. What is this force? The readiness with which it excites the nerve of the galvanoscopic leg resembles the action of electricity, and this view of its nature is favoured by the known fact that during muscular contraction heat is evolved, and in some of the marine animals, light also, according to the observations of Quatrefages. If heat and light be produced during muscular contraction, it is not unreasonable to expect that electricity should be evolved likewise. Matteucci's experiments, however, throw some difficulty in the way of viewing it as such. He finds that this force will freely permeate very imperfect conductors of electricity, whilst it will not traverse substances which are known to conduct electricity. If gold leaf be placed upon the muscle between it and the nerve, the con-

Fig. 2.



The limbs of a frog prepared according to Galvani's method, the nerve of the galvanoscopic leg being laid across the muscles of one thigh. When these muscles are thrown into contraction by any means, mechanical or galvanic, those of the leg contract at the same moment.

Fig. 3.



The limbs of a frog prepared after Galvani's fashion. In another frog the galvanoscopic leg is prepared, but the sciatic nerve is left in connection with the lumbar plexus and the spinal cord. If this nerve be laid across the thighs of the frog and the limbs be made to contract, contractions will be simultaneously excited in the galvanoscopic leg and also in the other one. It is plain that while the contractions in the galvanoscopic leg are excited by the direct stimulation of the sciatic nerve, those in the other leg are excited through the excitation of the spinal cord by the sensitive fibres of the same sciatic nerve.

* Phil. Trans. 1845, p. 303.

† Id. 1846, p. 487.

tractions of the galvanoscopic leg will not take place. If, however, a slight tear be made in the gold leaf, then the nerve may be excited. It is possible that this may arise from the electricity being carried off by the gold leaf, so that it does not affect the nerve at all. Matteucci never succeeded in obtaining the induced contractions when a solid body was interposed between the nerve and muscle, however thin it might have been and whatever might be its nature; for this purpose he used flakes of mica extremely thin, flakes of sulphate of lime, gold leaf, paper smeared with glue, and leaves of vegetables.*

On the other hand, in interposing some substances which are known to be bad conductors of electricity, the contractions were obtained. The induced contractions may be excited if the nerve be laid upon the skin over the muscles of the inducing frog. "The experiment," says Matteucci, "never fails of success, whether the inducing contraction be excited by the electric current or by any stimulus applied to the lumbar plexuses of the inducing frog." The use of a very bad conducting body, Venice turpentine, did not prevent the induced contractions. The nearly solid Venice turpentine was rendered more or less liquid by adding to it a little of the volatile oil of turpentine, and with this the muscles were smeared over, and the nerve of the galvanoscopic frog was wetted. To prove the bad conducting powers of the mixture employed, one pole of the exciting pile was applied to the muscle and the other to the galvanoscopic frog without exciting the least contraction. Yet the contractions were induced in the galvanoscopic frog by stimulating the muscles of the thigh. This experiment clearly proved, as Matteucci remarks, that the induced contraction may be excited through a stratum of an insulating substance that prevents the propagation not only of the muscular and proper currents, but also of that current which excites the inducing contraction.

We are forced then by the results of the remarkable experiments above detailed to adopt the conclusion at which Matteucci has himself arrived—that there is no *current* of electricity in the act of muscular contraction. What then is the evolved force? It is either an *electric discharge*† or a force very analogous to electricity, affecting nerves in a similar way, travelling apparently with great rapidity, traversing bodies which the galvanic current cannot traverse, and yet restrained by substances which freely conduct it.

I confess myself at a loss to understand how Matteucci comes to regard this as a phenomenon of the nervous force. In truth, it is a phenomenon which accompanies muscular contraction, and has no relation to the nervous force, excepting so far as that is the excitant of the muscular action. The essential point of the phenomenon is, that during the contraction of a muscle a nerve which is laid on it is stimulated just as it would be by electricity, and causes the muscles to which it is distributed to contract. The electric discharge from a muscle which is excited to contract through the exercise of nervous power is in close analogy with the electric discharge from the electrical organ of the Gymnotus or Torpedo, which is excited through the same agency.

Now the proved existence of a muscular force, the developement of which is accompanied with heat, and most probably electricity, and in some instances, if the statements of Quatrefages be correct, with light, justifies us in adopting the opinion, as regards the nervous force, that this is of an analogous kind, yet exhibiting still less resemblance to electricity than the muscular force; and it strikingly illustrates the remark of Faraday, that if there be reasons for supposing that magnetism is a higher relation of force than electricity, so it may well be imagined that the nervous power may be of a still more exalted character and yet within the reach of experiment.

We are thus led to these conclusions respecting the muscular and nervous forces.

1. That both are polar forces and in close analogy with light, heat, electricity—magnetism.

2. That either may be excited by or transformed into the other—the nervous may excite the muscular, or the muscular the nervous. It seems not improbable that it is by this reaction of the muscular upon the nervous force that the muscular sense is developed, and as Matteucci has ingeniously suggested, many movements independent on the will, yet following others which may be voluntary or otherwise, may result from the same cause.

3. That the same analogy which exists between electricity and magnetism is found between these organic polar forces; the muscular being more nearly allied to the former, the nervous to the latter.

4. Both these forces are dependent on the healthy nutrition of their respective tissues, muscle and nerve, and the slightest disturbance in that process in either tissue will readily affect the intensity of the force.

5. Nevertheless there is a certain mutual dependence between these two tissues and their forces; for the exercise of each is, within certain limits, impossible without the other; and as this exercise is necessary to maintain healthy nutrition, so these forces are to a certain extent dependent on each other for their normal developement. The practitioner in medicine will duly appreciate the great importance of this conclusion.

The mutual reactions of the nervous and muscular forces constitute a new and highly important field of inquiry, which, if duly cultivated, may clear up many obscurities in the physiology and pathology of the nervous system.

Having thus far considered certain generalities in the physiology of the nervous system, we may now proceed to inquire into the share

* Phil. Trans. 1845, On induced contractions.

† From a letter addressed to M. Dumas by Professor Matteucci, and published in the Comptes Rendus for March 15, 1847, it appears that he now is rather disposed to regard it as an electric discharge, as he says, "C'est après avoir prouvé que des décharges electriques de la bouteille tellement faibles qu'elles ne pouvent être montrées par aucun instrument, excepté par la grenouille, que j'ai pensé que la contraction induite pouvait être due à une décharge electrique de ce genre."

which each part of this great system takes in the production of nervous phenomena. This inquiry naturally divides itself into two branches, namely, first, the functions of nerves; secondly, those of nervous centres.

Of the functions of nerves.—Nerves are internuncial; they possess in themselves (separate from the nervous centre) only a very limited power of developing the nervous force, and that only in response to a physical stimulus, for connection with a centre is necessary for the exercise of a mental stimulus.

In inquiring into the function of any particular nerve, the problem is to determine whether it propagates the nervous force *centrad* or *peripherad*, and whether it be connected with the *centre of sensation* or with *the centre of volition;* whether, in short, it be sensitive or motor. It must be always borne in mind that most nerves contain nerve-fibres of different endowments, and that the office of any given nerve will be determined by the endowment of the greatest portion of its fibres. When we say, therefore, that a nerve is motor or sensitive, it is not to be understood that all its fibres are exclusively of that function, and that it contains no others of a different endowment.

In enquiring into the function of a nerve, the first point to determine is its anatomy, whereby we learn whether it be distributed to muscular parts or to sentient surfaces; and then to ascertain whether its distribution in man corresponds with that in the inferior animals. Anatomy, human and comparative, affords by far the most certain grounds to enable us to decide upon the endowment of a nerve: if the nerve be distributed to muscular parts, it is evident that it cannot be a merely sentient nerve, although it may contain some sentient fibres.

Experiment upon animals recently dead also affords considerable aid in reference to questions of this kind. Mechanical or chemical or galvanic irritation of a nerve will cause muscular contractions if it be a motor nerve, and will produce no perceptible change in either nerve or muscles if it be not muscular. Under certain circumstances, however, simple irritation of a nerve, while it evinces no change in the nerve itself or in the parts with which it is connected, will affect the portion of the nervous centre in which it is implanted, and will through that excite certain motor nerves to stimulate their muscles. To affect motor nerves through sensitive ones, it is generally necessary to stimulate their peripheral fibres, the entire trunk remaining uninterrupted in its course; and it would appear as if a certain peripheral organisation, as for instance a developement of papillæ on the tegumentary surface, were necessary for this purpose. Very rarely irritation of *the trunk* of a sentient nerve produces this effect; the least equivocal instance indeed in which, so far as I know, muscular action can be produced in this way, i. e, by irritation of the central segment of the trunk of a nerve, is in the case of the glosso-pharyngeal nerve. Dr. John Reid has succeeded, after section of this nerve, in producing contraction of the pharyngeal muscles by stimulating its central segment

MM. Longet and Matteucci affirm that a motor nerve may be distinguished from a compound one by the different effect produced on each by opening or closing a galvanic current, according to the direction in which it passes in the nerve. We have referred above to the results of experiments on compound nerves, the sciatic for instance, by means of the electric current. Compound nerves, as has been shown by these means, may at first be affected equally on opening as on closing the circuit, whether the current be direct or inverse; but after a time they are excitable, as shown by the contraction of the muscles below the point stimulated, only on *closing the direct current* or *opening the inverse.* With a purely motor nerve, however, such as the anterior root of a spinal nerve, a different result is obtained after the first period has passed; inasmuch as the contractions of the muscles can only be excited *on opening the direct current or closing the inverse.**

Experiment upon living animals likewise affords us some assistance in determining the functions of nerves. This mode of inquiry, however, must be used with great circumspection, and great caution must be observed in the interpretation of the results which it elicits. Section of a nerve paralyses its function, and occasions loss of motor or of sensitive power, according to the nature of the parts to which the nerve is distributed. Experiment of this kind, however, frequently leads to very unsatisfactory results, because it is often a matter of extreme difficulty to reach the nerve in question; the operation for that purpose may involve other parts and nerves as well, and sometimes it may be impossible to divide one nerve without injuring another immediately adjacent to it. Moreover, the shock of a severe operation frequently produces so much disturbance in the entire system of the animal as to render it extremely difficult to form any accurate opinion as to the effects of the section of the nerve under examination.

Clinical medicine gives very important aid to physiological enquiries of this nature. Disease or injury of certain nerves impairs or destroys or modifies certain functions. The various forms of partial paralysis, especially those affecting the face, may be referred to in illustration of this assertion. Thus a very distinct series of signs accompany disease of the facial nerve or the portio dura of the seventh pair; and these signs mark it very distinctly as

* Matteucci et Longet, sur la relation qui existe entre le sens du courant electrique, et les contraction musculaires dues à ce courant. Paris, 1844.

It is an extraordinary circumstance that the excitability of motor nerve-fibres should be modified by their simple juxtaposition with sensitive fibres.

I learn from a recent communication from Prof. Matteucci, (May, 1847,) that he finds that etherization in dogs modifies the excitability of the nerves, so that the mixed nerves, while connected with the nervous centre, react with the direct or inverse current as the motor nerves do, and excite contractions on opening the direct current or closing the inverse; but the moment their connection with the cord is destroyed they exhibit the phenomena of mixed nerves, causing contraction with the direct current on closing, and with the inverse on opening.

the motor nerve to the muscles of the features, and to the orbicular muscles of the eyelids. Clinical research, indeed, taken in conjunction with anatomy, forms the basis of our present accurate knowledge of the office of this nerve. In like manner we learn that loss of sensibility of the face is dependent on disease affecting the fifth nerve, and from the parts of the face which are affected by anæsthesia we can tell what portions of that great nerve are diseased. Here again anatomy and clinical medicine have mainly contributed to the advance of our knowledge. The partial palsies which affect the muscles of the eye-ball likewise give very distinct interpretation to the functions of these nerves, such as the third and sixth, the action of whose muscles is well understood. Many other instances might be quoted which clearly show that, while clinical medicine and anatomy are of infinite service in building up and confirming our knowledge of the function of nerves, this knowledge, in its turn, does great service in increasing the facility with which we can distinguish disease.

Of the functions of the roots of spinal nerves.—The greatest part of the body is supplied with nerves which are implanted in the spinal cord, or which, in anatomical language, have their origin in that nervous centre. As these nerves present very definite and constant characters as regards the manner in which they are connected with the centre, characters which are not limited to the human subject, but which belong to all classes of vertebrate animals, it was a point of primary importance to discover the object of an arrangement so peculiar as regards its anatomical characters, and so universal. To our countryman, Sir C. Bell, belongs the great merit of having seen the importance of determining this point as a preliminary step in the investigations into the nervous system; and to him must be awarded the credit of having achieved the discovery of the difference in the endowment of the anterior and of the posterior roots of these nerves. He experimented on young rabbits, by removing the posterior wall of the spinal column. "On laying bare the roots of the spinal nerves," says Sir C. Bell, "I found that I could cut across the posterior fasciculus of nerves, which took its origin from the posterior portion of the spinal marrow, without convulsing the muscles of the back; but that, on touching the anterior fasciculus with the point of the knife, the muscles of the back were immediately convulsed." *

Numerous experimenters, subsequent to Bell, obtained precisely similar results. Muller, however, obtained the most decisive evidence of the proper functions of the roots of the nerves, by experimenting on frogs instead of on mammalia; in the former the spinal canal is of great width, especially at its lower part, and the roots of the nerves can be exposed with great facility, whilst in the latter the operation is tedious, painful, and bloody, the spinal canal narrow, and the roots of the nerves small and difficult to get at. Moreover, the excitability of the nerves lasts very much longer in frogs than in mammalia, and on this account the former animals are well adapted for displaying the effects of section of the roots and the influence of mechanical and other stimuli upon them.

In these experiments, (which I have frequently repeated with similar results,) irritation, mechanical or galvanic, of the anterior root of the spinal nerve always provokes muscular contraction. No such effect follows irritation of the posterior root. Section of the anterior root causes paralysis of motion; section of the posterior root, paralysis of sensation. This latter effect is shown by the entire insensibility to pain evinced on pinching a toe, whilst in the limb of which the posterior roots of the nerves remained entire such irritation is evidently felt acutely. If the anterior roots of the nerves which are distributed to the lower extremities be cut on one side, and the posterior roots on the other, voluntary power without sensation will remain in the latter, and sensation without voluntary power in the former.

Valentin, Seubert, Panizza, and Longet have performed similar experiments on mammiferous animals with precisely similar effects.

I have never seen motion produced by irritation of one of the posterior roots of the spinal nerves still in connexion with the cord, excepting when the galvanic stimulus has been applied, and too strong a current has been employed. Valentin states that he has observed motions so produced in rabbits, but not in frogs and tortoises. Dr. Hall has seen them in the turtle and skate. Van Deen speaks of them as constantly occurring. But Müller denies the power of the posterior roots to excite motion, except by "traction on the cord itself." No such effect ever follows any kind of stimulation of the posterior root when it has been separated from the cord.

The conclusion which inevitably follows from these experiments is that the *anterior root of each spinal nerve is motor, and the posterior sensitive.*

Comparative anatomy confirms this conclusion, by showing that a similar arrangement of the roots of spinal nerves prevails among all classes of vertebrate animals, and that if in any particular class either the motor or sensitive power predominate, there is in correspondence with it a marked developement of the anterior or posterior roots. The frequent occurrence, likewise, of paralysis of sensation and motion, as a consequence of disease within the spinal canal, also tends to the same inference.

Kronenberg finds a small nerve of communication between the posterior and the anterior root, which is looked upon by some as being

* Sir C. Bell's first essay on this subject was printed in 1811. In 1822 Majendie published his first essay in the Journal de Physiologie Exp. t. iii; in 1831 Müller's experiments were published in the Annales des Sciences Nat. and in Froriep's Notizen. Mr. Alexander Shaw has published a temperate and judicious vindication of Sir C. Bell's claims in a volume entitled, "Narrative of the Discoveries of Sir C. Bell in the Nervous System." Lond. 1839.

Valentin is so satisfied of Sir C. Bell's claim to the discovery of the distinct endowments of the roots of the spinal nerves, that he designates the law thereby determined by a title not very euphonous to English ears, Lex *Bell*iana.

the means of giving to the anterior root the slight degree of sensitive power which Majendie attributes to it.

From the determination of the office of each root of the spinal nerves we obtain the further important result, that the nerve, which is formed by the junction of these two roots, is sensitive and motor, and that nervous fibres of different endowments may be bound together in the same sheath constituting one nerve, which is compound in its functions. And the anatomical distribution of spinal nerves, both in man and the inferior animals, to the muscles and sensitive surfaces of the trunk and extremities, is entirely confirmatory of the results thus derived from experiment.

By the use of the various means for determining the functions of nerves, above detailed, and aided by the determination of the law discovered and developed by Bell and others, as to the motor nature of the anterior and the sensitive endowment of the posterior roots, and the subsequent binding together of these fibres in one sheath to form a compound nerve, physiologists have made great advances in determining the functions of the various encephalic nerves, and our knowledge on this subject may be said to have approached more to perfection than that of any other physiological questions. The main facts connected with the anatomy and physiology of each of these nerves will be found under the articles headed by their names.

Of the functions of the nervous centres.—In examining into the functions of the various parts of the cerebro-spinal axis I shall adhere to the definitions already adopted in the previous part of this article, and use the term *spinal cord* as denoting the nervous cylinder within the spinal canal, and the *encephalon* as the intra-cranial mass, consisting of *medulla oblongata, mesocephale, cerebellum,* and *cerebrum.*

Of the functions of the spinal cord.—It was long held that the spinal cord was no more than a bundle of nerves proceeding from or to the brain, and emerging at various points of the vertebral canal to be distributed to their destined regions.*

The anatomy of the organ, however, sufficiently exposed the error of this opinion. The existence of a large quantity of vesicular matter in it varying in quantity according to the bulk of its segments showed that it was more than a mere fasciculus of nerves. Although the true office of the spinal cord was known to physiologists long before, to Prochaska for example, Gall appears to have been the first who adduced the best proofs from anatomy to show that the spinal cord was not a mere appendage to the brain, but a special centre in itself. His principal arguments were derived from the want of any constant proportion in bulk between it and the brain, the spinal cord being small with a large brain, as in man, and large with a small brain, as in the inferior mammalia and in other vertebrata, from the fact that it does not taper gradually in proportion as it gives off nerves, but on the contrary is alternately large or small according to the number and volume of the nerves which are given off from its various segments; and, lastly, from the analogy which he indicated between the spinal cord of vertebrata and the ganglionic chain of articulata, the former consisting of a series of ganglia fused together, the latter remaining separate by reason of the peculiar disposition of the bodies of these animals in distinct segments.

The determination of the functions of the nerves which are intimately connected with or implanted in the spinal cord affords some clue to the solution of the problem as to its own office. There can be no doubt that as the nerves of sensation as well as those of motion of the trunk and extremities are all, to say the least, intimately connected with the cord, this organ must be the medium of the reception and propagation of the sentient impressions made upon the one, and of the mental or physical impulses which excite the others.

If, moreover, we look to the results of experiments on the lower animals, or to the effects of injury or disease in the human body, we obtain the following important facts:—1st, that the perfect connexion of this organ, in all its integrity, with the encephalon is the essential condition for the full and complete exercise of the nervous force, whether for sensation or voluntary motion, as far as regards the trunk and extremities; 2nd, that division of the cord, so as completely to separate the lower from the upper segment, causes paralysis both of sensation and voluntary motion in the parts supplied with nerves from the lower segment; 3rd, if the section be made high up in the neck so as to separate the cord from the medulla oblongata, *all* the parts supplied by spinal nerves will be paralysed in the same way; by such an experiment the spinal cord remains entire, but its continuity with the encephalon is interrupted.

In cases of injury to the vertebral column it may be laid down as the rule that the higher the seat of injury the more extensive will be the paralysis. A man who has received extensive injury of the spinal cord high up in the neck is like a living head and a dead trunk, dead to its own sensations, and to all voluntary control over its movements. The same rule prevails with regard to the effects resulting from disease of the vertebræ or from any intra-spinal growth, or from a morbid state of the cord itself, there being only this difference, that where the morbid change is chronic, the paralytic effects are less marked than in injury or acute disease. In all cases the *extent* of the paralysis affords a correct indication of the seat of the solution of continuity.

If the spinal cord be divided partially in the transverse direction, there will be paralysis of parts *on the same side* with the injury. Dr. Yellowly has put on record an experiment of Sir Astley Cooper's, in which he divided the right half of the spinal cord in a dog just above the first vertebra. The effect was paralysis of the motions of the ribs on the right side, and of the right posterior and posterior extremities, with irritation of those of

* That this was Willis's view a perusal of chapters xviii. and xix. of his Cerebri Anatome will shew.

the left side.* A longitudinal section of the cord along the median line in frogs does not cause paralysis; it gives rise, however, to a temporary disturbance of the functions of the cord which soon subsides.†

Continuity of the spinal cord and encephalon is then the condition necessary to establish the control of the former organ over the *voluntary* movements and *sensations* of the trunk. The disunion of the cord or any portion of it from the encephalon dissociates the cord or the separated segment of it from all participation in mental nervous actions. So long as the cord is united with the brain, it takes a certain share in mental nervous actions, in acts of sensation and volition; this, however, it loses when disease or accident separates the one from the other.

It is plain, then, that the spinal cord, although apart from the encephalon it takes no share in sensations and voluntary actions, (for then, indeed, these phenomena cannot take place as far as regards the trunk and extremities,) while united with the encephalon participates fully in sensori-volitional actions, and its integrity is quite necessary to the perfection of those actions.

I repeat that we are not justified in supposing that the mind localises itself exclusively in some or all of the gangliform bodies, the assemblage of which constitutes the encephalon; but this we may assert, with perfect justice, that when the cord has been separated from the encephalon, the mind appears as it were to cling to the latter organ, and to lose all its connection with the former.

Does then the cord, under these circumstances, lose all its power? Does it, when separate from the encephalon, shew no indication of acting as a nervous centre? Undoubtedly it does show abundant indications. A series of actions, which had attracted the notice of several physiologists, are still capable of being developed through the instrumentality of the whole cord or of any portion of it, the nerves of which may remain uninjured both as to their central and peripheral connections.

Phenomena of this nature may be produced in all vertebrate animals. They are, however, especially marked in the cold-blooded classes, in consequence of the more enduring character of the nervous force in those creatures than in the warm-blooded. Hence frogs, salamanders, snakes, turtles, fishes, have been generally selected by physiologists for exhibiting these phenomena. In the young of warm-blooded animals they are more manifest than in adults of the same class.

If a frog be pithed by dividing the line of junction of the medulla oblongata with the spinal cord, the following effects may be observed. After the first disturbance, general convulsions, &c., consequent upon the division of the cord, the animal, if placed on a table, will assume his ordinary position of rest. In some cases, however, frequent combined movements, much resembling acts of volition, will take place for a longer or shorter time after the operation. When all such disturbance has ceased the animal remains perfectly still and as if in repose, nor does it exhibit the slightest appearance or give the least expression of pain or suffering. It is quite unable to produce any spontaneous or voluntary movement of parts supplied with nerves from below the section, that is, of the trunk or extremities. However one may try to frighten it, it remains in the same place and posture. The only appearance of voluntary motion is the winking of the eyelids, which, however, probably is not excited by the will. If, now, a toe be pinched, instantly the limb is drawn up, or the animal seems to push away the irritating agent, and then draws up the leg again into its old position. Sometimes a stimulus of this kind excites both legs, and causes them to be thrown violently backwards. A similar movement almost constantly follows stimulation of the anus. If the skin be pinched at any part, some neighbouring muscle or muscles will be thrown into action. Irritation of the anterior extremities will occasion movements of them; but it is worthy of note that these movements are seldom so energetic as those of the posterior extremities.

We may remark here, that phenomena of this kind are not confined to the trunk and extremities, which are supplied only by spinal nerves. The head and face, with which the encephalon remains in connection, exhibit similar actions. The slightest touch to the margin of either eyelid or to the surface of the conjunctiva causes instantaneous winking; the attempt to depress the lower jaw for the purpose of opening the mouth is resisted; and the act of deglutition is provoked by applying a mechanical stimulus to the back of the throat.*

Actions similar to those which take place in the decapitated frog, occur in the human subject when the spinal cord has been separated from its encephalic connections by disease or accident. In such cases it is found that although the will cannot move the paralysed parts, the lower extremities for instance, movements do occur

* Med. Chir. Trans. vol. i. p. 200.

† See Flourens' Experiments, Syst. Nerveux.

* Sir Gilbert Blane, in his admirable Croonian Lecture on muscular motion, having drawn the distinction between instinctive and voluntary actions, makes the following remarks. "There are facts which show that instinctive actions, even in animals endowed with brain and nerves, do not depend on sensation. I took a live kitten, a few days old, and divided the spinal marrow by cutting it across at the neck. The hind paws being then irritated by pricking them, and by touching them with a hot wire, the muscles belonging to the posterior extremities were thrown into contraction, so as to produce the motion of shrinking from the injury. The same effects were observed in another kitten after the head was entirely separated from the body." And again, "In an acephalous monster, the like phenomena were observable. It moved up its knees, when the soles of its feet were tickled; it performed the act of suction; passed urine and fæces; and swallowed food." * * * "The like takes place with regard to insects; for, after the head of a bee is separated from the body, the hinder part will sting, upon the application of such a stimulus as would excite the same action in the animal in a perfect state."

in them of which the individual is wholly unconscious, and which he is utterly unable to prevent. Sometimes these take place seemingly quite spontaneously; at other times they are excited by the application of a stimulus to some surface supplied by spinal nerves. The movements of this kind, which seem to occur spontaneously, exhibit so close a resemblance to voluntary actions as to render it impossible to distinguish them, did not the consciousness of the patient in some cases assure him of the inactive state of his will in reference to them.

The comparison of the phenomena which occur in pithed or decapitated animals with the actions developed in man under these morbid states, affords most conclusive evidence as to the important question of the connection of these phenomena with the mind. In a pithed or decapitated animal we can only judge of the exercise of volition or the perception of sensitive impressions by external signs. And so far as these go we are justified in maintaining that, while the mental principle is unextinguished, it nevertheless has lost its influence over or connection with that portion of the cerebro-spinal axis which is separated from the encephalon. But in the human subject we have the evidence of the individual himself, who, from his own consciousness, avows the integrity of his will and perception, but admits their dissociation from those parts of the body whose nerves are implanted in the severed portion of the cord.

Let us refer to such a case as has been already quoted. A man has fallen from a height and fractured or displaced one or more of his cervical vertebræ; we find the patient presenting the following phenomena. His trunk and extremities appear as if dead, excepting the movements of the diaphragm, while the head lives. In full possession of his mental faculties and powers, he is, nevertheless, unconscious, save from the exercise of his sight, of any changes which may affect the parts below his head, nor is the utmost effort of his will sufficient to produce a movement of any, even the smallest, of these parts. If the stunning effect of the accident have passed off, tickling the soles of the feet will be found to cause movements, of which, as well as of the application of the stimulus, the patient *is unconscious;* the introduction of a catheter into the urethra, which the patient *does not feel*, excites the penis to erection. The limbs may be irritated in various ways, but without exciting any effect which the patient can perceive, excepting movements, and these he is aware of only from his happening to see them. It is important to notice that, in cases of this kind, movements are difficult of excitation in the upper extremities, while they are aroused with great facility in the lower.

In these cases movements may be excited in both lower extremities by passing a catheter into the bladder. Sometimes internal changes, the precise nature of which we cannot always appreciate, but which are often the result of the irritation of flatus or other matters in the intestinal canal, excite movements in the lower or even in the upper extremities, and the patient is disturbed by cramps and spasmodic movements, more or less violent, at night. It is very remarkable, that while a patient is almost wholly insensible to external stimuli, he feels and even suffers pain from cramps of this kind.

In the hemiplegic paralysis which results from an apoplectic clot, or some other lesion affecting one side of the brain, when the paralysis is complete, the influence of the will over the paralysed side is altogether cut off, sensibility, however, generally remaining. In such cases it is wonderful how easily movements may be excited in the palsied leg—very rarely in the arm—by the application of stimuli to the sole of the foot, or elsewhere with less facility. The patient, who acknowledges his utter inability to move even one of his toes, is astonished at the rapidity and extent to which the whole lower extremity may be moved by touching the sole of the foot, even with a feather. It is proper to add that there is much variety as regards the extent to which these actions take place in hemiplegic cases, owing to causes not yet fully understood; still they do occur in a large proportion of instances, and in the most marked way. Their developement is frequently in the inverse proportion of the withdrawal of the power of the will. When the paralysis to volition is only imperfect, the effect of stimuli in exciting motions is less obvious, because of the restraining power of the will.

The cases of anencephalic fœtuses may be properly referred to as affording instances of similar movements. In these beings we have no movements which can be supposed to originate in any effort of the will, nor is there any proof of the existence of sensibility. Movements, however, of definite kind do occur under the influence of a stimulus applied to the surface.

Actions of the same kind, i. e., provoked by stimuli applied to some surface to which nerves are distributed, will continue to be manifested in animals after decapitation, not only in the trunk and extremities, but also in those segments of the former with which a portion of the spinal cord remains connected. If the body of a snake or an eel be divided into several segments, each one will exhibit movements for some time upon the application of a stimulus. The same thing may be observed in frogs, salamanders, turtles, and other cold-blooded creatures. It may be shown in a remarkable manner in the male frog in the early spring, during the copulating season. At this period an excessive developement of the papillary texture of the integuments covering the thumbs takes place; and this seems to be connected with the tendency which the male frog exhibits during this period of sexual excitement to lay hold on any thing that is brought within the embrace of his anterior extremities and in contact with the enlarged thumbs. If the animal be made to lay hold firmly of any object, two fingers of the observer, for instance, the head and the posterior half of the trunk may be removed, and yet the anterior extremities will maintain their grasp with as much firmness as if the animal were unmutilated. And when the frog is in full vigour, they will continue their hold for as long as a quarter of an hour or twenty minutes after the removal of the head and the posterior segment of the body. But let the portion of the cord which is connected with the anterior extremities be destroyed, and all such power of movement becomes completely annihilated.

In birds and mammalia phenomena of this kind are less conspicuous than in the cold-blooded animals, because in them the nervous power becomes extinct so speedily after any mutilation of the body. The power itself is no doubt more energetic, as the muscular power is, but it is less lasting.

In the articulate classes movements of precisely the same nature may be observed. The common earthworm may be divided into several pieces, and each piece will continue to writhe so long as the irritation produced by the subdivision remains, and after that has ceased, movements may be excited in any segment by stimulating its surface: the same phenomena are observable in leeches and various insects. These actions are exactly analogous to those in the segments of the divided body of a vertebrate animal. Each portion of the articulate creature has in its proper ganglion the analogue of the piece of the spinal cord remaining with the segment of the vertebrate animal. These phenomena of function, conjoined with certain anatomical resemblances, make it quite certain that the abdominal ganglionic chain of the articulata is analogous, not, as formerly supposed, to the sympathetic system, but to the cerebro-spinal centres of Vertebrata. In both the Vertebrata and the Invertebrate Articulata each segment of the body is provided with its proper ganglionic centre, which is to a certain extent independent of the rest. In the latter, the centres of the segments remain distinct, although connected by fibres which pass from one to the other; but in the former they are as it were fused together at their extremities, and from that fusion results the single cylindrical nervous centre which we call *the spinal cord*.

An experiment, to which attention has been directed by Flourens, illustrates very well the difference in the character of the actions of two portions of the spinal cord, according as the brain is connected with or dissociated from it. The spinal cord of an animal is divided about its middle; when the anterior segment (that which still retains its connection with the brain) is irritated, not only are movements of the anterior extremities produced, but the animal evinces unequivocal signs of pain; when, however, the posterior extremity is irritated, the animal seems not only insensible to pain, but unconscious even of the movements that have been excited in the posterior extremities. If a frog be divided in the back into two segments, the anterior portion crawls about, exhibiting all the indications of sensation and volition; the posterior segment remains quite motionless unless some stimulus be applied to it, when movements more or less active may be excited.

Nothing can be more conclusive than such an experiment, in illustration of the fact that connection with the encephalon is necessary to sensation; and that movements, not only without volition, but also without consciousness, may be excited by stimulating the segments separated from it. But there is nothing in this experiment to justify the conclusion that during the entire and unmutilated state of the cerebro-spinal axis the mind has no connection with the spinal cord. The experiment only shows that when a portion of that great centre has been removed, the mind retains its connection with the higher or encephalic portion, deserting that which is merely spinal.

Direct irritation of the spinal cord is capable of exciting these movements as much as when the stimulus is applied to the skin.

All these motions cease when the spinal cord is removed; no movement of any kind, voluntary or involuntary, can then be excited, except by directly stimulating the muscles, or the nerves which supply them, and such movements want the combined and harmonious character which belongs to those which are excited through the nervous centre.

Division of all the roots of the nerves at their emergence from the spinal cord annihilates these movements as completely as the removal of the cord itself. Under such circumstances no motion can be excited by stimulation of the surface of the body, nor by irritating the cord itself; and this fact may be regarded as an unequivocal proof that the nerves, in ordinary actions, are propagators of the change produced by impressions to or from the centres; and that in the physical nervous actions the stimulus acts, not from one nerve to another directly, but through the afferent nerve upon the centre, which in its turn excites the motor nerve.

All these facts in the physiological history of the spinal cord lead unequivocally to the following conclusions respecting its office:—1. that the spinal cord (that term being used in its simple anatomical sense, *the intra-spinal mass) in union with the brain* is the instrument of sensation and voluntary motion to the trunk and extremities; 2. that the spinal cord may be the medium for the excitation of movements *independently* of volition or sensation in parts supplied by spinal nerves, either by direct irritation of its substance, or by the influence of a stimulus conveyed to it from some surface of the trunk or extremities by its nerves distributed upon that surface.

Of the physical nervous actions of the cord.—We must pause here to make a more extended reference to those actions of the spinal cord which are capable of being excited by peripheral stimulation, and which are independent of mental change. There is no point in the physiology of the nervous system of more interest or importance than this, inasmuch as these actions are not limited to the cord, but take place in other portions of the cerebro-spinal centre, in which nerves are implanted, and even in ganglions from which nerves take their rise.

The existence of a class of actions like these has long been known to physicians and physiologists. By the name of *sympathetic actions* they excited great interest as to the mode of their production. And anatomists explored the frequent and often intricate anastomoses of nerves in their peripheral distribution with the hope of finding in them some clue to the explanation of these phenomena.

To these actions I prefer to apply the name *physical nervous actions* to mark their peculiar characteristic, namely, *independence of the mind*, and to denote that they are the result of a physical change produced by a physical impression, and therefore, in their causation, wholly independent of mental influence. The term *excito-motory* has been applied to them by Dr. Hall. To this term, however, there appear to me to be several serious objections. First, this term implies that the excitation of motion takes place in no other way than by a mechanism similar to that by which these movements are produced. Secondly, it denotes the existence of a peculiar excito-motory power different from the ordinary *vis nervosa*, the agent in all nervous phenomena. As if this force were not capable of being roused into action at one time by a mental stimulus, at another by a physical stimulus, or at a third by a mental and physical stimulus united. Persons get into the habit of using the terms "excito-motory power," "excito-motory phenomena," as if this power, or these phenomena were something quite peculiar, quite *sui generis*, and limited to a special part of the nervous system, losing sight of the real truth that they differ from voluntary actions only in their mode of excitation, that is, by a physical and not by a mental stimulus. Thirdly, it limits the reflecting power of the nervous centres (*i. e.* the propagation of the change induced by the application of a physical stimulus at the periphery) to reflection *from* sensitive to *motor* nerves. Now there are many facts which shew that reflection may take place from a sensitive to another sensitive nerve, and many of the phenomena of sympathy admit of no other explanation excepting on this principle. And I am by no means prepared to affirm that reflection may not take place from motor to sensitive nerves, or even from motor to other motor nerves, under circumstances of an exalted polarity of the nerves and the centres. Fourthly, some of these so-called *excito-motory* phenomena have nothing to do with muscular action. Take, for example, erection of the penis: it has not been shown that muscular fibres take any part in the production of this phenomenon, or that the stimulus which gives rise to it does more than create a change in the vessels of the penis, which seems due to muscular relaxation rather than to muscular contraction. The excitation of a gland to secrete by stimulating some surface connected with it, as the mammary gland by stimulating the nipple, is no doubt a phenomenon of the same kind, but not one in which muscular fibres are excited to contract.

The term "reflex actions," in accordance with Prochaska's view of the reflecting power of the nervous centre, is objectionable inasmuch as it fails to denote fully the physical character of the phenomena; and, moreover, it is applicable only to a class of the actions in question, those, namely, in which the excitation of a motor or sensitive nerve takes place through the primary excitation of another motor or sensitive nerve. Either this term, however, or that which I have proposed, may be used without inconvenience to science because they involve no particular theory, and yet sufficiently express some leading feature of the phenomena, *reflection* at the centre, in the one case—a physical exciting cause of a phenomenon purely physical in the other. It may be objected to the term "physical nervous action" that the actions produced by the mental stimulus are equally physical in their intrinsic nature. When, however, the term is habitually used in contrast with "mental nervous action," all practical difficulty or objection vanishes—both are physical phenomena,—but one is physical in its essence and also in its exciting cause; the other is physical in its essence, but mental in its cause. The term *physical nervous actions* may be regarded as a generic expression for all those nervous phenomena in which the mind takes no necessary share; *reflex actions* being a specific term denoting those physical nervous actions of which reflexion at the centre is a prominent character. In this sense I shall use these terms respectively.

By none were these phenomena more carefully studied than by Whytt and Prochaska. In 1764 Whytt published his "Observations on Nervous Diseases," a work full of the most valuable clinical and practical information. In the first chapter of this book, "on the structure, use, and sympathy of the nerves," he enumerates various instances of sympathetic actions, and discusses the mode of their production. To show that he regarded in this light the actions which we are now considering, I shall quote one which he adduces as an example. He says: "When the hinder toes of a frog are wounded, immediately after cutting off its head, there is either no motion at all excited in the muscles of the legs, or a very inconsiderable one. But if the toes of this animal be pinched, or wounded with a penknife, ten or fifteen minutes after decollation, the muscles not only of the legs and thighs but also of the trunk of the body are, for the most part, strongly convulsed, and the frog sometimes moves from one place to another."*

Whytt's most important work, in which this subject has been most fully discussed, is the essay on the vital and other involuntary motions of animals, published ten years earlier, in 1754. This physiologist was deeply imbued with a righteous dread of materialism, which led him to such extraordinary lengths in spiritualism, that he ascribed every action and movement of the body to "the immediate energy of the mind or sentient principle;" while he completely repudiated all notion of any mechanical disposition in the intimate nature of these phenomena. As an example of his mode of reasoning upon this subject, and as further evidence that he was well acquainted with the class of actions which we now call reflex or physical, the following passage from the eleventh section of this essay may be cited:—

* Whytt's Works, 4to. edit. p. 501.

"The objection against the mind's producing the vital motions, drawn from their being involuntary, must appear extremely weak; since there are a variety of motions equally independent upon our will, which yet are certainly owing to the mind. Thus, as had been already observed, the contraction of the pupil from light, and the motions of the body from tickling, or the apprehension of it, undoubtedly flow from the mind, notwithstanding their being involuntary. The shutting of the eyelids, when a blow is aimed at the eye, is another instance of a motion performed by the mind in spite of the will; for, as the threatened blow does not, by any corporeal contact, affect the orbicular muscle of the palpebræ, its contraction must necessarily be deduced from the mind, moved to perform this action from the apprehension of something ready to hurt the eye: and if there are some who, by an effort of the will, can restrain this motion of their eyelids, yet this does not proceed so much from the mind's making no attempt, in consequence of the apprehended danger, to close the palpebræ, as from the superior eyelid's being kept up by a strong voluntary contraction of its levator muscle. We cannot, by an effort of the will, either command or restrain the erection of the penis; yet it is evidently owing to the mind: for sudden fear, or anything which fixes our attention strongly and all at once, makes this member quickly subside, though it were ever so fully erected. The titillation, therefore, of the *vesiculæ seminales* by the semen, lascivious thoughts, and other causes, only produce the erection of the penis, as they necessarily excite the mind to determine the blood in greater quantity into its cells."

Whytt's view is best explained in the following passage of the same work:—"Upon the whole, there seems to be in man one sentient and intelligent PRINCIPLE, which is equally the source of life, sense, and motion, as of reason; and which, from the law of its union with the body, exerts more or less of its power and influence as the different circumstances of the several organs actuated by it may require. That this principle operates upon the body, by the intervention of something in the brain or nerves, is, I think, likewise probable; though, as to its particular nature, I presume not to allow myself in any uncertain conjectures; but, perhaps, by means of this connecting medium, the various impressions, made on the several parts of the body, either by internal or external causes, are transmitted to and perceived by the mind; in consequence of which it may determine the nervous influence variously into different organs, and so become the cause of all the vital and involuntary motions as well as of the animal and voluntary. It seems to act necessarily and as a sentient principle only, when its power is excited in causing the former; but in producing the latter it acts freely, and both as a sentient and rational agent."*

* Op. cit., 8vo ed., p. 290.

The third fasciculus of the Annotationes Academicæ of Geo. Prochaska was published in 1784. It contains the Essay on the Functions of the Nervous System. It is impossible to speak too highly of this profound and accurate dissertation. Although short, it comprehends all the leading facts connected with the working of the nervous system, and affords abundant indications that its author had thought deeply on the subject. I know of no essay, of more modern date, which exhibits the same profound knowledge of nervous phenomena, and which is equally comprehensive. How it came to be so long neglected can only be explained by the too general incompetency of physiologists to appreciate his views. Yet his language is remarkably clear and precise. No one can have done more ample justice to his predecessors and contemporaries. His literary research was extensive and accurate, and his historical summary is most interesting and instructive. The attentive perusal of this essay more frequently than once has impressed me strongly with the conviction that Prochaska was a man of the highest mental capacity and of great power of generalization, and I shall rejoice to see his work made easily accessible to all medical readers.

A brief summary of this important work will not be out of place here.

In the first chapter, the first seven sections are occupied with an historical account of the views of preceding philosophers, beginning with Aristotle and Galen. In the eighth section, he remarks, "At length we abandon the Cartesian method of philosophizing in this part of animal physics, and embrace the Newtonian, being persuaded that the slow, nay, the most uncertain road to truth is that by hypothesis and conjecture, but that by far the more certain, more excellent, and the shorter way is that, quæ a posteriori ad causam ducit. Newton distinguished the inscrutable cause of the physical attractions by the name 'force of attraction;' he observed its effects, arranged them, and detected the laws of motion, and thus established a useful doctrine, honourable to human genius. In this way we ought to proceed in the study of the nervous system; the cause latent in the nervous pulp, which produces certain effects, and which hitherto has not been determined, we shall call *vis nervosa*; its observed effects, which are the functions of the nervous system, we shall arrange, and expose their laws, and in this manner we shall be able to construct a true and useful doctrine, quæ arti medicæ novam lucem et faciem elegantiorem datura est pro certo." Haller, he admits, had previously used the term "vis nervosa" to express the power by which nerves cause muscles to contract, but to Unzer he assigns the credit of having thrown the greatest light upon this subject, although he states that to accommodate himself to the times in which he wrote and to make himself more generally understood, he still used the term "animal spirits," although his doctrine was quite independent of such an hypothesis.

In the second chapter Prochaska gives an admirable summary of the leading anatomical characters of the nervous system. His succinct description of the nervous centres is excellent, and shows that he had anticipated views which long afterwards were put forward as original. Speaking of the crura cerebri, he describes them thus, "duo magna crura cerebri, in quibus omnis medulla ab utroque cerebri hemisphærio collecta videtur." The compound origin of the fifth and spinal nerves and the existence of the ganglion on one of their roots he was well acquainted with. He concludes thus, "However complex be the mechanism of the nervous system, I think it can be divided into three parts, just as the functions themselves are conveniently divisible into three classes: namely, first, the animal organs, or those associated with the faculty of thinking, these are the brain and cerebellum; secondly, the *sensorium commune*, which consists of the medulla spinalis and oblongata, not excepting also such part of the medulla of the brain as gives immediate origin to nerves; and, thirdly, the nerves properly so called, which are prolonged from the sensorium commune to the whole body."

An examination of the comparative anatomy of the nervous system next follows, affording a clear and concise exposition of the existing state of knowledge on that subject.

The question discussed in the succeeding section is, "quid per vim nervosam intelligitur, et quæ sint generales ejus proprietates?" and he affirms the principle of the inherence of the vis nervosa in the nervous structure itself, and the developement of that force by changes taking place in it. Leaving it to those who devote themselves to the study of experimental physics to inquire into the nature of the nervous force, he endeavours to determine its general properties or laws before inquiring into the special functions of the nervous system.

1. The first law which he lays down is that the vis nervosa requires, for its action, a stimulus. Here, likewise, he repeats the assertion, that the *vis nervosa* is an innate property of the nervous medulla—"innata pulpæ medullaris proprietas. Sicut scintilla latet in chalybe ac silice, nec prius elicitur, nisi attritus mutuus chalybis, silicisque accesserit: ita vis nervosa latet, nec actiones systematis nervosi prius producit donec stimulo applicito excitatur, quo durante durat, ablato cessat agere, et redeunte iterum reddit."

2. The stimulus necessary for the developement of the nervous force is twofold, *stimulus corporis* and *stimulus animæ*. The former is any body fluid or solid applied externally or internally to the nervous system. The latter is that of the mind, which, through its connection with a part of the nervous system, is capable of influencing, to a certain extent, the rest of that system and through it the body.

3. The vigour of the nervous actions bears a direct relation to that of the nervous force and to the power of the exciting stimulus. The actions of the nervous system will be greater and more vigorous in proportion as the vis nervosa may be more active (mobilior) and the stimulus more efficacious; on the other hand, the nervous force will be more sluggish and the stimulus less effective, where the nervous actions are more languid. A less stimulus is sufficient for a more active vis nervosa, as the application of a stronger stimulus may compensate for a more sluggish vis nervosa, yet an equal effect may be produced in the nervous actions. The nervous force, however, is not equally susceptible to every kind of stimulus; sometimes it obeys one more than another, although both may appear equally powerful: nay, sometimes it experiences a more powerful effect from the stimulus which may seem the mildest. According to Haller, the heart and intestines are more powerfully stimulated to contract by air blown into them than by water or by any poison; on the contrary, a drop of water let fall into the trachea excites violent cough, whereas air passes through it in breathing as if unfelt by it.

4. The nervous force is augmented by various circumstances. Among these he enumerates *age*—at an early age the vis nervosa being greater than at a more advanced period of life—*climate*, and *disease*.

5. On the other hand, the vis nervosa may be depressed or diminished by all causes which depress the powers of life, by the direct application of opium and other sedatives to the nervous matter.

6. "Vis nervosa est divisibilis et absque cerebro in nervis subsistit." In illustration of this law he adduces the instances of nerves remaining excitable after they have been separated from the cord or from the brain; also the excitability of paralytic limbs by the electrical stimulus. And, he states, the vis nervosa not only remains for a long time in the spinal cord and nerves which have been separated from the brain, but even in nerves which never had any connection with the brain, as is shown by the acephalous fœtus, which, without a brain, and by the sole force of the nerves and medulla spinalis, if this be not deficient, lives the full time in the uterus of the mother, is nourished, grows, and, when it comes into the light, shows often no obscure signs of life. To this law he attributes the persistence of the rhythmical action of the heart after the decapitation of animals.

7. Idiosyncrasy is a peculiar affection of the nervous force. Among the examples of idiosyncrasy he enumerates, fainting at the sight of blood, the uneasiness and even terror produced in some persons by the exhalations from a cat, which may be in the same room, although unseen; fainting from the perception of particular odours.

In his third chapter Prochaska proceeds to examine the functions of nerves. He describes the mode of action of nerves, their power of receiving impressions with great facility, and of propagating them with the greatest velocity either to the centre or to the periphery. This power he calls the vis nervosa of nerves, which also may be called the sensibility or mobility of nerves, and to which Unzer had given the name *corporeal sense without concomitant perception*. And he shows that this power is inherent in the medullary pulp of the nerves, and is not simply derived from the brain, but that a certain cohesion of the medullary pulp of the nerves is necessary for the developement of the vis nervosa, because if by compressing a nerve strongly we injure its medulla, so as to disturb the connection of its particles, the nervous force ceases in that part of the compressed nerve, nor are impressions propagated further by it, nor if that part of the nerve be stimulated can sensation or motion be produced.

Although, he says, a nerve is necessary for sense and motion, it is not it alone which feels or moves; it feels by the brain, which, when an impression made upon a nerve is conveyed to it, represents that impression to the mind; and a nerve causes motion by the muscle when an impression, communicated to the nerve, descends to the muscle and excites it to motion. He concludes thus: "Par itaque nervi, in sensu et motu ciendo, est officium, nimirum impressionem stimuli recipere, et per totam suam longitudinem celerrimé propagare, quæ dum ad cerebrum pervenit, sensus perceptionem causat, dum vero ad musculum, ejus contractionem ciet."

Prochaska recognises the influence of the nerves upon the bloodvessels, and ascribes various familiar phenomena to this influence, either excited by direct contact of the nerves of the part, or, if the nerves be indirectly affected through the brain (si isti nervi non immediate, sed mediante cerebro afficiantur) Thus he refers to redness of the skin of the face occasioned by exposure to a cold wind, redness of the conjunctiva caused by some irritant, erection of the nipple of the breast by titillation, erection of the penis by similar means or through mental emotion, blushing, &c. He puts forward the notion that the augmentation of the nervous force in any part causes an attraction of fluids to that part, as sealing-wax, when rubbed with cloth, becomes electrical and attracts various small particles. To a similar attraction of fluids he ascribes muscular action and many other phenomena, such as the menstrual flux, the action of the iris, &c. He also discusses the question whether the nerves have any power over the secretions, whether they contribute in any way to the production of animal heat, and how far they are necessary to nutrition.

The fourth chapter describes *the sensorium commune*, its functions, and its seat. Here it is that Prochaska has put forward his views respecting reflex actions. External impressions, which are made upon sensitive nerves, are propagated with great velocity throughout their entire length to their origin, where, (to use his own phrase,) when they have arrived, they are reflected according to a certain law, and pass into certain and responding (certos ac respondentes) motor nerves, by which again being very quickly propagated to muscles they excite certain and determinate movements. This place, he says, in which, as in a centre, nerves of sense and of motion meet and communicate, and in which "the impressions of sensitive nerves are reflected into motor nerves," is called, by a term already received by most physiologists, "*the sensorium commune.*" Having referred to the various views of different physiologists as to the seat of the sensorium commune, he expresses his own opinion, that the sensorium commune, properly so called, extends throughout the medulla oblongata, the crura cerebri and cerebelli, a part of the optic thalami, and the entire spinal cord,—in a word, as far as the origins of the nerves extend. That the sensorium commune extends to the spinal cord is shown by those movements which continue in animals after decapitation, which cannot be effected without the cooperation of nerves which arise from the spinal cord; for if a decapitated frog be pricked, not only does it retract the stimulated part, but also it creeps, and leaps, which could not be done without the consentaneous action (absque consensu) of sensitive and motor nerves, the seat of which consentaneous action must be in the medulla spinalis, *superstite sensorii communis parte.*

That Prochaska viewed these acts as purely physical in their nature, is apparent from his statement, that they take place under peculiar laws, *written, as it were, by nature on the medullary pulp of the sensorium.* The general law, however, whereby the sensorium commune reflects sensorial into motor impressions (impressiones sensorias in motorias reflectit) is our preservation; so that certain motor impressions should succeed to such external impressions as might be injurious to our bodies. In illustration he refers to certain acts of this class, such as, irritation of the mucous membrane of the nose creating a violent act of expiration (sneezing) to expel the offending material from the nostril; the spasmodic closure of the glottis when a particle of food or a drop of fluid touches it, or the act of winking excited by the finger being brought close to the eye.

Prochaska points out that these reflex actions may take place with or without consciousness (vel animâ insciâ, vel vero animâ consciâ). In proof of this occurrence without consciousness he refers to certain acts which are observed in apoplectic patients, to the convulsions of epilepsy, and to certain actions in profound sleep; all those actions which occur in decapitated animals he refers to this class, and regards them as being regulated by the remaining portion of the sensorium commune which is seated in the spinal cord. "Omnes istæ actiones ex organismo et *physicis* legibus, sensorio communi propriis, fluunt, suntque, propterea, spontaneæ ac automaticæ." Actions, however, which the mind directs and moderates by its control, although the *sensorium commune* may take its share in producing them, may be called *animal*, and not automatic.

The second paragraph of this chapter contains an excellent discussion of the question, how far the anastomoses of nerves contribute to their mutual action upon each other, or whether that takes place only through the sensorium commune. On this subject Prochaska adopts the opinions of Whytt, who regarded the nervous centre as essential to these actions, and in the next paragraph he enquires whether nerves can establish any communication or consent with each other in their ganglia, and also discusses the use of ganglia, giving his assent, in some degree, to the doctrine which he assigns to Unzer and Winterl,* that external impressions are capable of being reflected by ganglia as they are reflected in the sensorium commune, and that ganglia are particular centres of sensorial impressions (sensoria particularia). He supposes that the action of the heart may be explained in this way through the impressions made by the blood upon its sensitive nerves which are reflected at the ganglia;† and he concludes by admitting it to be probable that besides the sensorium commune which resides in the medulla oblongata, the medulla spinalis, &c., there are *sensoria particularia* in ganglia and anastomoses of nerves (concatenationibus nervorum) in which external impressions are reflected, without their reaching the sensorium commune.‡

In the fifth and last chapter Prochaska discusses the animal functions of the nervous system. He shows that the soul, *ens incorporeæ prosapiæ*, uses the nervous system as an instrument, and that, in all animal functions, it is the *principium agens et determinans*. He describes the principal parts into which the animal functions can be conveniently resolved, as perception, judgment, will, to which may be added imagination and memory. For the exercise of these he lays down that the joint and harmonious action of the mind and brain is necessary, and he assigns to each of them a different locality in the brain. In the last section he again defines the animal actions, and distinguishes them from those which are dependent on a physical exciting cause: and argues against the Stahlian doctrine, which placed each movement and function of the body under the control of the soul.

These doctrines are repeated and somewhat enlarged upon in a much later work by Prochaska, published at Vienna in 1810, entitled, "Lehrsätze aus der Physiologie des Menschen," a third and much enlarged edition of a text book for his lectures. The whole section on the nervous system will repay an attentive perusal, and especially the chapter headed "Verrichtung des allgemeinen Sensoriums," which contains a review of the doctrine of reflex actions. A later edition of the same work, somewhat compressed in some parts, published in 1820, contains a repetition and a distinct enunciation of the same doctrines (p. 92).*

It is not a little remarkable, and at the same time highly discreditable to physiologists, that views so comprehensive and so striking should have been suffered to fall into neglect and to become almost wholly forgotten, and that the peculiar power of nervous centres to develope motions in response to sensorial impressions, or, in Prochaska's language, "to reflect sensorial into motor impressions," should have been lost sight of. Le Gallois, indeed, had recognized this power, and Blane had evidently much insight into it: Mayo, likewise, had formed a very correct appreciation of it, as shown by his observations on the actions of the iris. But none of these physiologists were fully impressed with its immense importance. It is to Dr. Marshall Hall in this country and to Professor Müller in Germany that science is most indebted for awakening the attention of physi-

* Unzer, Gundriss eines Lehrgebaudes von der Sinnlichkeit der thierischen Korper, 1768; also, Ertse Grunde einer Physiologie der eigentlichen thierischen Natur thierischer Korper. 1771. Winterl, Inflammationis nova theoria, Viennæ, 1767. I have not had an opportunity of perusing any of the works of Unzer. They are, indeed, little known in this country, having first appeared at a time when German literature was scarcely at all cultivated here. The only English medical writer with whom I am acquainted, who has made distinct reference to Unzer from having apparently studied his works, is Sir Alexander Crichton, who seems to have formed a high estimate of Unzer's Erste Grunde einer Physiol. as I gather from his work on Mental Derangement, published in 1798. Dr. Baly, the learned translator of Muller's Physiology, also refers to Unzer; and I must express my obligations to an interesting article in Dr. Forbes's journal (the British and Foreign Medical Review) for July, 1847, which contains a good abstract of Unzer's views, with an account of his writings. From this it is plain that Unzer had very enlarged views with reference to the phenomena of the nervous system, and perfectly appreciated the distinction to be made between those actions with which the mind is concerned either as excitor or recipient, and those which in their causation and developement are wholly independent of the mind, although not unperceived by it. The publication of Unzer's principal works and also of Prochaska's in an English dress would be a great boon to the student of the physiology of the nervous system, and would most legitimately come within the scope of the Sydenham Society.

† This is the doctrine in most favour at the present day.

‡ It is plain from the context that Prochaska had no idea of these *sensoria* having any connection with the mind, or with the mental power of perception.

* Geo. Prochaska was born in 1749, and studied medicine at Vienna, where he was clinical assistant to the celebrated De Haen. He published an inaugural dissertation *de urinis*, but the works which first attracted notice were his Quæstiones Physiologicæ, Vienna, 1778; and his treatises De Carne Musculari, and De Structura Nervorum. In 1778 he was made professor of anatomy and of ophthalmic surgery at the University of Prague, where he formed a valuable cabinet of preparations of morbid parts. In 1791 he was translated to a similar chair in the University of Vienna, with the title of Lehrer der höhern Anatomie, Physiologie, und Augenarzneykunde. M. Dezeimeris, from whose Dictionnaire Historique de la Médecine (art. Prochaska) this account is abridged, remarks of him that "he was one of those who strove to reduce the laws of life to the general laws of nature, and to make physiology a branch of experimental physics." Prochaska died on the 17th of July, 1820. The works in which he propounded his views respecting the nervous system are, 1. Annotation. Academic. fasc. iii., Prague, 1784. 2. Lehrsätze aus der Physiol. des Menschen, 1st ed., 1797, in 2 vol.; 2nd ed. 1802; 3rd ed. 1810. 3. Opera minora Physiologici et Pathologici Argumenti, p. i. et ii. 4. Physiologie oder Lehre von der Natur des Menschen, 1820. To these, perhaps, may be added a Latin edition of his Physiology, Institutiones Physiologiæ Humanæ, 1805-6; and Disq. Anatom. Phys. Organismi Corporis Humani, ejusq. Processus Vitalis, 1812; but neither of these works have I seen.

ologists to the existence of a power in the nervous centres which no doubt exercises a wide influence on the phenomena of living creatures; and yet it seems extraordinary that neither of these physiologists in their earlier writings should have made the slightest allusion to Prochaska, who had offered a more precise and more comprehensive, and, as I hope to show, a truer explanation of the phenomena than either of them.

I shall here cite various facts, in addition to those already adduced, which unequivocally demonstrate that a power exists in the cord of exciting movements in parts which receive nerves from it, by changes occurring in its substance, which may arise there from some modification of its nutrition developed in the cord itself, or be excited by a stimulus brought to act upon it by afferent or sensitive nerves.

But more than this: the cord has the power of reflecting the change wrought in it by impressions conducted to it into adjacent sensitive nerves, thus creating a large class of reflex phenomena under the name of reflex or radiating sensations.

When a stimulus is applied to the spinal cord, either directly or through the medium of afferent nerves, the actions excited by it are generally limited to those parts which derive their nerves from that segment of the cord which has received the stimulus. In some instances, however, parts supplied from other and even distant segments are thrown into action. Thus irritation of one leg may cause movements of one or both of the upper extremities; the introduction of a catheter into the urethra will sometimes give rise to forcible contractions of the muscles of the lower extremities or even of all the limbs. These effects are due, no doubt, to the extension of the stimulation in the cord beyond the point first acted upon; and they may be regarded as proofs that that peculiar state of physical change which nervous stimulation can excite in a centre may be propagated in the spinal cord upwards, downwards, or sideways, from the seat of the primary stimulation.

This fact was pointed out first, so far as I know, by Dr. M. Hall, who regards it as a property of the cord in its normal state. This, I am inclined to think, is an error; I believe it to be a property of the cord, only when its polarity is exalted. It is, however, an important property, and we shall, by-and-bye, make use of it in considering the mechanism of the various actions of nervous centres. Meantime we may obtain, from examining into the morbid states which are apt to arise in the spinal cord and in other parts of the cerebro-spinal centres, interesting confirmation of it.

A wound in the sole of the foot or ball of the thumb, or in some other situation favourable to the maintenance of prolonged irritation, is capable of exciting a particular region of the cord, from which the state of excitement spreads so as to involve not only the whole cord, but part of the medulla oblongata also; and in this state a large proportion of the motor nerves participate, so as to induce tonic contraction of the muscles they supply. This is the rationale of the developement of that fearful malady called *tetanus*. It consists not in an inflammatory condition of the cord or of its membranes, nor in congestion of them, but simply in a state of prolonged physical excitement, the natural polar force of the centre being greatly exalted and kept so by the constant irritation propagated to it by the nerves of the wounded part. Intestinal irritation is capable of producing a similar condition, which, if the irritation have not been allowed to remain too long, may be speedily removed by getting rid of the irritating cause. The following case illustrates this: an unhealthy looking girl, about fifteen years of age, was brought into King's College Hospital suffering from severe tonic spasms of the muscles of the spine and lower extremities. The spasms were so powerful as to produce successive paroxysms of opisthotonos, during which the trunk became bent like a bow, so that the patient rested on her occiput and on her heels. This state was speedily removed by the use of a large purgative clyster containing turpentine, which brought away a large number of ascarides from the rectum.

In cases of paraplegia from disease of the spinal cord, the paralysed parts are frequently troubled with cramps and startings occurring chiefly at night, and preventing sleep and occasioning great distress to the patient. These are very often traceable to intestinal disturbance, the presence of irritating matters, which, stimulating the mucous membrane, through its nerves excite the spinal cord, and thus produce these involuntary movements.

The rigid and contracted state of the muscles of paralysed limbs, which frequently accompanies red softening of the brain, arises from the propagation of the excited state of the diseased part of the brain to that portion of the spinal cord which is connected with it, and from which the nerves of the paralysed parts arise. These nerves likewise participate in the irritation of the cord, and thus keep the muscles in a state of continued active contraction. There is no organic lesion of the cord in these cases; its state of excitement is dependent on the cerebral irritation, and disappears if the latter yields to the influence of remedial measures.

To a similar extension of cerebral irritation, although of a much briefer duration, the convulsions of epilepsy may be attributed. The brain becomes the seat of irritation, and this spreads to the whole or a part of the spinal cord and to the nerves which arise from it. In many instances of epilepsy the convulsions are limited to one half of the body, and this is especially the case where a chronic lesion exists in the brain and forms a focus of irritation, which is propagated only to one half (the opposite) of the cord.

Some substances exert a peculiar influence upon the spinal cord and throw it into a state of considerable polar excitement. Strychnine is the most energetic substance of this class. If a certain quantity of this drug be injected into the blood or taken into the stomach of an animal, a state of general tetanus will quickly ensue, sensibility being either unaltered or somewhat exalted. The slightest touch upon the surface of the body, even a breath of wind blown upon it, will cause a general or partial convulsive movement. The whole extent of the spinal cord is in a state of excitement, and even the medulla oblongata may be involved in it, whence the closed jaws, the spasmodic state of the facial muscles, the difficult deglutition. When this polar excitement is raised to its highest degree, the slightest mechanical stimulus applied to any one point of the cord affects the whole organ and throws all the muscles which it supplies into spasmodic contraction, just as the least stimulus to peripheral parts has the same effect.

It is a very interesting fact, which I have frequently satisfied myself of by careful examination, that, however great the polar excitement may have been into which the cord has been thrown by strychnine, it exhibits no change of structure which can be detected by our means of observation. The nerve tubes and other elements entering into the formation of the cord have preserved their natural appearance in all the cases which I have examined.

Opium has the effect of creating a similar state of polarity in the cord. This is most conspicuous in cold-blooded animals; it produces a similar effect in the warm-blooded classes, but in a much less degree. Hence there is an objection to the use of opium in large doses in cases of tetanus; and experience has shewn the inefficacy and the injurious influence of this drug when administered in large quantities. When the cord is in this state of excitement, a stimulus applied to one part may excite a remote part of it with great facility.

The curious tendency already referred to, which the male frog has to grasp objects presented to them by his anterior extremities, is to be attributed in part to a spontaneous exaltation of the polar force of the cord which takes place at the copulating season, in the spring of the year, and which is associated with an extraordinary developement of the papillary texture of the integument of the thumb.

This exaltation of the polar force of the cord, in connection with the generative function, is a point highly worthy of the attention of the physiologist as offering some explanation of the sympathy which exists between different organs, between those even which are remote from each other, during the rutting season, or during utero-gestation.

It is worthy of notice here that cold has a considerable influence in controlling this polar state of the spinal cord, and of other nervous centres likewise. Ice applied along the spine, or the cold douche, may be frequently employed with great benefit in cases of muscular disturbance dependent on this polar state of the cord. It seems to me more than doubtful that many of those drugs which have the character of possessing a sedative influence upon the nervous system can be employed for this purpose either with safety or advantage. This applies certainly to hydrocyanic acid and to opium in large doses; animals poisoned by these substances become convulsed before death, and this denotes their tendency to exalt the polarity of the cord. Conium and belladonna, according to my experience, exercise the most beneficial influence of any of the sedative drugs, and I have found them very useful in restraining the cramps and startings in paraplegic cases.

I have ascertained by several experiments that the inhalation of ether has considerable effect in controlling the natural polar state of the cord, as well as that which may be produced by strychnine. A pigeon deprived of its cerebral hemispheres lives in a state of sleep for a considerable time; it flies when thrown in the air, spreading and flapping its wings; stands when placed on its feet. A bird thus mutilated was made to inhale ether; it could not stand, and when thrown into the air it fell to the ground like a heavy log, its wings remaining applied to the sides of its body, or if the wings were drawn out as it was thrown into the air, they quickly collapsed. As soon as the effects of the ether had passed off, it stood and flew as before. I gave strychnine to a rabbit, a guinea-pig, and a dog, so as to excite the tetanoid state. Immediately the spasms showed themselves, I brought it under the influence of ether; the spasms ceased immediately, and the animal became perfectly relaxed; but as soon as the effects of the ether passed off, the spasms came on again, but were soon subdued by a fresh inhalation of ether. And thus I found that the life of an animal poisoned by strychnine could be greatly prolonged through successive inhalations of ether; for animals of the same kind, poisoned by equal doses of strychnine, but not subjected to the influence of ether, perished very rapidly.

The examples which show that the spinal cord possesses the power of reflecting sensitive impressions are chiefly derived from disease. Every practitioner is familiar with the pain in the knee which accompanies the early stages of disease of the hip joint. The patient sometimes refers his sufferings so exclusively to the former joint, that the disease of the latter may be entirely overlooked by his medical attendant. Yet the really painful part is healthy, while the hip joint is the seat of a morbid process. The pains which are felt in the thighs from the presence of a stone in the bladder, and the itching which is referred to the extremity of the prepuce from the same cause, are phenomena of the same nature. Pain in the right shoulder from irritation of the liver is a well-known sympathetic sensation: sometimes this pain extends over a very large surface.

Numerous other instances of similar sympathetic phenomena might be adduced, but the above are sufficient for our present purpose. Taking into account the well-proved fact that nerves form no real junction of their fibres in their anastomoses, and that there is no more than a simple juxta-position of the nerve-tubes in these anastomoses, it is plain that we must trace these fibres up to the nervous centres to discover any connection between the fibre first irritated and that to which pain is referred. In the case of hip-joint disease, the nerves of the hip are those primarily irritated: there is no connection at the periphery between these nerves and those of the knee; both, however, are of spinal origin, and must be implanted near to each other in the spinal cord. This, then, is the only situation at which any communication may be established between them, and it is probable that that communication takes place through the vesicular matter in which both are implanted. The irritation from the hip, then, extends to the cord; it is there propagated to the vesicular matter in which the nerves of the knee are implanted: in other words, it is reflected to them, and thus pain is referred to the peripheral extremity of those nerves, in conformity with the known law of sensitive nerves, and in this way the pain is felt in the knee. A similar explanation applies to the other cases referred to.

There is no other mode of explaining these phenomena consistently with the known disposition and properties of nerve-fibres; and as experiment demonstrates the reflecting power of the cord from sensitive to motor, we are justified in referring these phenomena to a similar reflecting power from sensitive to sensitive nerves. We shall see further on that other nervous centres possess the same power.

The functions of the body with which the spinal cord is immediately concerned are the following:—1. The voluntary movements and sensations of the trunk and extremities, and of the viscera contained in the thorax, abdomen, and pelvis. For these, however, the integrity of its connection with the brain is necessary. 2. The physical actions, or, in other words, the involuntary movements of the trunk and extremities. 3. The actions necessary for locomotion, which are a combination of mental and physical nervous actions. 4. The physical actions of some of the internal organs. These are the heart, the intestinal canal, the bladder, and the generative organs, both male and female. The influence of the spinal cord over all these organs is, however, very limited, and inasmuch as they have a considerable degree of inherent muscular power, as well as receive nerves connected with other centres, namely, the sympathetic ganglia, they are in a great degree independent of the cord.

Dr. M. Hall's doctrines.—Using the term spinal cord to designate a centre or axis of physical nervous actions *(the true spinal cord)*, provoked by "excitor" nerves of the head, neck, trunk, and extremities, and of parts connected with them, Dr. Marshall Hall assigns to it very extended functions.

"Every act of ingestion, of retention, of expulsion, or of exclusion," says this physiologist,* "is a reflex act; an excito-motor act, an act of the true spinal system, performed through its incident nerves, its central organ (the true spinal marrow), and its reflex motor nerves; an act of the special power seated in this system." * * * * * "If we wish, then, to know what are the special acts of the true spinal system, we have only to ask what are the acts by means of which masses of matter are ingurgitated into and expelled from the animal economy." And in a table which follows these paragraphs, and which is intended to display at one view the physiology of the true spinal system (so called), he refers to this source, I. The excited actions: 1, of the iris and eyelids; 2, of the orifices—the larynx and the pharynx; 3, of the ingestion (1, of the food, as in suction and in deglutition; 2, of the air in respiration; 3, of the semen or conception); 4, of exclusion; 5, of the expulsion or of egestion (1, of the fæces; 2, of the urine; 3, of the perspiration; 4, of the semen; 5, of the fœtus or parturition); 6, of the sphincters (1, of the cardia; 2, the valvula Coli? (sic); 3, the sphincter ani; 4, the sphincter vesicæ). II. The direct action or influence: 1, in the tone; and 2, in the irritability of the muscular system.*

I shall content myself here with pointing out how slight are the grounds upon which so large a function is assigned to the spinal system, and so exclusive a view is taken of the various actions which are affirmed to be under its control. Further on I hope to show that the hypothesis of a special centre (the true spinal narrow) with its incident and reflex nerves is inadequate to the explanation of the phenomena of the nervous system.

A careful analysis of the various acts of ingestion, &c. will show that they cannot be regarded entirely as reflex acts. Thus the ingestion of food is effected by prehension, which is voluntary, by suction, as in the young, which is partly voluntary and partly reflex, and by deglutition. Now this last act is partly voluntary, as in the mouth; when the food has been brought within the grasp of the fauces it is reflex, and that portion of the act which takes place in the œsophagus is partly reflex and partly due to the influence of the stimulus of distension upon the muscular coat. The most purely physical portion of the act of deglutition is that which takes place in the vicinity of the rima glottidis, which, if not regulated by very exact physical changes, and if not, in a great degree at least, independent of mind, might frequently endanger the life of the individual by the deviation of the morsel of food from its proper course, so as to plug up or encroach upon the orifice which leads to the respiratory organs.†

The act of respiration is undoubtedly essentially reflex, but it is likewise very much under the control of the will, and may at any time be increased or diminished in frequency under the influence of either volition or emotion.

In conception, or what Dr. Hall calls the ingestion of semen, I am at a loss to conceive what reflex act can occur. The grasping of the ovary by the extremity of the Fallopian tube is more likely to be an act of emotion due to the general sexual excitement than a reflex phenomenon excited by the stimulus of coition. And as to the ingestion of the seminal fluid, that

* New Memoir on the Nervous System, 1843, p. 51, § 191-192.

* Loc. cit. p. 52.

† Here we notice the operation of the law of our preservation, which, according to Prochaska, regulates these reflex acts.

is wholly independent of the nervous system, and is effected partly by the forcible injection of the fluid into the vagina and uterus, and partly by the ciliary movement of the spermatic particles, the so-called spermatozoa.

The acts of retention cannot certainly be regarded as wholly reflex. Taking the instances quoted by Dr. Marshall Hall, the action of the sphincters, we shall find but little evidence in support of his view. The sphincter ani, the most perfect and complete of the sphincters, is *a voluntary muscle*, endowed with a high degree of contractile power; its circular form renders it very prone to act under the stimulus of distension, and it therefore resists any distending force, whether from above or below. This resistance, however, is powerfully increased by voluntary effort, as on the other hand it is materially diminished if the muscle be separated from cerebral influence. The habitual closed state of the anus, during the quiescence of the rectum, is effected by the tone or passive contraction, which requires for its perfect developement only that the muscle should enjoy a healthy nutrition. As long as this remains, the sphincter closes the orifice of the rectum sufficiently to prevent the escape of a small quantity of matter from it; this power, however, does not enable it to resist any considerable pressure; such resistance can only be effected by the active contraction of the muscle, effected partly by the stimulus of distension, and partly and chiefly by volition.

The voluntary nature of the actions of the sphincter is obvious from the personal feelings of each individual. It is also sufficiently indicated by the fact that if the spinal cord be divided in any region by disease or injury, so as to induce complete paralysis of the lower extremities without muscular rigidity, the sphincter will be paralysed, however extensive the inferior segment of the cord may be. Were its actions entirely or even chiefly of the reflex kind, the continuance of the lower segment of the cord in the healthy state ought to preserve their integrity. But this is never the case excepting in the rare instance of a persistent state of irritation of the inferior segment of the cord sufficient to maintain rigidity of the muscles of the lower limbs, and also to provoke a continued state of active contraction. It is, however, possible that a physical stimulus applied to the mucous membrane of the rectum or anus may excite by reflex action the contraction of the sphincter, and thus come in aid of voluntary power, and of the inherent contractility of the muscle; but such aid is called forth only under peculiar circumstances, and either not at all or to a very trifling extent in the ordinary action of the sphincter. Moreover, in deep-seated and extensive lesion of the brain, paralysis of the sphincter ani is a constant symptom, the spinal cord being perfectly healthy, and the reflex actions of the paralysed lower extremity (for in such cases the paralysis is generally hemiplegic) well marked. Such cases must be regarded as affording the most conclusive evidence against the reflex nature of the action of the sphincter ani, and all the facts that I have mentioned denote abundantly that the reflex action of the sphincter ani is the exception and not the rule.

The experiments which Dr. Hall adduces in support of the reflex nature of the action of the sphincter are inconclusive for this purpose. They consisted in the division of the spinal cord in a horse and a turtle, and the excitation of reflex actions *immediately* afterwards. If the experiment be repeated in a dog, the following result will be observed: immediately after the division of the cord the sphincter will contract repeatedly without the application of any new stimulus, and the dog will raise and depress his tail, and these phenomena will continue as long as the irritation produced in the cord by the section remains. When this irritated condition shall have passed off, the experimenter will find it impossible to excite the action of the sphincter muscle by stimulating the anus. If the actions of this muscle were of the reflex kind, surely they ought to continue as long as the segment of the cord with which its nerves are connected shall retain its powers intact.

A remarkable degree of sensibility exists in the cutaneous covering of the verge of the anus in most animals, which is calculated to mislead with reference to the reflex nature of the action of the sphincter. In the decapitated frog, stimulation of the anus excites forcible extension of the posterior extremities. Mr. Grainger describes a phenomenon which was noticed by Professor Bischoff in the green frog (*Rana arborea*), so common in many parts of Germany. "Upon irritating the cloaca in one of these animals which had been decapitated, the most violent emotions were excited in the hind legs, and *repeated attempts were made by these limbs to remove the instrument* with which the cloaca was touched. This fact," adds Mr. Grainger, "I have since repeatedly seen in the green and common frog, both when the head was removed and when the spinal cord was divided in the back."* I can add my testimony to this fact, having witnessed it many times in the common frog.

Dr. Hall himself, indeed, furnishes experimental evidence well calculated to cast a doubt upon his views of the nature of the action of the sphincter, and to indicate the existence of some source of fallacy in his experiments. The subject of experiment was a turtle; in one experiment, it is stated, "the sphincter was perfectly circular and closed; it was contracted still more forcibly on the application of a stimulus."† In a second experiment, he says, "if, when the cloaca is distended, the integuments over it are stimulated, the water is propelled to a considerable distance."‡ Here are two opposing actions caused by stimulation of the same region of the integument!

With regard to the sphincter vesicæ, or more properly to the circular fibres of the muscular coat of the bladder, the influence of the will cannot be denied. Voluntary influence through the vesical nerves and the irritability of the

* Grainger on the Spinal Cord, p. 59.

† First Mem. § 37.

‡ Second Mem. § 172.

muscular coat of the bladder are the usual means by which the action of this viscus is promoted. It is possible that, as with the rectum, under peculiar circumstances the physical stimulus acting reflexly on the muscular fibres themselves may come in aid of that of volition; but such a mode of action is not the ordinary one. A line of argument similar to that which disproves the reflex nature of the action of the sphincter ani tells equally against that of the sphincter vesicæ. Were the action of this muscle reflex, it ought to remain perfect whenever a sufficiently large segment of the cord remains in connexion with the bladder. Now when the spinal cord is severed in any region so as to occasion paralysis of the lower extremities, there is almost always incontinence of urine from the removal of voluntary influence from the sphincter vesicæ: such ought not to be the case, if Dr. Hall's views were correct.

Respecting the cardia and the valvula coli, I shall only remark that the evidence of reflex action is extremely defective. The cardia, indeed, has no sphincter; it is closed by the lower circular fibres of the œsophagus, which keep that canal in a contracted state by their tone or passive contraction. The pylorus is provided with a sphincter muscle of great power, which closes that orifice by its passive contraction, and which in animals recently killed will continue to close the orifice as long as the muscle retains its tone. If an animal be killed during stomach digestion, the stomach may be removed, and yet the pylorus will retain the food in it even against gravity; the cardia, if a sufficient portion of the œsophagus be retained, will resist the escape of the food; but, from the absence of a true sphincter, to a much less degree than the pylorus. It is impossible that, under these circumstances, there could be any reflex action, as the stomach is removed from its connection with the nervous centre. The valvula coli appears to act simply on mechanical principles.

There is, I apprehend, no more evidence of the exclusively reflex nature of the acts of expulsion than of that of the acts of retention. The expulsion of the fæces and that of the urine are voluntary acts, aided essentially by the contractile power of the muscular fibres of each viscus, and perhaps, under peculiar circumstances, by a physical excitant. Were this power reflex, the expulsion would be no doubt much more frequent and much less under control, and, therefore, productive of frequent serious inconvenience. The expulsion of perspiration is probably effected by the simplest mechanical means, the newly secreted fluid pushing before it that which was previously formed. The expulsion of the semen does, indeed, exhibit the characters of a true reflex act; but here how marked is the physical stimulus, and how necessary that it should reach a certain point of excitement before the action of expulsion responds to it! As to the expulsion of the fœtus in parturition, while I am willing to admit that the physical power of the cord excited by the sensitive nerves at the neck of the uterus may exercise some influence on the contractions of the uterus, it seems to me quite evident that the actions of this organ are reflex only to a very slight degree. In the first place, anatomy teaches us that the muscular parts of the uterus have a very trifling connexion with the spinal cord; the nerves distributed to it being few, and these only partially derived from the spinal cord. Secondly, parturition may take place even when the spinal cord has been diseased or divided so as to cut off its influence upon the inferior half of the body. Thirdly, it has lately been ascertained that in women under the influence of ether, the act of parturition may take place with vigour, although the nervous power have been very considerably depressed by the influence of that agent

The immediate agent of expulsion in defæcation, micturition, and parturition is the inherent contractility of the muscular coat of the proper organ. Being hollow muscles, the stimulus of distension is well adapted to excite them to contract. The will exercises considerable power in defæcation and micturition, both upon the muscular fibres of the viscera themselves, and on the abdominal muscles. In parturition the voluntary contraction of these latter muscles may give some assistance, but the main force of expulsion is due to the contraction of the uterine muscular fibres. In all the three actions, however, the influence of the muscular fibres of the viscera respectively engaged may be materially promoted by the contractions of the abdominal muscles, which are partly voluntary and partly reflex, being excited by the pressure of the mass to be expelled on the sensitive nerves in the neighbourhood, which, acting on the spinal cord, stimulate the muscular nerves, and through them cause the muscles they supply to contract, in harmony with the muscular tunic of the expelling viscus, rectum, bladder, or uterus, as the case may be.

I may here remark, that whilst it is sufficiently evident that expulsion of the semen is a physical or reflex act, it cannot be admitted that erection of the penis is essentially so in its ordinary mode of production. This act is one of emotion—a simple emotion of the mind is sufficient to develope it: it may, however, be developed by the application of a stimulus to the penis or scrotum, when it clearly partakes of the character of a reflex act, although even under these circumstances it would be incorrect to say that emotion had no influence in its production. It is well known, however, that in cases where the spinal cord has been severely injured, severed indeed, by fracture and displacement of some of the vertebræ, erection of the penis may be produced, although the organ is insensible, and the influence of the mind over the lower half of the body is suspended, and that even a slight stimulus, as the friction of the bedclothes, or the introduction of a catheter, is sufficient for this purpose. This is clearly a purely reflex act, wholly independent of sensation or emotion; but it may be likewise produced or kept up by the irritated state of the cord itself. The painful erection of the penis, called *chordee*, which occurs in cases of inflammatory gonorrhœa, is partly a reflex phenomenon, but is chiefly due to a change in the circulation of the penis, to an increased attraction of blood to the organ in virtue of the inflammatory state.

Enough has been said to shew that, to lay it down that every act of ingestion, of retention, of expulsion, and of exclusion, is a reflex act, is opposed to all that we know of the intimate nature of these actions. The power resident, not in the spinal cord only, but in every nervous centre in which nerves are implanted, whereby, to use Prochaska's words, sensory impressions may be converted into motor impulses, is no doubt of immense importance to the animal economy; but Dr. M. Hall has been evidently led, by an imperfect analysis of the functions we have been considering, to assign to this power too large an influence in them; and on the other hand, he has overlooked its obvious and important influence in other phenomena.

Dr. Marshall Hall also attributes to the spinal cord a direct action or influence which manifests itself, first, in the tone, and secondly, in the irritability of the muscular system.

I regret to be compelled to differ again from Dr. Hall with respect to this point, and to express my opinion that this dogma is inconsistent with established doctrines of physiology.

By the *tone* of the muscular system, I understand that state of passive contraction which every healthy muscle exhibits when not in active contraction. It is this state which gives the firm, resisting, resilient feel, which the physician knows to be characteristic of a healthy state of the muscle. By virtue of it a muscle can adapt itself to changes which may take place in the distance between its two points of attachment; and it is in virtue of this property that a muscle shortens itself when the stretching force of its antagonist has been removed. When the muscles of one side of the face have been paralysed for some short time, the features lose their balance, because the muscles of the sound side have contracted to within a smaller space, having lost the resistance of those of the opposite side. It is equality of tone which preserves the equilibrium between symmetrical muscles; it is tone or passive contraction which keeps hollow muscles quite closed, if they are empty, or firmly contracted on their contents, if not so, as the heart and intestine; the tone of the predominant flexor muscles keeps limbs, whilst at perfect rest, in a semi-flexed position; it is tone which keeps sphincter muscles in a closed state.

The question is, do the muscles derive their state of tone from the spinal cord, and is this property dependent on that organ?

This question is answered in the negative, if we can shew that there are good and sufficient grounds for affirming that muscles possess within themselves all the conditions necessary for the generation of their proper force. That muscles do enjoy these conditions is manifest from the following considerations: 1. their peculiar chemical composition, their main constituent being *fibrine*, a substance which, we know from the phenomena of the coagulation of the blood, exhibits a remarkable tendency to contract; 2. their anatomical constitution; the arrangement in fibres, the intimate texture of those fibres, which in the muscles of the greatest power, the voluntary muscles, is highly complicated; 3. from the large quantity of blood sent to muscles, which are probably more freely supplied with that fluid than any other texture in the body, and which receive it in the greater quantity when that contractile power is more active; 4. from the fact pointed out by Mr. Bowman, that a single muscular fibre, entirely deprived of all nerves, may be made to contract by a slight stimulus applied to any part of it; 5. from the knowledge which we now possess that the mechanism of these actions may be seen by the microscope even in detached portions of muscular fibres; 6. from the fact that muscles dissociated from the nervous centres by the section of all the nerves distributed to them, retain their power of contraction for a very considerable period, long after the nerves which sink into them have lost their excitability.

All these points afford the highest degree of probability that there is no direct dependence of muscle upon the nervous centres for the developement of its proper force; and that this force is the result of the nutrient actions of muscle. The only way in which the nervous system can be said to have an influence upon the muscular force is by promoting the actions of the muscles, and thereby their nutrition. If a muscle have its nerves divided, and be left to itself, its nutrition fails after a certain period, and its contractility with it; but if it be exercised daily by galvanic stimulation, its nutrition remains unimpaired, and its contractility likewise.

The tone of a muscle is nothing but the effect of the continuous developement of the muscular force resulting from the natural changes in the muscle; it is this state of tension which denotes that these changes are actively proceeding, and that a uniform degree of attraction is being exerted between all the parts of the muscular fibre, in a degree proportionate to their masses, and that by this the muscles are maintained in a uniform state of tension so long as they are undisturbed by stimuli conveyed to them through the nervous system, or from some other source.

It seems, therefore, as reasonable as any proposition in physiology, to affirm that the passive contraction or tone of muscles is due to a property inherent in the muscular tissue itself, and dependent solely on its proper nutrition, and that it is not derived from any other tissue. And if this be true, it is clear that the spinal cord cannot be the source of the tone of the muscular system.

This statement is confirmed by the result of the experiment of removing the whole spinal cord in frogs or other animals. When this has been done, the limbs of the animal fall quite flaccid, the muscles being no longer capable of preserving that degree of *active* contraction which is necessary to maintain attitude. A decapitated frog will continue in the sitting posture through the influence of the spinal cord, but, immediately this organ has been removed, the limbs fall apart from the loss of the controlling and co-ordinating influence of the nervous centres. And careful examination of the muscles in such a case as this will show that the molecular phenomena which characterise passive contraction continue in the muscular fibres. The state of *rigor mortis*, which is analogous to that of tone, comes on just as readily in animals which have been deprived of the brain and spinal cord, as in those in which these centres have been undisturbed before death. In short, healthy nutrition supplies all the conditions necessary for the maintenance of tone or passive contraction; nor is the spinal cord (although itself healthy) able to preserve the tense condition of the muscles, if they are not well nourished.

These remarks apply equally to Dr. Hall's doctrine, that the spinal cord is a direct source of irritability to the muscular system. The same arguments which prove that tone is not derived from it are of equal weight with reference to irritability.

It cannot be admitted as an argument in favour of the view which derives muscular irritability from the spinal cord, that muscles lose their firmness and waste, when they have been for some time separated from their proper nervous connections. They suffer, in this way, merely for want of a proper amount of exercise, which they cannot obtain in consequence of the influence of the will being cut off from the limb. If, however, the paralysed limb be exercised artificially, as by the galvanic current, their nutrition and their plumpness may be preserved. For this important observation we are indebted to Dr. John Reid, who likewise called attention to the confirmatory fact, that, in those palsies with which there is combined more or less of irritation of the nervous centre, the muscles do not suffer so much in their nutrition, in consequence of the exercise they undergo in the startings so frequently excited in them by the central irritation. This is not unfrequently seen in cases of paraplegia from irritant disease of the spinal cord.

The supposition that the spinal cord might be the source of irritability to the muscles led Dr. Hall to the very extraordinary inference, that in hemiplegic paralysis, in which the influence of the brain is cut off from certain muscles, while that of the cord remained, *the irritability of those muscles becomes augmented.* He arrives at this conclusion by the following line of argument: assuming the cord to be the source of the irritability of the muscles, the brain may then evidently be looked upon as the exhauster of that irritability in the voluntary actions; if, then, the influence of the brain be cut off, it naturally follows that, as the great agent of exhaustion has lost its power, the irritability, which is ever, as it were, flowing from the cord, will accumulate in the muscles. From numerous experiments I am enabled to state that in nearly all the cases of hemiplegic paralysis from cerebral lesion there is no evidence of any augmentation of the irritability of the muscles of the palsied limbs. If the readiness with which they will respond to the galvanic stimulus be taken as a test, it may on the other hand be stated very confidently that there is evidence of the *diminution* of the irritability of the paralysed muscles, for in nearly all these cases the same current being passed through both sound and palsied limbs at the same time, the latter have contracted either not at all or with very little power as compared with the healthy limbs.

But there are exceptions to this: in some cases (and only in those in which there is more or less rigidity of the paralysed muscles) these muscles respond to the galvanic stimulus with more force and readiness than the sound ones. In these cases the palsied muscles are kept in a state of excitement by some irritant disease within the cranium, and this constant condition of more or less active contraction augments the nutrition, and therefore the irritability of the muscles.

It seems, however, most probable that in all the cases of paralysis, the excitability of the muscles to the galvanic stimulus is dependent not so much upon any change in the condition of the muscles themselves as upon the state of the nerves. If the nervous force in the nerves on the palsied side be depressed, the galvanic stimulus will produce little or no effect upon the muscles of that side, whilst those of the other side will be distinctly excited: but should the nerves participate in any excitement propagated to them from disease within the cranium, as in red softening, or an irritating tumor, or a contracting cyst, they will then respond to the galvanic current more readily than those of the opposite side.*

I have thus endeavoured to show that the spinal cord is a centre of nervous actions, *mental* and *physical, to all parts which derive nerves from it*, the mental actions, however, requiring its association with the brain. Whatever physical nervous actions occur in parts whose nerves are spinal, must be referred to *the cord alone;* and whatever mental nervous actions occur through the agency of spinal nerves must be referred to the *cord in conjunction with the brain.*

Of the office of the columns of the cord.—I shall now inquire whether the parts into which the anatomist can divide the spinal cord have special functions. These parts are, on each side of the median plane, an antero-lateral column and a posterior column. It has been a very prevalent opinion that the antero-lateral column corresponds in function with the anterior roots of the spinal nerves, and that the posterior column corresponds with the posterior roots. This doctrine might have had a good foundation if it could be proved that the posterior or sensitive roots were implanted solely in the

* I have discussed this subject more at large in a paper presented to the Royal Medico-Chirurgical Society in June last, and which will appear in the forthcoming volume of its Transactions. August, 1847.

posterior, and the anterior roots solely in the anterior columns. Nothing, however, is more certain than that both roots are implanted in the antero-lateral columns, and it is extremely doubtful that the posterior roots have any connection at all with the posterior columns. Hence, as far as anatomy enables us to judge, this distinction of function between the two columns cannot be admitted. On the contrary, anatomy indicates that the antero-lateral columns are compound in function. Their connection with the corpora striata and optic thalami, and with the mesocephale through the anterior pyramids and fasciculi innominati, their reception of both the anterior and posterior roots, and their size in each region of the cord bearing a direct proportion to that of these roots, denote that these columns with the associated vesicular matter are the seat of the principal nervous actions, both mental and physical, with which the cord is concerned.

This view of the office of the antero-lateral columns is confirmed by comparative anatomy, which shows that the bulk of the organ or the variety in the size of its various parts depends mainly on these columns.

Pathological observations are also in favour of this doctrine. They distinctly denote that lesion of the antero-lateral columns impairs the sensitive as well as the motor power to an extent proportionate to the amount of lesion. It is worthy of note, however, that while a slight lesion of the cord appears sufficient to impair or destroy the motor power, it requires a considerable extent of injury or disease to impair in any very marked degree the sensitive power. Some lesions of these columns destroy the physical nervous actions of the diseased or injured part of the cord—augmenting those of the portion below the seat of lesion, doubtless by increasing its polarity; this is seen especially in cases of injury to the cord by fractures or dislocations of the spine.

Direct experiments afford no aid in determining the functions of the columns of the cord. Attempts to expose this organ either in living or recently dead animals are surrounded with difficulties, which embarrass the experimenter and weaken the force of his inferences, if, indeed, they afford any premises from which a conclusion may be drawn. The depth at which the cord is situate in most vertebrate animals, its extreme excitability, the intimate connection of its columns with one another, so that one can scarcely be irritated without the others being affected, the proximity of the roots of its nerves to each other, and the difficulty, nay the impossibility, of stimulating any portion of the cord itself without affecting either the anterior or the posterior roots, are great impediments to accurate experiments, and sufficiently explain the discrepancies which are apparent in the recorded results of experiments undertaken by various observers. Moreover, the resultant phenomena, after experiments of this kind, are extremely difficult of interpretation, especially with reference to sensation. "The gradations of sensibility," remarks Dr. Nasse, "are almost imperceptible; the shades are so delicately and so intimately blended, that every attempt to determine the line of transition proves inadequate. There is a great deal of truth in an expression of Calmeil, that it is much easier to appreciate a hemi-paralysis of motion than a hemi-paralysis of sensation. If the anterior fasciculi of the cord possess sensibility but only in a slight degree, the mere opening of the spinal canal and laying bare the cord must cause such a degree of pain as would weaken or destroy the manifestations of sensibility in the anterior fasciculi. This has not been sufficiently attended to by experimenters. Again, the practice of first irritating the posterior fasciculi, and afterwards the anterior, must have had considerable effect in producing the same alteration. It is plain, that in this way the relation which the anterior fasciculi bear to sensation must be greatly obscured; yet, with the exception of some few experiments, this has been the order of proceeding generally adopted."*

All the experimenters agree in attributing to the antero-lateral columns more or less power of motion, but we gain no satisfactory information from this source respecting their sensitive power, and probably for the reasons so well expressed by Nasse in the passage above quoted. But, indeed, we do not need the appeal to experiment in reference to this question, although, if a distinct and unequivocal response could be elicited by means of it, the additional evidence would be of great value.

There is great difficulty in determining precisely the functions of the posterior columns of the cord.

Both anatomy and comparative anatomy are opposed to the view which assigns them sensitive power. In the first place, as already stated, there is no evidence to show that the posterior roots of the spinal nerves are connected with them; even Sir C. Bell, who once held that these columns were sensitive because the sensitive roots were connected with them, gave up that view, having satisfied himself that no such connection existed.† Secondly, if they were sensitive, it is not unreasonable to expect that they would exhibit an obvious enlargement at the situations which correspond to the origins of the largest sensitive nerves; so little, however, is this the case, that the posterior columns exhibit little or no variation of size throughout their entire course. Thirdly, the researches of the morbid anatomist afford evidence unfavourable to the assignment of the sensitive function to these columns. Cases are on record which show that disease of the posterior columns does not necessarily destroy sensibility; that perfect and even acute sensibility is compatible with total destruction of the posterior columns in some particular region, the posterior *roots* remaining intact: and others

* Nasse, Untersuchungen zur Physiologie und Pathologie, Bonn, 1835-36. The passage is quoted from an abstract of the work published in the Brit. and For. Med. Review, vol. iv.

† See his paper on the relations between the nerves of motion and of sensation and the brain. The Nervous System, p. 234. 8vo ed., 1844.

have occurred in which sensibility has been impaired or destroyed, while the posterior columns remained perfectly healthy. In a remarkable case related by Dr. Webster, there was complete paralysis of motion in the lower extremities, but sensibility remained; yet there was total destruction of the posterior columns in the lower part of the cervical region. Dr. Webster did me the favour to allow me to examine the spinal cord in this case, and I was struck with the complete solution of continuity of the posterior columns in the region of the neck: it was impossible in this case that the nervous force could have travelled along the course of these columns, whether from above downwards, or from below upwards. Such a case as this shows distinctly that sensation may be enjoyed in the inferior extremities *independently of the posterior columns*, and if it does not prove that these columns are not the ordinary channels through which sensitive impressions are conveyed to the brain from parts supplied by spinal nerves, it at least shows that there must be some other channel besides them for the transmission of sensitive impressions.

Other cases to the same purport are on record. Mr. Stanley published an account of a case of this kind in the twenty-third volume of the Medico-Chirurgical Transactions. He states, "there was no discoverable impairment of sensation in any part of either limb: on scratching, pricking, and pinching the skin, nowhere was any defect of feeling acknowledged by the patient. In the upper limbs there existed no defect, either of motion or sensation." There was inability to expel the urine or retain the fæces. The report of the post-mortem appearances in this case is not quite so exact as might be desired. The posterior half of the cord and the posterior columns are spoken of as if synonymous; now it is evident that the posterior half of the cord consists of a great deal more than the posterior columns; it includes the posterior part of the antero-lateral columns. The record of the case states as follows: "The substance of the cord throughout its posterior half or column, and in its entire length, from the pons to its lower end, had undergone the following changes of colour and consistence; it was of a dark brown colour, extremely soft and tenacious. The substance of the cord through its anterior half and entire length exhibited its natural whiteness and firm consistence; and on making a longitudinal section of the cord through its centre, and in the antero-posterior direction, the boundary line between the healthy and diseased nervous matter was seen to be most exact: it was a straight and uninterrupted line from the pons to the lower end of the cord. The roots of the spinal nerves were unaltered."

Supposing that the posterior columns are the media of sensation to parts supplied by spinal nerves, we can by no means infer that the lesion in this case recorded by Mr. Stanley was sufficient to *destroy* sensation; it cannot, however, be conceded that, if this view were correct, such a lesion could exist without impairing sensation in some way or other, inasmuch as the whole of the posterior columns were involved in a notably diseased condition.

The following case is related by Cruveilhier. A young amaurotic girl, paraplegic of movement only, died from some unknown cause. The spinal cord presented on its posterior surface in its entire length a large reddish-grey (gris-rosé) column, formed by the posterior columns. All the rest of the cord was perfectly healthy.

In a case recorded by Dr. Wm. Budd it is stated that the lower extremities were quite deprived of motion, "but with sensation unaffected." The disease was the result of a severe blow on the back from the boom of a ship, which led to a curvature of the spine, formed by prominence of the dorsal vertebræ from the fourth to the ninth inclusive. After death a portion of the cord, about two inches in length, corresponding to the curvature, was found softened in the posterior columns. The tissue was not diffluent, but became flaky and partially dissolved when a small and gentle current of water was poured on it. In this case, no more than in that of Mr. Stanley, the lesion was not enough to *destroy* sensation, but surely it was sufficient to *impair* it, if the posterior columns are to be regarded as the channels of sensation.*

Serres records the case of a woman who had been paraplegic for two months: sensibility was preserved in the lower extremities; the lesion consisted in disease of the posterior columns of the cord below the middle of the dorsal region.†

In two cases which occurred in King's College Hospital under my own care, the prominent symptom was impairment of the motor power, without injury to the sensitive; yet the seat of organic lesion in both was in the posterior columns of the cord.

Nasse, in the paper before referred to, alludes to several cases of the same nature, in which disease affected the posterior columns, but did not impair sensation.

Longet, who is a warm advocate for the identity of function between the posterior *roots* and posterior *columns*, cites some instances in which total loss of sensibility coexisted with degeneration of the posterior columns as the only lesion: in these cases, however, the posterior *roots* of the nerves were involved in the disease, and their function became impaired or destroyed in consequence. A case of this kind, to be conclusive upon the point in question, ought to exhibit complete destruction of the posterior columns, or of a considerable portion of them, with perfect integrity of the posterior roots and of the antero-lateral columns. If in such a case there were total loss of sensibility in the parts in nervous communication with the diseased portion of the spinal cord, then, indeed, we would be justified in affirming that the antero-lateral columns took no part in propagating sensitive impressions, and that the loss of sensibility was due to the morbid state of the posterior columns.

* Med.-Chirurg. Trans., vol. xxii.

† Anat. Comp. du Cerveau, vol. ii., p. 221.

When to these results, obtained from pathological researches, we add those of experiment, nothing is gained which can be favourable to the attribute of sensitive power to the posterior columns of the cord. Dr. Baly's experiments on tortoises showed that movements might be excited whether the anterior or the posterior columns were irritated, much stronger motions being excited by the posterior than by the anterior columns. Longet found that motions might be excited by irritation of the posterior columns of the cord if the experiment had been made immediately after the transverse division of the cord, and he refers such motions, probably with justice, to an excited state of the cord. After a little time this subsides, and then M. Longet was able to pass the galvanic current through each or both of the posterior columns, without exciting any motions when the lower segment of the cord was acted upon, but causing pain, as evinced by loud cries and writhing of the body, when the upper segment was tried. From experiments of this kind no satisfactory deductions can be made: to irritate the posterior columns of the spinal cord in a living dog without affecting in some degree the posterior roots of the nerves, appears to me to be quite impossible, even in the hands of the most practised vivisector.

Neither anatomy, pathological observation, nor experiment, lend sufficient countenance to the doctrine of the identity of the function of the posterior roots and posterior columns to justify us in concluding that these columns are the ordinary channels for the transmission of the sensitive impressions made upon the trunk and extremities.

I have long been strongly impressed with the opinion that the office of the posterior columns of the spinal cord is very different from any yet assigned to them. They may be in part commissural between the several segments of the cord, serving to unite them and harmonize them in their various actions, and in part subservient to the function of the cerebellum in regulating and co-ordinating the movements necessary for perfect locomotion.

This view is suggested by a comparison of the spinal cord with the brain, and by the anatomical connections of the posterior columns.

The brain is an organ composed of various segments, which are connected with each other by longitudinal commissures. The cord is obviously divisible into a number of ganglia, each forming a centre of innervation to its proper segment of the body. These portions must be connected by similar longitudinal commissures to those which confessedly exist in the brain. If we admit such fibres to be necessary to ensure harmony of action between the several segments of the encephalon, there are as good grounds for supposing their existence in the cord as special connecting fibres between its various ganglia to secure consentaneousness of action between them.

The attribute of locomotive power rests upon the connection of the posterior columns with the cerebellum, and the probable influence of that organ over the function of locomotion and the maintenance of the various attitudes and postures. If the cerebellum be the regulator of these locomotive actions, it seems reasonable to suppose that these columns, which are so largely connected with it, each forming a large proportion of the fibrous matter of each crus cerebelli, should enjoy a similar function, and that, as they are the principal medium through which the cerebellum is brought into connection with the cord, it must be through their constituent fibres that the cerebellum exerts its influence on the centre of innervation to the lower extremities and other parts concerned in the locomotive function, and on the nerves distributed to these parts.

The nearly uniform size of the posterior columns in the different regions of the cord, whilst it may be noted as unfavourable to their being viewed as channels of sensation, may be adduced as a good argument in favour of their being concerned in locomotion and acting as commissural fibres. It is a fact worthy of notice that these columns experience no marked diminution in size until the large sacral nerves, which furnish the principal nerves of the lower extremities, begin to come off. The reason of this is probably because the fibres of these columns connect themselves in great part with the lumbar swelling of the cord, and some of them perhaps pass into the sacral nerves.

The following remarks will serve to explain the manner in which the posterior columns may contribute to the exercise of the locomotive function. In examining a transverse section of the cord in the lumbar region, we observe a great predominance of its central grey matter; the posterior columns appear large, and the antero-lateral columns seem inadequate in proportion to the large roots of nerves which emerge from it. Now, an analysis of the locomotive actions shows, with great probability, that they are partly of a voluntary character, and partly dependent on the influence of physical impressions upon that segment of the cord from which the nerves of the lower extremities are derived. There are two objects to be attained in progression, namely, to support the centre of gravity of the body, and to propel it onward. The former object is attained by physical nervous actions, the latter by mental. The support of the centre of gravity of the body requires that the muscles of the lower extremities, the pillars of support to the trunk, should be well contracted in a degree proportioned to the weight they have to sustain. The contraction of these muscles seems well provided for in an arrangement for the developement of nervous power by a stimulus propagated to the centre, and then reflected upon the motor nerves of these muscles. The stimulus is afforded by the application of the soles of the feet to the ground; it is therefore proportionate to the weight which presses them downwards. It is well known that reflex actions are more developed in the lower than in the upper extremities, and the surface of the sole of the foot is well adapted for the reception of sensitive impressions. No object can be assigned for this peculiarity, unless it have reference to the locomotive actions, and the great developement of the vesicular nervous matter in these regions betokens the frequent and energetic evolution of the nervous force. All the structural arrangements necessary for this purpose are found in the antero-lateral columns. The posterior columns come into exercise in balancing the trunk and in harmonizing its movements with those of the lower extremities.

Some support is obtained for this view of the function of the posterior columns from the phenomena of disease. In many cases, in which the principal symptom has been a gradually increasing difficulty of walking, the posterior columns have been the seat of disease. Two kinds of paralysis of motion may be noticed in the lower extremities, the one consisting simply in the impairment or loss of the voluntary motion, the other distinguished by a diminution or total loss of the power of co-ordinating movements. In the latter form, while considerable voluntary power remains, the patient finds great difficulty in walking, and his gait is so tottering and uncertain that his centre of gravity is easily displaced. These cases are generally of the most chronic kind, and many of them go on from day to day without any increase of the disease or improvement of their condition. In two examples of this variety of paralysis I ventured to predict disease of the posterior columns, the diagnosis being founded upon the views of their functions which I now advocate; and this was found to exist on a post-mortem inspection; and in looking through the accounts of recorded cases in which the posterior columns were the seat of lesion, all seem to have commenced by evincing more or less disturbance of the locomotive powers, sensation being affected only when the morbid change of structure extended to and more or less involved the posterior roots of the spinal nerves.

Bellingeri put forward the opinion that the anterior columns of the spinal cord influenced movements of flexion, and the posterior columns those of extension; to the grey matter he assigned the office of propagating sensitive impressions to the brain; and the lateral columns, according to him, exercised an influence upon the organic functions of nutrition and circulation.

The views already referred to respecting the grey matter show that it cannot be regarded as devoted exclusively to one function of the nervous system; nor can it be viewed as capable of taking its part in nervous actions without the white or fibrous matter.

Valentin adduces some experiments not unfavourable to the supposition that the nerves of extensor muscles pass towards the posterior part of the cord, and those of the flexor muscles to the anterior part. He found that if, in frogs, the posterior surface of the cord on one side of the posterior median fissure in the region of the second or third vertebra were irritated by the point of a needle, the anterior upper extremity of the same side was extended and drawn backwards. When the anterior surface was irritated, the limb was drawn forwards to the head. Irritation of the posterior column in the region of the sixth vertebra and below it caused extension of the posterior extremities, but they were thrown into flexion by irritation of the anterior columns.

These are remarkable results; they need, however, the confirmation of other observers. If they be correct, the fact of the connection of the nerves of extensor muscles with the posterior columns has an interesting relation with the supposed locomotive function, for there can be no doubt that movements of extension contribute largely to the ordinary attitudes and to the various modes of progression.

Valentin refers to cases in which the anterior columns having been the seat of tumor or of softening, more or less permanent flexion of the lower limbs had ensued. These cases do not favour his view unless he can show that the lesion in all the cases was of the irritant kind, inducing a spasmodic contraction of the flexor muscles; for if the lesion be of a paralysing kind, the effect would be to paralyse the flexor muscles and allow the extensors full sway. The explanation of the flexed state of limbs in cases of this kind is probably to be derived from a chronic state of contraction induced in the muscles themselves by the lesion of the nervous centre, and the state of flexion is assumed rather than extension in consequence of the predominance of flexor muscles over extension.

Sir Charles Bell's doctrine, which assigned to that portion of the cord which is intermediate between the roots of the nerves, (*his middle column,*) a special power over the movements of respiration, has long ceased to gain attention from physiologists. It wanted the support of anatomy. The so-called middle column had no defined limits, nor could it be proved that any respiratory nerves were connected with this region of the cord, excepting a few fibres of the spinal accessory nerve. The distinct anatomy of a respiratory system of nerves existed only in the imagination of the inventor of the doctrine. It could not be shown by experiment that the so-called nerves of respiration had any special respiratory function beyond that which they exercised as the motor nerves of certain muscles. And among the nerves which Sir C. Bell had classed together as nerves of respiration, were some which certainly had no necessary connection with that function. Of these the portio dura and the glosso-pharyngeal are examples.

Influence of the spinal cord upon the organic functions.—The influence of the spinal cord upon certain organic functions has engaged a large share of the attention of experimental physiologists. It has been said to have a very direct control over the functions of circulation, calorification, secretion, especially that of the kidneys.

If it can be shown that the organs concerned in these functions receive several nerves from the spinal cord, then we do not stand in need of vivisections to indicate to us that the functions with which they have to do are, to a certain extent at least, influenced by this organ. Now it is almost certain that the heart and kidneys receive filaments from the cord which pass to them chiefly in the sympathetic nerve; but as it is equally certain that they receive nerves from other sources likewise, as from the vagus nerve, and the proper filaments of the sympathetic, it would be erroneous, so far as anatomy teaches us, to affirm that these organs were wholly dependent on the cord.

As regards the heart, observation and experiment on man and animals tend to confirm the conclusion which anatomy indicates, namely, that while the heart possesses a certain inherent power, and while it has an immediate connection with the medulla oblongata and with the sympathetic, it is also not independent of the spinal cord. A slight injury to the cord or a chronic lesion of it affect the heart but little or not at all, because of its other sources of innervation; but a sudden and extensive injury to the cord, or a rapidly-developed destructive disease of it, materially depresses and weakens the action of the heart, and thereby the general circulation. The experiments of Clift, Wedemeyer, and Nasse may be cited as leading distinctly to this conclusion. Nasse's experiments were on dogs, in which he maintained artificial respiration; he found that as soon as the spinal cord was destroyed, the heart failed so completely that the jet of blood from the femoral artery, which before had gone to a distance of some feet, could not reach as many inches, or the blood did not escape per saltum from the wounded artery. In performing a similar experiment, Longet compared the action of the heart in two dogs, destroying the cord in one, but allowing it to remain intact in the other, and he found that in the animal whose spinal cord was destroyed the cardiac movements became enfeebled in a very striking manner, when compared with those of the animal whose cord was left uninjured.

If, then, we can prove that the spinal cord exercises an influence upon the central organ of the circulation, there can be no doubt that its power extends to the peripheral parts of the circulating system, to the capillary vessels, and, therefore, that injury or disease of it, especially if sudden or extensive, must to a certain extent affect the functions which are performed through the agency of these vessels, namely, nutrition, calorification, and secretion.

It seems most probable that it is only in this secondary manner that the influence of the spinal cord becomes extended to these functions, and that they suffer, when, through lesion of the cord, this influence has been greatly diminished or removed. The indications of its connection with nutrition and calorification are derived from the wasting and the coldness which are manifest in the paralysed parts when there is lesion of the spinal cord of a depressing kind. Sometimes, too, the nutrition of these parts is so feeble that gangrenous sloughs are formed on parts exposed even to slight pressure. This is more apt to be the case where the disease of the cord has been of a destructive kind, and has involved a considerable portion of the organ and of the roots of its nerves.

The influence of the spinal cord upon secretion has been inferred chiefly from the frequent occurrence of an alkaline state of urine in connection with injuries of that organ, and less frequently in diseased states of it. The urine, when passed, is found to be highly alkaline from the existence in it of a large quantity of carbonate of ammonia. The urine, in cases of this kind, is very apt to contain more or less of what has been very commonly, although erroneously, called *ropy mucus*, which is in truth pus formed from the mucous membrane of the bladder. This membrane is irritated and inflamed by the sojourn in it of the urine which the paralysed bladder is unable to expel. The secretion of a large quantity of phosphate of lime and of mucus, and afterwards of pus, is provoked by inflammation of the vesical mucous membrane. And the addition of these matters to it, especially the former, neutralises all free acid and gives rise to decomposition of the urea, and the production thereby of carbonate of ammonia. The alkalescence of the urine favours the precipitation of the triple phosphate. Hence urine obtained from patients suffering under spinal disease resembles very closely that of patients with diseased bladder without spinal disease. We may see in it mucus or pus globules, triple phosphates, blood particles, and amorphous masses of phosphate of lime mingled with the mucus. But in some instances the period of the sojourn of the urine in the bladder appears too short for these changes to take place; and hence it has been supposed that the urine may be secreted alkaline by the kidneys. Mr. Smith, of St. Mary's Cray, in Kent, made experiments on this subject by washing out the bladder carefully with warm water several times, withdrawing the water each time and testing for ammonia until all indication of its presence ceased. He then injected a small quantity of clear water, and allowed it to remain fifteen or twenty minutes; it was then drawn off, and the odour of ammonia could be distinctly perceived. It is to be regretted that a more accurate test of the presence of ammonia had not been used. Admitting, however, that ammonia did exist in this fluid, the experiment by no means disproves the formation of ammonia in the bladder. So small a quantity of urine as might trickle into the bladder in twenty minutes might readily be neutralised and decomposed by any alkali or mucus present in the bladder which might have eluded the previous washing out of that organ. If the secretion of urine in the alkaline state were common, it might reasonably be expected that such urine would be more frequently met with than it is in spinal complaints. Dr. Golding Bird, indeed, states that in the case of a woman in Guy's Hospital, labouring under complete paraplegia, and passing, with the aid of a catheter, fetid, alkaline, and phosphatic urine, he washed out the bladder with warm water, and after the lapse of half an hour obtained some urine from the bladder by the catheter; this he found to be acid, a sufficient proof that the urine was not alkaline when secreted, but underwent the change during its stay in the bladder.

In those affections of the spine which are not attended by a paralysed state of the bladder, the urine is not alkaline; let, however, the power of the bladder be impaired, even to a slight degree, and the quality of the urine will soon suffer. And it is well known that in cases where impediment to the flow of urine from the bladder occurs independently of any paralysis of the organ, as from stricture of the urethra, a similar derangement in the quality of the urine is apt to take place.

It must not, however, be forgotten that chronic disease of the brain or spinal cord is frequently accompanied by phosphatic urine, even when the power of the bladder is unimpaired, and that in such urine the addition of a little liquor ammoniæ or potassæ will cause a more or less copious precipitate of triple phosphate. There can, therefore, be no doubt that the cerebral or spinal lesion affects in some way or other the renal secretion so as to favour the developement of alkaline phosphates in it, and thus to create a tendency to its becoming alkaline. This, however, may arise not from any special influence upon the kidney, but from an undue waste of nervous matter, which would furnish the material for the formation of the phosphatic salt.

A very striking connection between the spinal cord and the kidneys, whereby a diseased state of the latter organs induces a functional derangement of the former, is shown by the history of those cases to which the attention of medical men was first called by Mr. Stanley. The patients are more or less completely paraplegic, and all the symptoms of disease of the spinal cord exist: but at the same time there exists irritation or actual organic lesion of the kidneys, which, however, may be overlooked or attributed to the spinal disease. When the renal disease has been completely removed and the kidneys restored to their normal condition, the paralysis gets well; but more frequently both the renal disease and the paraplegia resist all remedial means, and the patients die. On examination, both the brain and spinal cord are found perfectly free from any organic lesion; but distinct evidence of inflammatory or other irritant disease of the kidneys exists.*

In a case of this kind which came under my own observation, there was, along with complete paralysis of sensation and motion in the lower half of the body, excessive hæmaturia, which had all the characters indicative of renal hemorrhage. From the man's habits and history I suspected that the affection of the kidney had something to do with suppressed gout, and accordingly I used every means to attract gout to the feet. These means were successful, for, no sooner was my patient attacked with an active paroxysm of gout in one great toe than the renal disease began to subside, and the paralytic affection disappeared simultaneously.

Rayer, in his valuable work on diseases of the kidneys, relates several cases, which, in addition to those put on record by Mr. Stanley, leave no room to doubt that renal irritation may be propagated to the cord, and may occasion such an amount of disturbance of the functions of that organ as to give rise to paralysis of the lower extremities.

There seems no other mode of explaining these cases than by ascribing them to irritation of the cord excited by irritation of the kidneys, the nerves of the latter organ being the medium through which the renal affection excites the spinal. Yet there is no special connection between the nervous system of the kidney and the spinal cord, excepting probably through such tubular fibres as may be found in the renal plexus. These probably run a short course, and their origin in the cord is in close proximity to their distribution in the kidney; and on this account they may be more obnoxious to the influence of irritant disease of the latter organ.

The power which irritation of the cord has to develope erection of the penis may be here noticed as a remarkable instance of the influence of that organ over a local circulation. For it is only by assigning it to a temporary turgescence of the complex vascular system of the penis that we can explain this erect state. Even in ordinary erection, excited by a stimulus applied to the glans, as already pointed out, the influence of the cord is called into action, and the phenomenon is produced by a reflex, or what Dr. M. Hall would call an excito-motor act. Yet, (and here we may notice how ill-chosen has this term "excito-motor" been,) there is in reality no excitation of muscular action, but the influence of the stimulus propagated to the spinal cord is extended by a reflex act to the nerves which are distributed to the vessels of the penis, and they, instead of being excited to any contraction, become rather relaxed, and are thus prepared to receive a larger supply of blood; or by the extension of this excited influence of the cord, the attractive force (vis a fronte) of the capillaries is increased, and thus a larger quantity of blood is attracted to the organ, and erection takes place. The influence of the nervous system on this act is shown by the most convincing evidence—by the highly sensitive state of the organ, especially of the glans; by the large size of its nerves; by the effects of injury or disease affecting the cord immediately, or by extension from some part of the encephalon; and lastly, by the experiment of Günther, who divided the nerves on the dorsum of the penis in a stallion, and thereby destroyed the power of erection, although the vessels were uninjured.

On the mechanism of the functions of the cord.—Having shown that the spinal cord is concerned in voluntary motions and in sensation, (mental nervous actions,) and in certain reflex actions, as well as in certain organic functions, (physical nervous actions,) it is im-

* Med. Chir. Trans. vol. xviii.

portant to ascertain what is *the mechanism* by which these various actions take place.

The most convenient way to discuss this point will be to examine into the value of certain hypotheses which have been framed to explain it. We shall find it necessary in this discussion to keep before us two propositions in favour of which sufficient evidence has already been adduced. These are, 1. That the brain or some part of it is essential to the production of mental nervous actions; in other words, that acts of volition and sensation cannot take place without the brain: and, 2. That the vesicular is the truly dynamic nervous matter, that which is essential to and the source of the developement of all nervous power.

The first hypothesis which we shall notice is one of so much ingenuity that one is tempted thereby to adopt it, and would gladly do so if it were found sufficient to explain the phenomena, and if it were consistent with that simplicity which characterises the mechanism of the body. It originated with Dr. Marshall Hall, and has been advocated by him with great zeal and ability; it may be distinguished as the hypothesis of an *excito-motory system of nerves*, and *of a true spinal cord*, the centre of all physical nervous actions.

This hypothesis may be stated as follows.*

The various muscles and sentient surfaces of the body are connected with the brain by nerve fibres which pass from the one to the other. Those fibres destined for or proceeding from the trunk to the brain pass along the spinal cord, so that that organ is in great part no more than a bundle of nerve fibres going to and from the brain. These fibres are specially for sensation and volition—*sensori-volitional*.

But, in addition to these, there is, according to Dr. Hall, another class of fibres proper to

* I am very desirous that this hypothesis should be stated correctly, as I consider that both physiology and practical medicine are greatly indebted to Dr. Marshall Hall for the attention his labours have awakened to the inherent powers of the nervous system. Nevertheless I have shown in the text that great advances in our knowledge of these powers had been made by certain physiologists of the last century, whose views and researches had been completely or almost forgotten.

I have collected the statement of Dr. Hall's hypothesis in the text chiefly from his later writings. The history of Dr. Hall's labours on this part of physiology, as I gather it from his writings, appears to be as follows:—

In 1832 a paper was presented by him to the Zoological Society, of which, so far as I can ascertain, no other record has been kept than that which is to be found in the printed summary of the Proceedings of that Society. I have not had any opportunity of consulting these proceedings, but find an extract from them printed in Dr. Hall's work entitled Memoirs of the Nervous System, published in 1837. This paper was entitled, "A brief Account of a particular Function of the Nervous System," and its object was to point out the existence of a source of muscular action distinct from all those hitherto noticed by physiologists. The peculiarity of this motion is stated to consist in its being excited by irritation of the extreme portion of the sentient nerves, whence the impression is conveyed through the corresponding portion of the brain and spinal marrow as a centre, to the extremities of the motor nerves. Experiments upon salamanders, frogs, and turtles were detailed, from which Dr. Hall drew the following conclusions: 1. that the nerves of sensibility are impressible in portions of an animal separated from the rest; in the head, in the upper part of the trunk, in the lower part of the trunk; 2. that motions similar to voluntary motions follow these impressions made upon the sentient nerves; and, 3. that the presence of the spinal marrow is essential as the central and cementing link between the sentient and motor nerves.

Other experiments were detailed in this paper upon frogs rendered tetanic by a solution of opium; these showed that in this state the cutaneous nerves became "extremely susceptive, and the motor nerves extremely excitative." Decapitation of a tetanized frog did not destroy the tetanic condition of the trunk and extremities. "The exalted condition of the function of the sentient and motor nerves continued in each part." "All was changed in removing the brain and the respective portions of the spinal marrow."

"These experiments," Dr. Hall continued, "appear to me to establish a property or function of the nervous system, of the sentient and motor nerves, *distinct from sensation and voluntary or instinctive motion.*"

Dr. Hall's next publication appears to have been a paper read before the Royal Society on the 20th of June, 1833. This paper is entitled "*On the reflex function of the medulla oblongata and medulla spinalis.*" Having noticed the conclusion arrived at by Le Gallois, and confirmed by the reporters of the Institute, that section of the spinal marrow in the neck arrests only the respiratory movements, leaving sensation and voluntary motion to remain in the whole body, he points out that the causes of muscular motion may be *centric* or *eccentric* in the nervous system. When the cause is *eccentric*, that is, distant from the nervous centres, Dr. Hall states that the phenomena are due to a peculiar function, which he considers had not previously been understood. Its characteristic is that it is "*excited* in its action and *reflex* in its course; in every instance in which it is excited, an impression made upon the extremities of certain nerves is conveyed to the medulla oblongata or medulla spinalis, and is reflected along other nerves to parts adjacent to, or remote from, that which has received the impression."

"It is by this reflex character," he adds, "that the function, to which I have alluded, is to be distinguished from every other." Yet, curious to say, he assigns to it powers which certainly cannot be excited in the reflex manner. He says, "the reflex function exists as a *continuous* muscular action, as a power presiding over organs not actually in a state of motion, preserving in some, as the glottis, an open, in others, as the sphincters, a closed form, and in the limbs a due degree of equilibrium or balanced muscular action, a function not, I think, recognised by physiologists."

Dr. Hall points out the distinctness of this function from sensation and voluntary motion, and relates experiments on decapitated animals, (snakes, turtles, vipers, toads, frogs, and efts,) to show that the motions which occur in them are not spontaneous but only excited, and that these "excited motions in decapitated animals are dependent upon a principle different from sensation and volition." He then shows the difference between the reflex movements and those arising from irritability, by comparing the motion of the heart, when touched, with that of the glottis of an animal when similarly stimulated. Both movements take place equally after the removal of the brain; but if the medulla oblongata be removed, the contractions of the larynx cease, while those of the heart continue. "The difference consists, then, in the presence of the medulla oblongata, which is essential to the

the spinal cord and to its intracranial continuation, which form a connection with the grey matter of the cord. Of these fibres some are afferent or incident, others efferent or re-

contractions of the larynx, but of which those of the heart are entirely independent. The influence of the stimulus upon the heart is immediate. That of a stimulus applied to the larynx must pass to the medulla oblongata, and be reflected upon the part moved."

The details of further experiments next follow. The author refers to the reflex function the power which the hedgehog has of assuming the form and firmness of a ball.(?) Cases of infants born without brain or cerebellum are referred to in proof of the existence of reflex actions in the young of the human subject. The experiment of dividing the spinal marrow between the nerves of the superior and inferior extremities is described, to show "two modes of animal life; the first being the assemblage of the voluntary and respiratory powers with those of the reflex function and irritability; the second, the two latter powers only;" "if the spinal marrow be now destroyed, the irritability alone remains, all the other phenomena having ceased."

Dr. Hall next shows that the reflex function admits of *exaltation* and *diminution*. Frogs are made tetanic by opium and strychnine, and the tetanus disappears on removing the spinal marrow. On the other hand, a few drops of hydrocyanic acid placed upon the tongue of a frog depress the reflex function; "the contractions which depend on the reflex function are observed to become less and less energetic and excitable, and at length cease altogether."

Some highly interesting references are made to the light thrown upon the nature of certain diseases by our knowledge of this reflex function. The morbid states produced by dentition, epilepsy, asthma, tenesmus and strangury, tetanus and hydrophobia, are the principal diseases mentioned.

The rest of the paper consists of inferences from the preceding parts and a recapitulation.

Dr. Hall had formed, at this time, no distinct hypothesis respecting any special mechanism for the reflex function. He makes the following remarks, which seem to foreshadow his subsequent hypothesis referred to in the text. "It appears probable," he says, "that the facts of this paper may lead to some important additions to our knowledge of anatomy, by inducing an accurate inquiry into the origin, course, connection, and distribution of the subcutaneous, or submucous, and muscular nerves, which constitute the arcs of the reflex function."

In reviewing this interesting and important paper, it is impossible not to feel the greatest regret that its author should have done so much injustice to himself as well as to those who had preceded him, by neglecting to give an exact account of the state of science in reference to this question at the time he wrote. No one who peruses with candour the essay of Prochaska can deny that it contains, with regard to the reflex function, everything that Dr. Hall's paper contains, everything which will bear the test of careful analysis, omitting those views which are, indeed, peculiar to Dr. Hall, and which do not appear in this paper, assigning to the cord powers over ingestion, egestion, muscular tone, and irritability, &c. Throughout the whole paper no allusion whatever has been made to Prochaska's essay. The Report of certain members of the Institute upon the work of Le Gallois, (both of which Dr. Hall quotes,) makes distinct reference to Prochaska's views of the reflection of sensorial impressions. It must not, however, be forgotten that Prochaska's views had fallen into oblivion and neglect, and that Dr. Hall revived them, illustrated them by experiments, and showed their application to the pathology of the nervous system. I may add, that nothing would be more excusable than that a physician, working at these subjects in 1832, should be ignorant of Prochaska's essay published in 1784, more especially as it was overlooked even by his own countrymen—by such men as Treviranus, Rudolphi, and Müller.

Dr. Hall's next publications, as he himself states, (Preface to Memoirs on the Nervous System, 1837,) were a course of lectures, delivered from a printed syllabus in the summer, and repeated in the winter of 1835, of which one was inserted in the Medical Gazette for January, 1836, and the whole in his Lectures on the Nervous System and its Diseases, published in April, 1836.

It is in this latter work that, so far as I have been able to ascertain, Dr. Hall first put forward the hypothesis detailed in the text. It is stated, however, not as a hypothesis, but as *a discovered fact*. Having described two divisions of the nervous system, the first consisting of the cerebrum and cerebellum with sentient nerves, which pursue their course *to* them, and of motor nerves, which proceed *from* them either along the base of the brain or along the spinal marrow, and then along every external part of the animal frame, and the second comprehending the sympathetic, Dr. Hall goes on to say: "To these two subdivisions of the nervous system, I believe a third must be added before our views of that system can be considered as at all complete; it is one which I claim the merit of first pointing out in all its fullness. Suppose the cerebrum and cerebellum, the *centre* of the first subdivision of the nervous system, and the ganglionic or the second subdivision of this system removed, *this remains*. It consists of the *true* spinal marrow, distinguished from the sentient and motor nerves, which run along its course as an axis of *excitor* and motor nerves. It is the seat of a peculiar series of physiological phenomena, and of a peculiar class of pathological affections." "In the former are included *all* (sic) the functions which relate to the immediate acts of *ingestion* and *egestion*; in the latter, *all* spasmodic diseases." (Loc. cit. p. 11.)

Further on, in the same work, Dr. Hall gives an analysis of his true spinal or excito-motory system, which consists, according to his description, of, 1. the Membranes; 2. the True Medulla; 3. the True Spinal Nerves. The principal divisions of the true medulla, he specifies as follows:

1. The Tubercula Quadrigemina,
2. The Medulla Oblongata,
3. The Medulla Spinalis, and especially its
    1. Cervical,
    2. Dorsal,
    3. Lumbar, and
    4. Sacral portions.*

The reader who has perused with attention the analysis of Prochaska's work given in the text will perceive a striking resemblance between this *true Medulla* and the *Sensorium commune* of Prochaska, p. 24.

In this work there is no allusion to the important essay of Prochaska, although Sir Charles Bell is corrected for attributing the discovery of the ganglia on the posterior roots of the spinal nerves and on the portio major of the fifth to Monro instead of to Prochaska (p. 17), and two quotations are made from the latter author without specifying the work from which the passages are quoted.

In 1837 Dr. Hall published a quarto volume, with the title, "Memoirs on the Nervous System." This consists of a reprint of the paper published in the Philosophical Transactions, "On the Reflex Function of the Medulla Oblongata and Medulla Spinalis;" and also of a paper which was read

* An anatomical oversight, as the *medulla* spinalis has no sacral portion.

flex, and these two kinds have an immediate but unknown relation to each other, so that each afferent nerve has its proper efferent one, the former being *excitor*, the latter *motor*.

before the Royal Society on February the 16th and 23d, and March the 2d, 1837, but was not published in the Transactions. This paper is entitled, "On the true Spinal Marrow and the Excito-motory System of Nerves."

The object of this paper the author states to be the developement of a great principle in physiology—that of the special function of the true spinal marrow and of a system of excito-motory nerves.

"It is this principle," he continues, "which operates in all those actions which have been designated sympathetic, which regulates the functions of ingestion and expulsion in the animal economy, and which guards the orifices and sphincters of the animal frame."

"The principle to which I allude," he proceeds, "has been confounded with sensation, and voluntary, and what has been designated instinctive, motion, by *all* (sic) physiologists, with one single exception (Sir Gilbert Blane). It has been supposed to be a function of the rational (Stahl) or irrational (Whytt) soul. It has been considered by some (Haller, &c.) as attached to the brain; by others (Whytt, Soemmering, Alison, Muller,) as attached to the brain and spinal marrow; by others (Le Gallois, Flourens, Mayo,) as peculiarly attached to segments of the spinal marrow; it has been viewed by others as the function of the sympathetic (Tiedemann, Lobstein,) or of the pneumogastric nerve (Bell, Shaw); and, lastly, by others as operating through identity of origin or anastomoses of nerves (Mayo)."

How very strange it is that amidst all the research displayed in this paragraph, no mention should have been made of Unzer and Prochaska, the only authors who really had clearly stated the correct doctrine respecting nervous phenomena independent of the mind!!

In this paper Dr. Hall falls into the curious error of affirming that the power which is developed in the nervous system in connection with sensation and volition, is different from that through which the reflex actions are produced. To the latter he limits the term *vis nervosa*, and, having quoted Haller's very correct description of the course which it takes in motor nerves, he affirms that his researches have disclosed a series of phenomena "directly at variance with the conclusions of Haller."

I confess myself quite unable to discover in what respect Dr. Hall's results are at variance with the laws of the vis nervosa as laid down by Haller. All that the latter physiologist affirmed was that the nervous force travelled from trunk to branches in motor nerves, and that irritation of the spinal cord caused convulsions of the limbs which derived their nerves from below the point of stimulation. Now these facts are strictly true—by whatever stimulus the nervous force is excited in motor nerves it travels from trunk to branches; and the statement made by Haller respecting the spinal cord is equally true, namely, that the motor force travels downwards, and that irritation of the cord affects only the limbs below the irritated point. All that Dr. Hall has made out which is at variance with this proposition is, that *sometimes* the anterior extremities may be thrown into action by stimulating that segment of the cord from which the posterior extremities derive their nerves, from whence he concludes that "the motor power in the spinal marrow will act in a *retrograde* direction."

This conclusion, however, does not follow from the experiments adduced in support of it. If the spinal cord of a turtle be irritated in the segment from which the nerves to the hinder extremities spring, and all four extremities are thrown into action by that stimulus, we are not authorized to conclude that the *motor* power will act in the spinal marrow in a retrograde direction; all that we are justified in affirming is that the same change which would excite the nerves of the irritated part of it may be propagated from its lower to its upper part. How this takes place is uncertain, whether by sensitive fibres or by commissural fibres, or by vesicular matter, most probably by the last.

It may, however, be stated that such phenomena as those described take place chiefly in an excited state of the cord, as when the animal is under the influence of strychnine—or in tetanus—and their occurrence is far from being in accordance with a normal state of action of the spinal cord. I have frequently irritated the cord in healthy animals without producing any movements save in parts below the point stimulated. (Vide supra, p. 26.)

Dr. Hall in this paper draws the same conclusions as in his work last referred to as to the existence of a "*true spinal marrow* physiologically distinct from the chord of intra-spinal nerves; of a system of excito-motory nerves, physiologically distinct from that of the sentient and voluntary nerves; and of a nervous influence—the excito-motory power—operating in directions incident, upwards, downwards, and reflex, with regard to the true spinal marrow, the centre of this excito-motory system." When Dr. Hall uses the term *physiologically* distinct, of course he means, likewise, *anatomically* distinct. One part cannot be *physiologically* distinct from another without being *anatomically* so also.

In the second section of this paper Dr. Hall gives "a slight sketch of the opinions of physiologists upon the subject of this memoir." He alludes to the views of Haller, Monro, Whytt, Blane, Le Gallois, and the Reporters of the Institute upon Le Gallois' Essay, Mayo, Flourens, Alison, and Muller, but makes no allusion to either Unzer or Prochaska.

I pass over the third, fourth, fifth, and sixth sections, and proceed to the seventh. Here the laws of the excito-motory system are stated, and those extravagant powers are attributed to it, which I have in the text endeavoured to show it cannot exercise. But, in addition, this system is made to be the nervous agent of the appetites and passions! What strange confusion! that a system, devised as the special centre of nervous actions *independent* of the mind, should be the seat of phenomena preeminently mental, and intimately connected with sensation.

The remainder of this essay consists of further remarks on the anatomy, physiology, pathology, and therapeutics of the excito-motor system, and concludes with some observations on the ganglionic system of nerves.

In 1841 Dr. Hall published his work on the Diseases and Derangements of the Nervous System. In this work I am not aware that any new or additional fact has been stated not mentioned in those already quoted. It includes a reprint of several memoirs read to the Medico-Chirurgical Society.

In 1843 a "New Memoir on the Nervous System" appeared, dedicated to Professor Flourens as to one "who has in his responsible office displayed the most candid, impartial, and generous judgment of the works of others."

I find it necessary to notice an assertion contained in a note to the advertisement of this work Dr. Hall observes:—

"My first memoir was entitled, 'On the Reflex *Function* of the Medulla Oblongata and Medulla Spinalis.' This important *function* as the nervous agent in *all* the acts of ingestion and of egestion in the animal economy was previously unknown. It is not mentioned by Whytt, or Prochaska, or any other author; who, however they may cite the term reflex, or detail experiments, or treat of sym-

The aggregate of these fibres, together with the grey matter, constitutes the *true spinal cord* of Dr. Hall, which is not limited to the spinal canal, but passes up into the cranium as far as

pathetic actions, have not, I affirm, associated *one physiological act* with any such *reflex function* of the spinal marrow. This is, therefore, my discovery."

Upon this passage I must remark, 1st, that if Dr. Hall merely claims the discovery of the reflex function, it cannot be conceded to him, for Prochaska had already distinctly announced the existence of this function in the medulla oblongata and spinalis, using even the term *functio*, as in the following passage: — "Cum itaque *præcipua functio* sensorii communis consistat in reflexione impressionum sensoriarum in motorias, notandum est, quod ista reflexio vel animâ nesciâ, vel vero animâ consciâ fiat." Loc. cit. pp. 118-19.

If, however, Dr. Hall claims the discovery of this function "*as the nervous agent in all the acts of ingestion and egestion in the animal economy*," then I have only to remark that I know of no physiologist in the present or in former times who would care to dispute such a discovery with him. I have already shown that the idea that these acts of ingestion and egestion are dependent on this function is a fiction of the fancy—an *idolon specus*—which rests upon an imperfect and erroneous analysis of these acts, and on very narrow views of the nature and mode of developement of the nervous force. If, finally, Dr. Hall limits his claims, as he says he might do, to the discovery (?) of the anatomy and physiology of the true spinal system, as a combined system of "1, *incident nerves*; 2, *their spinal centre*; and, 3, *reflex nerves*, constituting the anatomy of the whole series of the acts of ingestion and egestion," I am quite sure that no anatomist or physiologist of the present day would seek to deprive him of such a discovery, or dispute the opinion of Professor Flourens that it belongs to Dr. M. Hall. That this so-called true spinal system is no more than an hypothesis, and one which has but an infirm basis to rest upon, I have endeavoured to show in the text. That a centre of reflex actions exists—but not distinct from the centres of sensori-volitional acts—every physiologist will admit, and the limits of that centre were most correctly defined more than fifty years ago by Prochaska under the name *sensorium commune*, which extends, according to him, "quam late patet nervorum origo," and which, as I have already remarked, completely foreshadowed Dr. Hall's "true spinal marrow."

In sections 5—11 of this work Dr. Hall states the real objects of his researches as follows.

"First, to separate the reflex actions from any movements resulting from sensation and volition.

Secondly, to trace these actions to an acknowledged source or principle of action in the animal economy—the *vis nervosa* of Haller—acting according to *newly discovered laws*.

Thirdly, to *limit* these actions to the *true spinal marrow*, with its appropriate incident and reflex nerves, exclusively of the cerebral and ganglionic systems.

Fourthly, to apply the principle of action involved in those facts to physiology, viz. to the physiology of all the acts of exclusion, of ingestion, of retention, and of expulsion in the animal frame.

Fifthly, to trace this principle of action in its relation to *pathology*, viz. to the pathology of *the entire class of spasmodic diseases*; and,

Sixthly, to shew its relation to *therapeutics*, especially to the action of *certain remedial and certain deleterious physical agents*.

Finally, it is to these objects, taken together as a *whole* or as a *system*, that I prefer my claims; and I do not pretend that an occasional remark may not have been incidentally made by some previous writer, bearing upon some one or other of them."

It is in this work that Dr. Hall has, for the first time, ventured to notice the remarkable views of Prochaska. I wish, for the sake of English physiology, and also for the sake of Dr. Hall's own character as one who professes great admiration for those who "display a candid, impartial, and generous judgment of the works of others," that the extracts which he has made from Prochaska's work, few and imperfect as they are, had been accompanied by some more dignified and more ingenuous remarks than those contained in the following paragraph.

"It is impossible to adduce specimens of more complete confusion than these, in which voluntary acts, and the actions of the *heart*, *stomach*, and *intestines*—functions of the *cerebral* and of the *ganglionic* systems respectively,—are arranged with certain reflex experimental facts, and *very obvious* sympathetic actions, which really belong to the true spinal system."

I have carefully examined the passages quoted from Prochaska by Dr. Hall, and I confess myself unable to discover any of that "complete confusion to which he alludes." Prochaska states, that numerous examples (plurima exempla) prove the general law of the reflecting power of the sensorium commune, of which, however, he says, it will suffice to adduce only a few. He mentions sneezing produced by irritation of the mucous membrane of the nostrils,* the violent cough produced by irritation of the glottis—per micam cibi vel guttulam potus illapsam,—and the winking excited by bringing the finger close to the eye. If these are not fair examples of reflex actions, I know not what are.

Prochaska then proceeds to show that these reflex actions may take place with or without the cognizance of the mind; and here I must refer to a very disingenuous proceeding on the part of Dr. Hall in his quotations. He displaces the passages from their right order and therefore from the context, and thereby introduces an appearance of confusion which does not exist in the original. The passage commencing "Si amicus digito," &c. occurs before and in a different paragraph from that commencing "Cum itaque præcipuo," &c., Dr. Hall quoting them as if the latter stood first. He has similarly transposed the passages commencing "Sed fieri tamen," &c. and "Motus cordis, ventriculi."

In the remaining portion of this work Dr. Hall has systematized his views more completely than in his previous writings—repeating, however, much the same experiments, re-asserting the same explanations of certain actions as before, and adding some new remarks in vindication of his views already expressed. Yet in this volume there are indications as if Dr. Hall had no great confidence in his own hypothesis, notwithstanding he had thought it worthy of being designated a discovery. At § 149, referring to Dr. Carpenter's and Mr. Newport's opinions in favour of the existence of excito-motory fibres distinct from sensori-volitional fibres, he remarks, "I doubt not that the investigations of these gentlemen are correct; they have, therefore, confirmed *what I had long previously* done." But in § 150, having mentioned Mr. Grainger's assertion that in the roots of the spinal nerves one set of fibres passes up to the brain, while the other pursues its course to the grey matter, he says, "It is probable, therefore, that the former are in reality nerves of sense and voluntary motion, whilst the latter are the nervous channels of the excito-

* Prochaska supposes that the *olfactory* nerves propagate the irritation which excites sneezing to the centre; — the office of the fifth nerve was not made out in his day.

the crura cerebri. (Its extent, indeed, is much the same as that which has been assigned by Prochaska to his *sensorium commune*.) These fibres are quite independent of those of sensation and volition and of the sensorium commune, using that term as indicating the centre of intellectual actions. Although bound up with sensitive and motor fibres, they are not affected by them, and they maintain their separate course in the nerves, as well as in the centres.*

motor power and action. I say it is probable this is the case." And in § 151 he says, "It has always appeared to me that, observing the difference between the cerebrum and the spinal marrow, the olfactory and the trifacial nerves, in regard to the psychical and the excito-motor properties, it is very improbable that in *any* part of the nervous system the two functions should co-exist in any one individual fibre." I am, therefore, not premature in refusing to accept as a discovery that which Dr. Hall himself regards only as *probable* -- and *not proved*. Lastly, at § 370, he quotes an experiment by Van Deen and Stilling, in which *one-half* of the spinal marrow is divided above the origin of the brachial nerves, and the other half below the same point, with the effect of leaving sensation and voluntary motion undestroyed. On this he remarks, "There is, therefore, no continuous rectilinear course of nervous fibre from the brain to the extremities."!!

I shall here contrast the points made out by Prochaska with the statement of Dr. Hall's "real objects" as quoted a few paragraphs back.

1. Prochaska forms a large estimate of the importance of the vis nervosa; he attributes to it a high place among the forces which concur in the production of vital phenomena—not limiting the term, as Haller did, to the force by which nerves excite muscles to contract, but viewing it as THE agent in the production of all the phenomena of the nervous system.

2. He investigates the *laws* of this force as it is developed in the pulp of the nerves, leaving the enquiry into its *nature* to those who are engaged with physical experiments.

3. He shows that this nervous force, although in truth an innate property of the medullary pulp, nevertheless needs a stimulus for its developement.

4. This stimulus, he further shows, may be either physical or mental.

5. He investigates the causes and effects of the increase and of the diminution of the vis nervosa, and how it is influenced by age, sex, and temperament.

6. He shows that the nervous force remains in nerves separated from the centres (within certain limits) even in "singulis dissectorum nervorum frustis."

7. Prochaska lays down that nerves act in producing motion and sensation in virtue of their power of propagating impressions made on them, whether at their origin or at their periphery.

8. He shows that external impressions made upon sensitive nerves are quickly propagated to their origin and there are *reflected*, according to a certain law, into corresponding motor nerves, whereby certain definite motions are effected.

9. This takes place whenever motor and sensitive nerves are implanted in the neighbourhood of each other, and all that part of the cerebro-spinal axis in which nerves are so implanted is called by Prochaska *sensorium commune*.

10. This reflexion of sensitive impressions into motor ones is a *physical phenomenon* independent of the mind.

11. The mind, however, may or may not be conscious of its occurrence.

12. Examples of reflex acts of this kind are found in sneezing, in the winking of the eye when the finger is suddenly directed close to it, in the violent cough produced by a particle of food or a drop of water passing into the trachea. In all these instances the effects of the stimulus applied to the sentient nerves of the part irritated are propagated to the centre, and there reflected into the nerves of those muscles by which the respective movements are produced.

13. The motions which may be produced in decapitated animals by excitation of the surface are of this kind, the reflexion taking place in the *residual portion* of the sensorium commune, which is in the spinal marrow; and those produced in patients labouring under apoplexy are of the same kind.

14. A similar reflexion takes place in ganglia to that which occurs in the sensorium commune.

15. Prochaska has, therefore, shown that the nervous centres may affect nerves implanted in them in three ways: 1, through mental change, as in voluntary actions; 2, through a physical change originating in the centres themselves; 3, through the reflexion of the change wrought in a sensitive nerve by peripheral stimulation, into a motor nerve: and that nerves may affect centres, 1, so as to excite a feeling in the mind (sensation); and, 2, so as to cause the reflexion of a peripheral change in the afferent sensitive nerve into an adjacent motor nerve, independently of the mind.

16. Prochaska concludes his observations by drawing a careful distinction between those motions which are *animal*, being directed by the mind, and those which are *mechanical* or automatic *(physical)*, of which the mind may or may not take cognizance, but in the production of which it takes no part. In these latter are included the reflex actions.

Such are the conclusions to which Prochaska's observations lead him respecting the nervous system, and in them I confess there appears to me to be a large and an exact view of the phenomena of the nervous system, more comprehensive than the views of Dr. M. Hall respecting an excito-motor power and a special system of excito-motor nerves, and their centre, the true spinal nerves.

In his latest publication, a volume of essays, (1845) Dr. Hall asserts his conviction of the truth of his views, and re-affirms his claims to discovery.

I feel that I owe the reader some apology for this long note. The views of Dr. Hall have been so zealously pressed upon the attention of physiologists and of medical men, that it seemed to me that a work like this ought to contain as full a statement of them as its limits would permit, more especially as I have felt it my duty to express my dissent from them to a very great extent, and to criticize them with much freedom.

Throughout all my remarks it has been my anxious wish to express my opinions regarding Dr. Hall's views as of a pure question of science, omitting all personal considerations. It would have been infinitely more grateful to my feelings to have been able to express my concurrence in these doctrines, (as, indeed, I was at one time much disposed to do,) than to have found myself compelled by regard to truth to refuse assent to his claims to original discovery as well as to his hypothesis, and even to the accuracy of some of his experiments. The cause of science demands that views which are essentially unsound, but which from the urgency with which they continue to be put forward on various occasions and in various shapes, are in danger of being adopted by those who have no time nor opportunity to investigate them closely, should be exhibited in their real shape and purport by means of a careful and searching analysis. Having weighed them in this balance, I must confess that they have been found wanting.

* It would be unjust to a most able physiologist and pleasing writer, Mr. Grainger, not to state that he has contributed much to the distinct enunciation and apt illustration of this hypothesis. See his excellent work on the Spinal Cord. Lond. 1837.

2. A second hypothesis is that which accords with the views of Müller and many other physiologists of the present day, and likewise probably with those of Whytt. It assumes that the fibres of sensation and volition proceed to and from some part or parts of the intracranial nervous mass,—that every nerve-fibre in the body is continued into the brain. Those which are distributed to the trunk and extremities pass along the spinal cord, separating from it with the various roots of the nerves, and in their course within the spine mingling more or less with the vesicular matter of the cord. There are, according to this hypothesis, no other fibres but these, (save the commissural,) and they are sufficient to manifest the physical as well as the mental acts. Nerves of sensation are capable of exciting nerves of motion which are in their vicinity; and they may produce this effect even when the spinal cord has been severed from the brain, for their relation to the grey matter of the cord is such that their state of excitement is readily conveyed to it.

3. According to a third hypothesis, it is assumed that all the spinal and encephalic nerves, of whatever function, are implanted in the grey matter of the segments of the cerebro-spinal centre with which they are severally connected, and *do not pass* beyond them. The several segments of the cerebro-spinal axis are connected with each other through the continuity of the grey matter from one to another, and through the medium of commissural fibres which pass between them. Through these means, motor or sensitive impulses may be propagated from segment to segment; and a stimulus conveyed to any segment from the periphery may either simultaneously affect the brain and cause a sensation, or it may be reflected upon the motor nerves of that segment and stimulate their muscles to contract. Or both these effects may take place at the same moment, as a result of one and the same stimulus. According to this hypothesis, each segment of the cord, so long as it retains its proper commissural connection with the brain (by commissural fibres and continuous grey matter), is part and parcel of the centre of volition as well as of that of sensation, and the mind is as directly associated with each segment of the cord as it is with any portion of the encephalon. Let that commissural connection be dissolved, and the mind will immediately lose its hold upon the cord; but the various segments of that organ may nevertheless still be acted upon by physical impulses, and may still continue to evolve the nervous force in connection with the natural changes which may take place within.

I am not aware that this view of the mechanism of the various actions of the nervous system had been ever distinctly enunciated before it had been stated by Mr. Bowman and myself in our work on the Physiological Anatomy and Physiology of Man, in 1845.* There is nothing, however, in this hypothesis at variance or inconsistent with the views of Prochaska; for this physiologist seems to have held the opinion that the nerves are implanted in the segment of the cerebro-spinal axis into which they sink, and do not pass beyond it.

I shall now examine into the merits of each of these hypotheses, and, first, of the excito-motory hypothesis.

It is unnecessary to repeat the objections already stated (p. 21) to the use of the term *excito-motory*. I shall only remark that some of these objections are equally opposed to the hypothesis as to its name.

Nevertheless this hypothesis has much to commend it: and not the least argument in its favour is that drawn from the compound nature of spinal nerves, as proved by Bell, in which nerve-fibres of different endowments are bound together in the same sheath. If it be proved (as it has been) that fibres of sensation and of motion may be thus placed in juxtaposition in the same nervous trunk, it seems not an unreasonable conjecture that fibres of other function (*excitors* and their corresponding *motors*) might be enclosed in the same sheath with them.

Both anatomy and experiment, however, unite to prove the existence of sensitive fibres distinct from motor fibres; they are found separate in the roots of the nerves, and combined in the nervous cords: but neither anatomy nor experiment favours the existence of a distinct series of excitor and of corresponding motor nerves. Anatomical research affords not the slightest indication of such a series of nerves. And experiments on the roots of the nerves, where it might reasonably be expected that the excitors would be separated from the motors (following the analogy of the motor and sensitive fibres), are by no means favourable to the existence of such fibres in the roots. The failure of experimenters to excite motion by irritation of the posterior roots of the spinal nerves has been already referred to. A new and extensive series of experiments is much needed to settle this question. I would remark that galvanism should not be used in them, as the results of stimulation by that agent are extremely fallacious, from its liability to extend beyond the parts included between the electrodes.

Other very serious anatomical objections may be urged to this hypothesis. It supposes the existence of two sets of fibres in the spinal cord. Evidence in favour of these is wanting just as much as in favour of those in the roots of the nerves. Many facts favour the conclusion that the fibres which constitute the roots of the nerves of any segment of the cerebro-spinal centre are implanted in the grey matter of that segment, and that none of them are continued beyond that segment up into the brain. They penetrate the spinal cord more or less obliquely, and form their connection with the grey matter a little higher up than the point of penetration; but there is no evidence to show that they assume a completely vertical direction to pass up to the brain.

The form and varying dimensions of the spinal cord in its several regions are opposed to this view. If the sensori-volitional fibres are

* The Physiological Anatomy and Physiology of Man, by R. B. Todd and Wm. Bowman, vol. i. p. 323.

all continued up into the brain, and the (so-called) excito-motor fibres are implanted in the cord, that segment of the cord should be the largest in which the greatest number of these fibres is to be found. Now the great extent of excitor surface in the lower extremities, the magnitude of their muscles, the importance of their movements, and, at the same time, the great developement of reflex actions in them, would lead most reasonably to the expectation that the lumbar segment of the cord to which these nerves belong should exceed considerably in size the cervical segment which gives nerves to the upper extremities, where the excitor surface is of less extent, where the muscles are less powerful, and the reflex actions considerably less conspicuous. Moreover, the lumbar region of the cord would be, if Dr. Hall's views were correct, the centre of those excito-motor acts connected with defæcation, micturition, parturition, &c., of which he speaks so much, and on this account might fairly claim a greater amount of substance. But the fact is, that the lumbar swelling of the cord is smaller than the cervical; and that while it contains, and owes its bulk mainly to, a large quantity of vesicular matter, but a small proportion of fibrous matter is found in it. Moreover, it is impossible to understand the great superiority of size of the lumbar portion over the dorsal segment of the cord, if we are to admit that this latter segment contains in addition to its own fibres (sensori-volitional and excito-motory) the sensori-volitional fibres of the lumbar swelling also, which ought to be very numerous.

It is very generally admitted that the only channel by which the will can influence the spinal cord is through the fibres of the anterior pyramids of the medulla oblongata, the greater number of which decussate each other along the median line. But it is in the highest degree improbable that these fibres, occupying so small a space as they do, should form the aggregate of the volitional fibres (still less of the sensori-volitional fibres) of the trunk and extremities. The whole of these fibres (of *both* sides) collected together would scarcely equal in bulk the anterior portion of *one* of the antero-lateral columns of the spinal cord.

It has been affirmed that much support is given to the excito-motory hypothesis by Dr. Carpenter's and Mr. Newport's supposed demonstration of the two sets of fibres in the Articulata. But these observations are far from deserving the name of *demonstration*. The inferences from them are derived from the *apparent* direction of certain fibres, and not from any actual tracing of them by dissection or by microscopic inspection. The observations, too, have been made with low powers, which are very insufficient for determining the precise disposition of the fibres and their relation to the vesicular matter of the ganglia.

These writers affirm that the longitudinal fibres of the ganglionic chain of Articulata pass up to the brain and constitute the sensori-volitional fibres, whilst other fibres pass in a transverse direction and are implanted in the ganglia. Were this the case, it might reasonably be expected that the brain would be the largest of the ganglia as containing the sum of the sensori-volitional fibres of the whole body. But let any one compare the size of the cerebral ganglia of the scorpion (as figured by Mr. Newport*) with the size of the animal and that of its cord, and it will be evident to him how disproportionately small such a centre is to the number of sensori-volitional fibres which must be distributed over so large a surface and to so many muscles. Anatomy, however, offers no objection to the hypothesis that the roots of the nerves are implanted in the ganglia, and that the longitudinal fibres act as commissures between different segments (adjacent and remote) of the cord.

Neither do Mr. Newport's experiments on the myriapods and other Articulata throw any new light on the question of the existence of two orders of fibres; nor do they add anything to our knowledge beyond the important fact that actions take place in certain Invertebrata after decapitation, which are of the same nature with those which occur in Vertebrata after a similar mutilation. The *mechanism* of these actions has not been at all elucidated by these experiments.

The excito-motory hypothesis is sufficient for the explanation of the movements of decapitated animals, of parts in connection with small segments of the spinal cord, of limbs paralysed to sensation and voluntary motion from diseased brain or spinal cord. But there are two phenomena familiar to those who observe disease with care, which cannot be explained by it; these are the movements which may be excited by mental emotion in limbs paralysed to the influence of the will, and the total paralysis of the sphincter ani, which frequently accompanies diseased brain, whilst at the same time the limbs are only affected to a partial extent or not at all.

Cases occur sometimes in which hemiplegia arises from an apoplectic clot, or other destructive lesion in one hemisphere of the brain. The arm and leg, or either of them, are completely removed from the influence of the will; yet occasionally, as the effect of some sudden emotion, fear, joy, surprise, the paralysed limb is raised involuntarily. Even so slight a cause as yawning (an act of emotional kind) will excite the palsied limb. Every time the patient yawns the arm will be raised involuntarily.

Such phenomena as these receive no adequate explanation from the excito-motory hypothesis. Mental emotions probably affect some part of the brain; if the only communication between the brain and the limbs be by fibres of sensation and volition, it is impossible to understand how the emotional influence could be conveyed to them through a channel which has long been interrupted. If we are to adopt the excito-motory hypothesis, it will be necessary to suppose with Dr. Carpenter the existence of certain emotional fibres to explain the phenomena of this particular case. But it is difficult to admit the existence of three orders

* Phil. Trans. 1844.

of fibres in each muscle, which, to be effective, must have the same relation to the component elements of the muscle. It is impossible to imagine how each order of fibre should comport itself with reference to the other two, so that their actions may not interfere. Nor can any one fail to perceive that the emotional fibres must be infinitely less frequently employed than the others, and in some individuals so seldom called into action as to be greatly exposed to the risk of atrophy for want of use.

Another phenomenon, which this hypothesis fails to explain, is the paralysis of the sphincter ani muscle which accompanies certain lesions of the brain, generally of grave import. Such lesions are almost always accompanied by paralysis, chiefly of the hemiplegic kind, but not necessarily complete. On the contrary, in several such cases distinct reflex actions exist, indicating that, although the brain's influence is withheld from the limbs, that of the cord is not. If, then, the cord be sufficiently free from morbid depression to allow of reflex movements taking place in the inferior limbs, why is the sphincter ani (the actions of which according to Dr. Hall are eminently reflex) so completely paralysed that it offers not the slightest resistance to the introduction of the finger into the anus? So long as the cord is free from lesion and so capable of performing its functions that the lower limbs exhibit reflex movements, the sphincter ani muscle ought not to be paralysed, if the excito-motor hypothesis be true. For, admitting that this muscle has sensori-volitional fibres which are paralysed by the cerebral lesion, it should have excito-motor fibres likewise which ought to enable the muscle to resist the entrance of the finger into the rectum. Such resistance, however, it certainly does not make, for the muscle is completely paralysed in the cases referred to. And it is plain that, according to the excito-motory hypothesis, a cerebral lesion ought not to affect the sphincter ani further than to destroy the control of the will over it, unless the depressing influence of the lesion extend to the whole cord, and in such a case there ought to be complete paralysis of the limbs likewise.

In fine, it cannot be denied that the excito-motor hypothesis takes a narrow and confined view of that power of the nervous centres which it professes to elucidate. As I have before remarked, it limits this power to the excitation of motion, and it confines the exciting agency to nerves which naturally propagate *centrad*, and which only propagate such impressions as may excite movements.

Now it admits of unquestionable proof that impressions on sensitive nerves may, by a process of reflexion, excite other sensitive nerves. Are we to suppose the existence of a special series of fibres for such phenomena? Such a supposition would involve the most palpable contradictions, and is wholly inadmissible.

The second hypothesis, which accords with the views of Müller, is just as competent to explain the phenomena of decapitated animals, and of limbs paralysed to cerebral influence, as that of Dr. Hall. It receives considerable support from the universal concurrence of sensation or mental perception with those normal actions which Dr. Hall would attribute to excito-motory fibres. If it be supposed that these fibres have a certain relation to the vesicular matter of the cord, there are as good grounds for the further supposition that they may continue to be affected by it after the brain has been separated from the cord. This hypothesis, however, is as inadequate as that of excito-motory fibres to explain the influence of emotion on paralysed limbs; and it likewise fails to explain the paralysis of the sphincter, which, under this hypothesis, ought to occur in every case of cerebral disease. The chief objection, however, to this hypothesis is anatomical; for it is far from being proved that the fibres of the spinal nerves are continued upwards through the cord into the brain. For instance, what evidence have we that the fibres of the lumbar region of the cord pass into the brain? The fibres of the anterior pyramids, no doubt, are true cerebro-spinal fibres, because they communicate equally with brain and cord, and distinctly pass from the one to the other; but it cannot be shown that they have any continuity with the fibres of any of the spinal nerves. Much less can it be shown that they contain the fibres which are continued up from, to say the least, the anterior roots of ALL the spinal nerves, which ought to be the case if this hypothesis be correct. The bulk of the pyramids is very much opposed to this view. It is most probable that the pyramids are *cerebro-spinal commissures*. The apparent longitudinal course of the fibres in the spinal cord affords no indication that they pass into the brain, for it is well known that many of the fibres forming the roots of spinal nerves take a very oblique course from their point of separation from the cord to their emergence from the spinal canal; and it is probable that this obliquity is continued in the cord itself, so that their real origin would be much higher up than their apparent one. This great length of oblique course gives to the fibre the appearance of being strictly longitudinal, whereas it may be implanted in the vesicular matter of the cord.

The third hypothesis is more consonant than either of the others with what appears to be the true anatomy of the spinal cord—namely, that each segment has its proper nerves implanted in it, that it is connected with adjacent segments by commissural fibres, and that the whole cord is connected with the cerebrum and cerebellum by commissural fibres; by the anterior pyramids and olivary columns with the former, and by the restiform bodies with the latter.

This hypothesis, the reader will bear in mind, assumes that mental and physical actions are performed through the same fibres—affected by a mental stimulus in the one case, and a physical stimulus in the other—the change produced by the physical stimulus being, in the case of reflex actions, reflected at the centre. The same *afferent* and *efferent* fibres are excited in the one case as in the other, the former acting as *sensitive* or *excitor*, or both; the latter as channels for *voluntary*, *emotional*, or strictly *physical* impulses to motion.

The mechanism of a voluntary action in parts supplied by spinal nerves would be, according to this hypothesis, as follows:—The impulse of volition, excited primarily in the brain, acts at the same time upon the grey matter of the cord (its anterior horn), and through it upon the anterior roots of the nerves implanted in it. This grey matter, in virtue of its association with the brain by means of the anterior pyramids, becomes part and parcel of the organ of the will, and therefore as distinctly amenable to acts of the mind as that portion which is contained within the cranium. If we destroy the commissural connection with the brain through the pyramidal fibres, the spinal cord ceases to take part in mental nervous actions; or, if that connection be only partially destroyed, that portion of the cord which the injured fibres had associated with the brain is no longer influenced by the mind. Again, if the seat of volition in the brain be diseased, the cord or part of it participates in the effects of the disease as far as regards voluntary actions. That it is not too much to ascribe such power to the pyramidal fibres appears reasonable, if we consider how the fibres of the corpus callosum, and perhaps other transverse commissures, so connect the hemispheres and other parts of the brain that the separate divisions of a double organ act harmoniously so as to excite but a single train of thought, or, conversely, that two impressions from one and the same source on a double sentient organ are perceived as single by the mind.

An objection to this explanation will readily be raised—namely, that the excitation of the anterior horn of the grey matter, in the way stated, does not explain the remarkable power which the will has of *limiting* its action to one or two, or a particular class of muscles. To this, however, it may be replied that there can be no reason for denying to the mind the faculty of concentrating its action upon a particular series of the elementary parts of the vesicular matter, or even upon one or more vesicles, if we admit that it can direct its influence to one or more individual fibres, as the advocates of the first and second hypotheses do. If, indeed, we admit the one, we must admit the other; for whether the primary excitation of a fibre take place in the encephalon or in the spinal cord, the part first affected must probably be one or more vesicles of grey matter.

The series of changes which would develope a sensation admits of the following explanation according to this hypothesis:—A stimulus applied to some part of the trunk or extremities is propagated by the sensitive nerves to the *posterior* horn of the grey matter of the spinal cord, and from the junction of this part with the brain, either through the direct continuity of the vesicular matter of the cord with that of the centre of sensation, by the olivary column, or through longitudinal commissural fibres, analogous to or even forming a part of the anterior pyramids, this is simultaneously affected. To this, likewise, it will be objected that the limitation of sensation is not sufficiently explained. But the reply is obvious; the *intensity* and *kind* of sensation depend upon the nature of the primary stimulus at the surface, the *extent* upon the number of fibres there stimulated. Wherever these fibres form their proper organic connection with the vesicular matter, that matter will participate in their change to an extent proportionate to the number of fibres stimulated, and with an intensity commensurate with the force of the primary stimulus. It is not necessary to the developement of sensation that the fibre stimulated should be implanted directly in the brain; if it be connected with this centre through the medium of vesicular matter or through commissural fibres, all the conditions necessary for the developement and propagation of nervous force would appear to be fulfilled. It must not be supposed, however, that in making this statement we mean to assign the spinal cord to be the *seat* of sensation; all we assert is, that the posterior horn of the grey matter, as being the part in which the sensitive roots are implanted, is the seat of physical change excited by the stimulus applied to the sensitive fibres, which change must be *perceived* by the mind before true sensation can be produced. In fine, by the union of the posterior horns of the spinal grey matter with the vesicular matter of the brain, they become a part of the centre of sensation so long as that union is unimpaired.*

This hypothesis offers an explanation of the hitherto unexplained phenomenon of impaired sensation on that side of the body which is opposite to the seat of cerebral lesion. If we regard the anterior pyramids as commissures between the sensitive as well as between the motor portions of the cerebro-spinal centre, it will be obvious that the posterior horns of the spinal grey matter on the right side will be associated with the left centre of sensation, and *vice versâ*.

And we gain, moreover, an explanation of the almost universal association of sensation with reflex or physical nervous actions. The excitor nerves of these actions being the same as the sensitive nerves, the impression conveyed by them is calculated at once to excite motion and sensation. The controlling influence of the will prevents many of the sensitive impressions made through the spinal cord from developing corresponding movements. And this controlling influence is best explained by this hypothesis, for as it admits no other motor nerves connected with the cord but those over which the will can exert an influence, it follows that such mental influence, if more powerful than the physical stimulus which the sentient nerves convey, may prevail over it and neutralize its force. On the other hand, under certain conditions of great physical excitation, (exalted polarity,) physical changes overcome

* In all discussions relative to *sensation* it should be kept in view that true sensation involves a mental act, namely, the *perception* of a physical impression, and of the concomitant physical change in the nervous matter.

mental stimuli, and the mind loses all control; this is the case in poisoning by strychnine, in tetanus, in convulsions.

The difference of structure of the anterior and posterior horns of the vesicular matter of the spinal cord may be appropriately referred to as indicating a difference in functions between these horns. The anterior horns contain large caudate vesicles of a remarkable and peculiar kind, containing a considerable quantity of pigmentary matter; the posterior horns resemble very much in structure the vesicular matter of the cerebral convolutions and of other parts of the cerebrum, and do not contain caudate vesicles, except near the base. Here, then, we find associated with the well-attested difference in the *functions* of the anterior and posterior roots, a striking difference in the *structure* of the anterior and posterior horns of the spinal grey matter in which they are respectively implanted.

We gain from this hypothesis that which neither of the others could supply, namely, an explanation of the influence of emotion on limbs paralysed to volition. Mental emotion excites a change in the brain, probably in that part which forms the upper and posterior portion of the mesocephale: this change is readily propagated to the spinal grey matter through the olivary columns, independently of the pyramidal fibres. The spinal grey matter being excited, the nerves implanted in it are stimulated, and motions are produced closely resembling those which the will can develope.

We have noticed that the will can control reflex or other physical nervous actions. When the influence of the will is suspended, reflex actions may be more easily excited. These facts admit of the most obvious explanation by the hypothesis under examination.

Some reflex actions are imperfectly controllable by the will; such as the contraction of the pupil, and the movement of deglutition at the isthmus faucium. This, however, cannot be cited as at all opposed to the view we are advocating; for there is nothing in this hypothesis repugnant to the idea that certain nerves may be connected in the nervous centres with masses of vesicular matter over which the will usually exercises little or no control, and which, perhaps, may have but a slight connection with the centre of volition through commissural fibres. Still, respecting the two actions abovementioned, it must be remarked that in deglutition the mental influence is not sufficient by itself: we cannot perfectly contract the fauces, if food or some other physical stimulus be not present; the double stimulus—physical, as of the food, and mental, the will—appears necessary for the perfect performance of this act. In the action of the pupil, the mental stimulus can only be brought to bear on the pupil, by directing it to another muscle at the same time, namely, the internal rectus muscle of the eyeball. When the eyeball is directed toward the nose, the pupil is usually simultaneously contracted.

A double stimulus, mental and physical, appears to be necessary to the perfect developement of many actions. This hypothesis offers a ready explanation of the way in which the two stimuli may combine to promote the same action. The mental stimulus acts directly on the vesicular matter, the physical is propagated to it by sensitive nerves; and thus both acting on the same region of vesicular matter excite the same motor nerves. We have already noticed how this takes place in deglutition at the isthmus faucium. In locomotion there can be no doubt that the double stimulus is in operation: the degree of contraction of the muscles of the lower extremities necessary to maintain the superincumbent weight is obtained by the physical stimulus of pressure against the soles of the feet, where the skin is peculiarly fitted for the reception of such a stimulus; but the movements of the limbs, and the harmonizing association of the muscular actions, are effected by mental influence. The pressure against the soles is felt, however, and the skin of the soles is known to be highly sensitive; and the same nerve-fibres which excite the sensation stimulate the vesicular matter in which the motor nerves are implanted. In many actions of familiar occurrence the voluntary effort is greatly enhanced by the simultaneous application of a physical stimulus to a part of the surface which is supplied with nerves from the same region of the cord. The horseman feels more secure when his legs are in close contact with the horse's flank. We gain a much firmer hold of an object which adapts itself well to the palmar surface of the hand, than of one which, although of no greater bulk, is yet so irregular in surface as not to allow of such intimate contact with the palm. Closure of the eyelids in winking is an action of similar kind, resulting from a physical stimulus, which in the perfect state of the cerebro-spinal centre produces sensation, and excites motion which is at once the result of the physical impression, and of the exercise of volition provoked by the sensation. Every one must be conscious that he exercises considerable control over the movements of his eyelids, and that it requires a great effort to prevent winking for a certain period. At length, however, the physical impression, arising from the contact of air with the conjunctiva, and the diminution of temperature from evaporation on the surface of that membrane, which at first caused but a slight sensation, produces *pain;* the physical stimulus overcomes the mental resistance, and causes contraction of the orbicular muscle. And it may be remarked further, that the closure of the lids by voluntary effort is much more powerful if a stimulus be applied at the same time to the conjunctival surface, than if left solely to the exercise of the will.

In the action just referred to, as well as in all other instances of reflex actions which the will can prevent, no satisfactory explanation of this controlling power of the mind can be given by Dr. Hall's hypothesis. Do the volitional fibres exceed in number the excito-motory? If this were admitted, then we could understand that an excito-motory act might be prevented by substituting a voluntary act for it; but, in the cases in question, the mind prevents action altogether, notwithstanding the exciting influence of the impression. The true explanation seems to be, that the mind can exert upon the vesicular matter a power which can prevent the exercise of that change, or neutralise the change, without which the motor fibres will not be affected by a physical stimulus.

Reflex actions are more manifest in some situations than others: thus, in cases of hemiplegia from diseased brain, they are generally very obvious in the lower extremity, but totally absent in the upper. This, the advocates of the excito-motory theory ascribe to a paucity of excito-motory fibres in the latter limb, and to a larger amount of them in the former. Or, it has been attributed to the greater and more enduring influence of shock upon that segment of the cord from which the nerves of the upper extremities arise, as nearer the seat of lesion, than upon the lumbar segment. But another explanation of this important fact may be offered, which is equally satisfactory, and more accordant with other phenomena. A certain *disposition of the nerves upon the tegumentary surface is as necessary for the developement of reflex actions as of sensations;* and these movements will be more or less easily manifested, according as this organization of the nerves on the surface is more or less perfect.

That disposition of the cutaneous nerves which renders the surface easily excitable by titillation seems most favourable to the developement of these actions. Hence, there is no place where they are more readily excited than in the lower extremities by stimulating the soles of the feet or the intervals between the toes, both of which situations are highly susceptible of titillation. At the isthmus faucium the slightest touch on the surface excites a movement of deglutition; and this touch, at the same time, produces a very peculiar sensation of tickling, quite distinct from that which may be excited at other parts of the pharynx, or mouth. When this part of the mucous membrane is in a state of irritation as an effect of coryza, this tickling sensation is present, and repeated acts of swallowing are provoked.

Two facts may be stated here, which illustrate the position above laid down respecting the necessity of a certain disposition of the nerves *on the tegumental surface*, for the developement of reflex actions. The first is one which has been noticed by Volkmann, and which I have repeatedly observed, namely, that in frogs, and other animals, reflex actions are readily excited by stimulating the feet; but irritating the posterior *roots* of the spinal nerves, which supply those parts, is not sufficient for this purpose. I have already remarked that in numerous experiments upon the posterior roots of the nerves movements have not been excited whilst they have been subjected to irritation, except when galvanism was employed, which, being diffused, affected the cord itself: the recorded statements of most modern experimenters agree in the main with this statement. The second fact is this: in the male frog the developement of a papillary structure on the skin of the thumb seems to have reference to the excitation of the physical power of the cord, to enable the animal to grasp the female without the necessity of a prolonged exercise of volition. Stimulating the fingers will scarcely produce reflex actions, but the slightest touch to the enlarged thumb will cause the animal to assume the attitude of grasping. If the papillæ be shaved off the thumb, its power of exciting these actions is instantly lost.

When the polarity of the cord is greatly excited by strychnine or other substances, or when tetanus exists, all parts of the surface are equally capable of exciting reflex actions. The least touch will cause them, not only in the limb touched, but in all that side of the trunk, or even throughout the whole body. So general is the excitation, that the least impression made on the peripheral extremity of a sensitive nerve in any part of the body is instantly converted into muscular spasm, more or less general. A slight current of air, in tetanus, is sufficient to excite general spasm. Müller remarks that, in such states of the cord, the reflex actions excited by stimulating the nerves themselves are much less than those produced by excitation of the surface.

The readiness with which a physical change, induced in one part of the centre, is propagated to others, whether above or below it, is due no doubt to the vesicular matter. An experiment made by Van Deen illustrates this statement. If, in an animal poisoned by strychnine, the cord be divided in its entire length along the median line, leaving only a slight bridge of grey matter, stimuli applied to any part of the surface will exhibit as extensive reactions as if the cord were entire. It is evident that the only medium of communication between the opposite halves must be the small portion of vesicular matter left undivided.

Impressions conveyed to the cord by the posterior roots of any of its nerves, may be reflected to the corresponding motor nerves, and cause movement, or may extend irregularly along the posterior horns of grey matter and stimulate the nerves implanted in them, and thus give rise to new sensations, which may be referred to other and even distant parts of the body or to new motions.

The hypothesis under consideration affords us an explanation, more satisfactory than any other, of the paralytic state of the sphincter ani in brain disease, already referred to, as well as in that of the spinal cord. This muscle is certainly chiefly under the influence of the will. In ordinary cases of diseased brain, where the lesion is confined to one side, the centre of volition is not sufficiently impaired to affect its influence upon the sphincter. In graver lesions, however, although the will may still continue to exert its control upon one side of the body, it loses its power over the sphincter, which is not excitable by any stimulus. In disease of the spinal cord, there is paralysis of the sphincters if the lesion involve a sufficient portion of the cord's substance, in whatever region of the cord it may exist. Even when the lesion is situate high up in the neck, or in the dorsal region, leaving the lumbar portion perfectly whole, the sphincter will nevertheless be paralysed. In the former instances, the centre of volition in the cranium is diseased; in the latter, the defect consists in the destruction of the communication of the brain with that portion of the cord in which the nerves of the sphincter muscle are implanted.

An examination of the action of the sphincter will show, as has been already noticed, that the anus is kept closed ordinarily by the passive contraction of the muscle itself; but that its active contractions are mainly excited by voluntary influence, allowance being made for some slight action which may be produced by the stimulus of sudden distension, as in other circular muscles. Now, as a stimulus to sentient nerves constitutes no necessary part of any of these actions, it is probable that the motor nerves of the sphincter have little or no connection with the sentient ones; and, consequently, that muscle is not usually excitable to contraction by a stimulus appled to a sentient surface. Hence, whenever the influence of the will upon the lumbar portion of the cord is suspended, this muscle ceases to act, whether a mental or a physical stimulus be exerted.

We have remarked before that all that is shown by Dr. Hall's experiments on the horse and on the turtle is that the spinal cord influenced the sphincter only whilst it was in a state of irritation consequent upon its division. There probably was no real reflex action at all, and the closure of the anus on the application of a stimulus was probably only *apparently* due to that cause, frequent contractions taking place in the muscle in effect of the irritated state of the cord.

On the same principle, animals will exhibit movements of voluntary character for some time after decapitation, the continued irritation of the cord acting as a stimulus. A bird thus treated will fly for some distance, and with considerable energy, and will flap its wings if the cut surface of the cord be irritated. A fly decapitated pursues its course for some way immediately after the removal of the head; and Walckenaer observed a singular fact respecting the *Cerceris ornata*, a wasp which attacks a bee that inhabits holes: "at the moment that the insect was forcing its way into the hole of the bee, Walckenaer decapitated it; notwithstanding which, it continued its motions, and, when turned round, endeavoured to resume its position and enter the hole."* The change in the vesicular matter of the ganglia necessary for the movements of the wasp in pursuit of its prey, had already been excited by a powerful stimulus of volition, which continued even after the removal of the centre from which it had emanated. Actions at first voluntary, which by frequent repetition become habitual and involuntary, are, no doubt, to be accounted for by the persistence of that condition of the vesicular matter which the will at first induced, and to which the frequency of repetition gives a character of permanence. Thus Habit is due, as it were, to the fixation of a certain state of vesicular matter—it is the conversion of a mental into a physical nervous action by frequent repetition.

So similar is the change which a physical stimulus can excite in the grey matter to that produced by the influence of the will, that, as has been often remarked, the actions excited in decapitated animals present a striking resemblance to the ordinary voluntary movements. When a certain portion of the skin is irritated, the animal pushes against the offending substance, as if trying to remove or displace it. If the anus be irritated, both legs are excited to action. It may also be observed, that the same motions follow the same irritations of the skin. If, in a frog, the seat of irritation be on the right side, the corresponding hind-foot will be raised, as if to remove the irritating cause. The exact resemblance of these to voluntary movements seems to admit of being explained only on the supposition that the same fibres are employed in the execution of both.

It must be kept in view, that, while this hypothesis rejects the class of sensori-volitional fibres which are supposed to pass with the spinal nerves along the cord into the brain, it admits the existence of only three orders of fibres implanted in the various segments of the cord, viz. those at once sensitive and excitor; those at once for voluntary and involuntary motion; and commissural fibres; of which the former only contribute to form the nerves. It must not be supposed, however, that it is intended by this hypothesis to assume that the intervention of *sensation* (*i.e.* the perception of an impression by the mind) is *necessary* for the production of those muscular actions which are excited by stimulation of the surface. No more is affirmed than that the same stimulus to the sensitive nerve which can and does excite a sensation, may *simultaneously*, but *independently*, cause a change in the vesicular matter which shall stimulate the motor nerves; and that this change is of the same kind as that which the will may excite, and affects the same motor nerves.

Lastly, this hypothesis involves the enunciation of a highly important proposition with reference to nervous centres. It is this: that all the centres which are connected to the brain by commissural fibres, are thereby submitted to, and brought into connection with, the mind, to an extent proportionate to the number of connecting fibres, so that voluntary impulses act upon them as part and parcel of the centre of volition; and sensitive impressions, in affecting them, affect the mind simultaneously.

In voluntary actions, then, it may be stated that, while the brain is the part primarily affected, the mental impulse is also directed to that portion of the cord upon which the required action depends.

In the developement of sensation the stimulus affects the posterior horns of the grey matter of the cord, which, from its commissural connection with the brain, is in reality a part of the sensorium. When the power of mental

* Quoted in Müller's Physiology, by Baly, vol. i. p. 787*, 2nd ed.

interference is removed, or kept under controul, physical actions develope themselves; being effected through the same nerves as those which volition influences or which sensitive impressions affect. The latter are, in such instances, the excitors of the former, no doubt through the vesicular matter in which they are implanted. These actions become most manifest when the connection of the brain with the spinal cord has been severed; and they occur in the most marked way in those situations where the cutaneous nerves are so organized as readily to respond to the application of a stimulus applied to the surface, or they become universal when the cord is in a state of general excitement.

The movements in locomotion and the maintenance of the various attitudes are effected through the ordinary channels of the physical and volitional actions; and the posterior columns of the cord, by their influence on the vesicular matter of the segments in which the nerves are implanted, co-ordinate and harmonize the complicated muscular actions of the limbs and the trunk under the controul of that portion of the encephalon which probably is devoted to that purpose. This power of co-ordination is probably mental, and intimately connected with the muscular sense.

Functions of the Encephalon. — It will be convenient first to examine the functions of those parts of the encephalon which in structure most nearly resemble the spinal cord.

Functions of the medulla oblongata, mesocephale, corpora striata, and optic thalami.— The medulla oblongata most nearly resembles the cord in form and structure, at the same time that it exhibits most marked and important differences from it. Its subdivisions form connections superiorly with other parts of the brain, namely, the mesocephale, corpora striata, and optic thalami. These connections are so intimate, that, however convenient it may be to the descriptive anatomist to describe these parts each by itself, it is impossible, in examining into their functions, to separate them completely. The functions of one part are so readily affected by a change in any or all of the others, that the effects of experiments are not limited only to the part operated upon, but affect or are affected by the rest. Thus, the olivary columns, which form the central and most essential part of the medulla oblongata, extend upwards through the mesocephale to the optic thalami; and the anterior pyramids form an intimate connection not only with the vesicular matter of the mesocephale, but, to a great extent, with that of the corpora striata. All these parts taken together, with the quadrigeminal tubercles, will be found to be the centre of the principal mental nervous actions, and of certain physical actions which are very essential to the integrity of the economy.

The office of the nerves which arise from this segment of the encephalon throws light upon its function. These nerves are partly destined for respiration, partly for deglutition, and partly also for acts of volition and sensation.

Destruction of the medulla oblongata is followed by the immediate cessation of the phenomena of respiration; and this takes place whether it be simply divided, or completely removed. When an animal is pithed, he falls down apparently senseless, and exhibiting only such convulsive movements as may be due to the irritation of the medulla by the section, or such reflex actions as may be excited by the application of a stimulus to some part of the trunk.

If, in an animal which breathes without a diaphragm, as in a bird or reptile, the spinal cord be gradually removed in successive portions, proceeding from below, up to within a short distance of the medulla oblongata, loss of motor and sensitive power takes place successively in the segments of the body with which the removed portions of the cord were connected. But the animal still retains its power of perceiving impressions made on those parts of the body which preserve their nervous connection with the medulla oblongata, and continues to exercise voluntary control over the movements of those parts. The movements of respiration go on, and deglutition is performed. The higher senses are unimpaired.*

These phenomena are sometimes observed in man—in such cases as that alluded to in a former page; where, from injury to the spinal cord in the neck, below the origin of the phrenic nerve, the patient appears as a living head with a dead trunk. The sensibility and motor power of the head are perfect; respiration goes on partially, and deglutition can be readily performed. The senses and the intellectual faculties remain for a time unimpaired.

Irritation of any part of the medulla oblongata excites convulsive movements in muscular parts which receive nerves from it, and, through the spinal cord, in the muscles of the trunk. Spasm of the glottis, difficulty of deglutition, irregular acts of breathing, result from irritation of the medulla oblongata; and, if the excitement be propagated to the cord, convulsions will become more or less general.

If a lesion affect one half of the medulla oblongata, does it produce convulsions or paralysis on the opposite side of the body? This question may be certainly answered in the affirmative, when the seat of the lesion is in the continuations of the columns of the medulla oblongata above the posterior margin of the pons. It is not so easily solved, however, when the disease is situate below the pons. The results of experiment on this subject are contradictory, owing probably to the extreme difficulty of limiting the injury inflicted to a portion of the medulla on one side; and those of Flourens are of no value for the decision of this question, as it appears that he injured chiefly the restiform bodies. Anatomy suggests that a lesion limited to either anterior pyramid would affect the *opposite* side of the trunk, for it is known that such an effect follows disease of the continuation of it in the mesocephale or crus cerebri; and that lesion limited to the posterior half of

* Flourens, p. 179.

the medulla on either side would affect the *same* side of the body, no decussation existing between the fibres of opposite restiform or posterior pyramidal bodies. The irritating or depressing influence of the lesion would probably be extended to the spinal grey matter of the same side.

That the medulla oblongata is the channel through which the operations of the brain are associated in voluntary actions with the spinal cord, is shewn by the fact that paralysis of all the muscles of the trunk follows the separation of the latter organ from the former. It seems not improbable that the centre of volition is connected with one of the gangliform bodies in which the columns of the medulla oblongata terminate above (the corpora striata), so that the column connected with each corpus striatum (the anterior pyramid) is well placed for conveying voluntary impulses downwards. When the cerebral hemispheres have been removed, as in Flourens' and in Magendie's experiments, the bird is thrown into a deep sleep, a state of stupefaction, and insensibility to surrounding objects. But as he can maintain his attitude, stand, walk when first propelled, fly if thrown into the air, it may be inferred that some degree at least of mental or volitional effort remains. Some of the animal's movements have the appearance of the exercise of will, although, doubtless, many of them are in a great degree excited by physical stimuli. I may instance, in particular, what I have noticed in my own repetition of Flourens' experiments, a peculiar movement of the head, as if the bird were trying to shake off some object which irritated the head, and a frequent opening and shutting the bill, with movements of deglutition. Hence there seems reason to believe that the will may be exercised independently of the cerebral convolutions and their fibres, and that, under all circumstances, it exerts a primary influence upon either or both of these gangliform bodies, more vigorous when aided and guided by the power of the cerebral hemispheres. The frequent paralysis of motion apart from sensation, when the upward continuations of the pyramidal fibres in the corpora striata are diseased, renders it extremely probable that these fibres are the media of connection between the brain and cord in voluntary actions.

The medulla oblongata is also the medium for the transmission of sensitive impressions from all the regions of the head, trunk, and extremities; and from its olivary columns at their upper and posterior part in the mesocephale being, as it were, the concourse of all the nerves of pure sense, it seems fair to assign these parts as the prime seat of those central impressions which are necessary for sensation. The reception of these impressions by the cerebral hemispheres is the stage immediately associated with mental perception. Perfect sensation, therefore, cannot take place without cerebral hemispheres. In a sensation excited in parts supplied by spinal nerves, the first central change is probably in the posterior horn of the vesicular matter of the cord; and the olivary column of the medulla oblongata is simultaneously affected, from its connection with the cord. The change in this latter part is then propagated to the cerebral hemispheres.

Thus much is suggested by anatomy, as regards the share which the medulla oblongata takes in the mechanism of sensitive impressions. Experiment affords us no aid in this intricate and difficult subject; neither does pathological anatomy: for the parts are so closely associated with each other, that any morbid state of one readily involves the others, so that it is almost impossible to find a morbid state of the parts devoted to sensation, apart from an affection of those more immediately concerned in motion.

The function of the restiform bodies is probably associated with that of the hemispheres of the cerebellum, and of the posterior columns of the spinal cord.

The experiments of Le Gallois and Flourens make it certain that the medulla oblongata is the centre of respiratory movements. The latter physiologist assigns as the "primum movens" of these acts all that portion of the medulla which extends from the filaments of origin of the vagus nerve to the tubercula quadrigemina, the former only inclusive. Destruction of this portion, in whole or in part, invariably impairs or destroys the respiratory actions, and a morbid state of it gives rise to irregular or excited movements of respiration. Sighing, yawning, coughing, are probably connected with excitation of this centre, either direct, or propagated to it from some sentient surface. It seems not improbable that a portion of the spinal cord as low down as the spinal accessory nerve goes, is associated with this centre in the respiratory movements.

This portion of the encephalon is also the centre of action in the movements of deglutition, through fibres of the glosso-pharyngeal and vagi nerves. A morbid state of it occasions difficulty, or even paralysis, of deglutition. Animals deprived of the cerebral hemispheres and cerebellum will preserve the power of swallowing food introduced within the grasp of the fauces, so long as the medulla oblongata continues uninjured. In fœtuses born without cerebral hemispheres, those actions are present which depend on the spinal cord and medulla oblongata; all the movements of respiration and deglutition are performed as well as in the perfect fœtus. Mr. Grainger's experiments shew that puppies deprived of the hemispheres of the brain can perform the movements of suction with considerable vigour, when the finger is introduced into the mouth;* and the remarkable fact of the adhesion of the fœtus of the kangaroo to the nipple within the pouch, no less than its respiratory movements, must, as this author remarks, be regarded as a most interesting display of the physical power of the medulla oblongata, while the rest of the brain is as yet undeveloped.

The actions of respiration and pharyngeal

* Loc. cit. pp. 80-1.

deglutition are, to a great extent, of the physical kind, being excited by impressions propagated from the periphery. In those of respiration, the ordinary exciting cause is probably, as Dr. Hall suggested, due to the chemical changes in the respired air which are effected in the lungs. These movements may be, to a certain extent, controlled by the will; but every one is conscious, from his own sensations, that after a time the physical stimulus is capable of conquering the restraining influence of the mind; a striking example of a mental stimulus giving way to a physical one, and illustrative of the doctrine that the same fibres are affected by both stimuli. The excitation of the medulla oblongata in respiration does not, however, depend solely upon the pulmonary nerves. Those of the skin are capable of exciting it, either directly as the fifth pair, or through the spinal cord, as is proved by the inspirations which are instantly excited by suddenly dashing cold water on the face or trunk.

In deglutition, the exciting cause is the stimulus of contact applied to the mucous membrane of the fauces. So highly sensitive is the mucous membrane in this situation, that the slightest touch of it with a feather is sufficient to produce contraction of the muscles of deglutition, which the will is scarcely able to control. Without this stimulus, it is doubtful whether these muscles would obey the will alone, and it seems probable that this part of the act of deglutition must be regarded as one of those actions referred to at a former page, which require a double stimulus, both mental and physical, for their full performance.

The medulla oblongata and its continuations in the mesocephale appear to be the centre of those actions which are influenced by emotion. The common excitement of movements of deglutition or respiration, or of sensations referred to the throat, under the influence of emotion, evidently points to this part of the cerebro-spinal centre as being very prone to obey such impulses; and as the nerves of pure sense, especially the optic and auditory, are very commonly the channels of sensitive impressions well calculated to arouse the feelings, it seems highly probable that the centre of such actions should be contiguous to the origin of these nerves. This office may be assigned to that region of the mesocephale which is in the vicinity of the quadrigeminal tubercles. It is not a little remarkable that the nerves which arise from this and the neighbouring parts are very readily influenced by emotions. Thus, the third and fourth pairs of nerves regulate the principal movements of the eyeballs, those especially which most quickly betray emotional excitement; and the portio dura of the seventh pair, the motor nerve of the face, is the medium through which changes of the countenance are effected. It may be added, that the centre of emotional actions ought to be so situated that it might readily communicate with the centres of all the voluntary actions of the body, and with the immediate seat of the intellectual operations, as well as with the nerves of pure sense; and no part possesses these relations so completely as that now under examination.

In those diseases which mental emotion is apt to give rise to, many of the symptoms are referable to affection of the medulla oblongata. In hysteria, the globus, or peculiar sense of suffocation or constriction about the fauces; in chorea, the difficulty of deglutition, the peculiar movement of the tongue, the excited state of the countenance, the difficulty of articulation, may be attributed to the exalted polarity of the centre of emotional actions. In hydrophobia this part is probably always affected, and frequently so in tetanus.

Certain gangliform bodies are connected with the upward continuations of the medulla oblongata, both in the brain and in the mesocephale, which doubtless have proper functions. These are the corpora striata, optic thalami, and quadrigeminal bodies.

Corpora striata.—The anatomy of the corpora striata and optic thalami, while it denotes a very intimate union between them, also shows so manifest a difference in their structural characters, that it cannot be doubted that they perform essentially different functions. In the corpora striata the fibrous matter is arranged in distinct fascicles of various sizes, many, if not all of which, form a special connection with its vesicular matter. In the optic thalami, on the other hand, the fibrous matter forms a very intricate interlacement, which is equally complicated at every part. Innumerable fibres pass from one to the other, and both are connected to the hemispheres by extensive radiations of fibrous matter. The corpora striata, however, are connected chiefly, if not solely, with the inferior fibrous layer of each crus cerebri; whilst the optic thalami are continuous with the superior part of each crus, which is situate above the locus niger.

It will be observed, then, that while these bodies possess, as a principal character in common, an extensive connection with the convoluted surface of the brain, they are, in the most marked way, connected inferiorly with separate and distinct portions of the medulla oblongata; the corpora striata with the inferior fibrous planes of the crura cerebri and their continuations, the anterior pyramids; and the optic thalami with the olivary columns, the central and probably fundamental portions of the medulla oblongata. This anatomical fact must be taken as an additional indication that these gangliform bodies perform separate functions.

Now, it may be inferred, from their connections with nerves chiefly of a sensitive kind, that the olivary columns, and the optic thalami, which are continuous with them, are chiefly concerned in the reception of sensitive impressions, which may principally have reference merely to informing the mind (so to speak), or partly to the excitation of motion, as in deglutition, respiration, &c. The posterior horns of the grey matter of the cord, either by their direct continuity with the olivary columns, or their union with these columns through commissural fibres, become part and parcel of a great centre of sensation, whether for mental or physical actions.

The pyramidal bodies evidently connect the grey matter of the cord (its anterior horns?) with the corpora striata; and not only these, but also the intervening masses of vesicular matter, such as the locus niger, and the vesicular matter of the pons, and of the olivary columns; and, supposing the corpora striata to be centres of volition in intimate connection with the convoluted surface of the brain by their numerous radiations, all these several parts are linked together for the common purposes of volition, and constitute a great centre of voluntary actions, amenable to the influence of the will at every point.

It has been pretty generally admitted by anatomists, that both the corpora striata and the anterior pyramids are concerned in voluntary movements. The motor tracts of Bell were regarded by that physiologist as passing upwards from the anterior columns of the cord to the corpora striata, and, after traversing those bodies, as diverging into the fibrous matter of the hemispheres; and the fact of the origin of certain motor nerves, in connection with those fibres, was considered to be very favourable to this view. The decussation of the pyramids, likewise, so illustrative of the cross influence of the brain in lesions sufficient to produce paralysis, has been looked upon as an additional indication of the motor influence of these parts.

The invariable occurrence of paralysis as the result of lesion, even of slight amount, in the corpora striata, must be regarded as a fact of strong import in reference to the motor functions of these bodies.

Nor is this fact at all incompatible with the statements made by all experimenters, that simple section of the corpus striatum does not occasion either marked paralysis or convulsion; and that in cutting away the different segments of the brain, beginning with the hemispheres, convulsions are not excited until the region of the mesocephale is involved. The influence of the corpora striata is not upon the nerves *directly*, but upon the segments of the medulla oblongata or of the spinal cord, and, through them, upon the nerves which arise from them. Were the nerve-fibres continued up into the corpora striata, according to an opinion which has been long prevalent, there would be no good reason for supposing that they should lose in the brain that excitability to physical stimuli which they are known to possess in the spinal cord, and at their peripheral distribution.

The latest experiments of this kind, which are those of Longet and Lafargue, agree in the following result, which is not at variance with that obtained by Flourens. The animals remain immoveable after the removal of the corpora striata, whether those bodies have been removed alone or in conjunction with the hemispheres; nor do they show any disposition to move, unless strongly excited by some external stimulus. None of these observers had noticed the irresistible tendency to rapid propulsion, which was described by Magendie. Removal of the corpus striatum of one side caused weakness of the opposite side.

In order to form a due estimate of these experiments, it must be borne in mind, that the effects of simple excision of either corpus striatum would be very different from those of disease of it. The depressing effects of the latter would be absent, at least, until some alteration in the process of nutrition had been set up in the mutilated parts. Simple excision of the centre of volition, and inflammatory disease of its substance, or an apoplectic clot, must produce essentially different effects;—the one simply cuts off the influence of the will, the other affects the vital action, and, consequently, the vital power of the centre, and of the commissural fibres connected with it.

Judging from structure only, it might be conjectured that the *locus niger*, that remarkable mass of vesicular matter which separates the anterior and posterior planes of each crus cerebri, exerts a motor influence. It resembles in structure the anterior horns of the grey matter of the cord, and contains numerous large caudate vesicles with very abundant pigment, and is the immediate centre of implantation of a very important motor nerve, the third pair, which regulates the movements of nearly all the muscles of the eyeball.

Optic thalami.—The same line of argument which leads us to view the corpora striata as the more essential parts of the nervous apparatus which controul direct voluntary movements, suggests that the optic thalami may be viewed as the principal foci of sensibility, without which the mind could not perceive the physical change resulting from a sensitive impression.

The principal anatomical fact which favours this conclusion is the connection of all the nerves of pure sense, more or less directly, with the optic thalami or with the olivary columns. The olfactory processes, which apparently have no connection with them, form, no doubt, through the fornix, such an union with them, as readily to bring them within the influence of the olfactory nerves.

According to this sense of its office we must regard the optic thalami as the upper and chief portions of an extended centre, of which the lower part is formed by the olivary columns, which we have already referred to as taking part in the mechanism of sensation. The continuity of the olivary columns with the optic thalami justifies this view: nor is it invalidated by the fact, that some of the nerves which arise from the medulla oblongata are motor in function; for Stilling's researches render it probable that these fibres have their origin in special accumulations of vesicular matter, which contain caudate vesicles of the same kind as those found in the anterior horns of the grey matter of the cord.

The results which experiments have yielded add little that is positive to our knowledge of the functions of these bodies. Flourens found that neither pricking nor cutting away the optic thalami by successive slices occasioned any muscular agitation, nor did it even induce contraction of the pupils. Longet found that removal of one optic thalamus in the rabbit was followed by paralysis on the opposite side of the body. It appears, however, that this was done after the removal of the hemisphere and corpus striatum, whereby the experiment was so complicated as to invalidate any conclusion that might be drawn from it respecting the function of the thalamus. Indeed, vivisections upon so complex an organ as the brain are ill-calculated to lead to useful or satisfactory results; but one does not hesitate to refer to such as have been made, because they afford a certain amount of negative information, imperfect though it be.

Nothing definitive respecting the proper office of the thalami can be obtained from pathological anatomy. Extensive disease of these bodies is attended with the same phenomena during life, as lesion of similar kind in the corpora striata. Hemiplegic paralysis accompanies both; nor does it appear that sensation is more impaired when the thalamus is diseased, than when the corpus striatum is affected.

There is nothing in the phenomena attendant on morbid states of the thalami which can be fairly regarded as opposed to the conclusion which their anatomical relations indicate, namely, that they form a principal part of the centre of sensation. The intimate connection between the striated bodies and the thalami sufficiently explains the paralysis of motion which follows disease of the latter; whilst, as the thalami do not constitute the *whole centre* of sensation, but only a part thereof, it cannot be expected that lesion of this *part* would destroy sensation, so long as the remainder of the centre on the same side, as well as that of the opposite side, retain their integrity. Complete paralysis of sensation on one side is very rare in diseased brain: a slight impairment of it frequently exists in the early periods of cerebral lesion, apparently as an effect of shock; for it quickly subsides, although the motor power may never return.

According to the views above expressed, the corpora striata and optic thalami bear to each other a relation analogous to that of the anterior to the posterior horn of the spinal grey matter. The corpora striata and anterior horns are centres of motion; the optic thalami and posterior horns, centres of sensation. The anterior pyramids connect the former; the olivary columns, and perhaps some fibres of the anterior pyramids, the latter. The olivary columns, however, are in great part continuations of the thalami on the one hand, and of the grey matter of the cord on the other; and contain abundance of vesicular matter, in which nerves are implanted.

And it must be admitted that the intimate connection of sensation and motion, whereby sensation becomes a frequent excitor of motion,—and voluntary motion is always, in a state of health, attended with sensation,—would *à priori* lead us to look for the respective centres of these two great faculties, not only in juxta-position, but in union at least as intimate as that which exists between the corpus striatum and optic thalamus, or between the anterior and the posterior horns of the spinal grey matter.

Saucerotte, Foville, Pinel Grandchamps, and others, advanced the opinion that the corpora striata and the fibrous substance of the anterior lobes of the brain had a special influence upon the motions of the lower extremities, and that the optic thalami and the fibrous substance of the middle and posterior part of the brain presided over the movements of the upper extremities. We find, however, but little to favour this theory either in the results of experiments, in pathological observation, or the anatomy of the parts. Longet states, that, in his experiments upon the optic thalami, the paralysis affected equally the anterior and the posterior extremities. Andral analysed seventy-five cases of cerebral lesion limited to the corpus striatum or optic thalamus. In twenty-three of these cases, the paralysis was confined to the upper extremity: of these, *eleven* were affected with lesion of the corpus striatum or of the anterior lobe; *ten* with lesion of the posterior lobe, or of the optic thalamus; and *two* with lesion of the middle lobe.* Hence it is plain that a diseased state of the corpus striatum is as apt to induce paralysis of the upper extremity as lesion of the thalamus; and we are forced to conclude, that pathological anatomy is not competent to decide the question. Lastly, the anatomy of these two bodies renders it highly improbable that they perform a function so similar, as that of directing the movements of particular limbs. The great size of the optic thalamus, its multitude of fibrous radiations, its extensive connections both in the medulla oblongata and in the hemispheres by means of commissural fibres, the marked difference of its structure from that of the corpus striatum, its connection more with the posterior horns of the spinal grey matter than with the anterior ones, and its intimate relation to nerves of sensation, are sufficient anatomical facts to warrant the opinion that the thalami must perform a function which, although it may be subservient to, or associated with, that of the striated bodies, is yet entirely dissimilar in kind.

It has been supposed that the corpora striata are special centres or ganglia to the olfactory nerves, and to the sense of smell. But such a supposition is altogether superfluous, inasmuch as a very distinct and obvious centre to these nerves exists in the olfactory process or lobe, miscalled *nerve* by descriptive anatomists. The small olfactory nerves are implanted in the anterior extremity or bulb of this process, which is provided with all the structural characters of a nervous centre, and contains a ventricle. This lobe, moreover, is always developed in the direct ratio of the size and number of the olfactory nerves, and of the developement of the sense of smell; and in the Cetacea, a class in which the olfactory nerves and process either do not exist at all, or are so imperfectly developed as to have

* Clin. Med. t. v.

escaped the notice of some of the ablest anatomists, the corpora striata are of good size proportionally to that of the entire brain.

Corpora quadrigemina.—The marked connection of these gangliform bodies with the optic nerves plainly indicates that they bear some special relation to those nerves, and to the sense of vision; and this indication becomes more certain when we learn, from comparative anatomy, that in all vertebrate tribes in which the encephalon is developed, special lobes exist, bearing a similar relation to the optic nerves. When the optic nerves are large, these lobes are large; and in the Pleuronecta, in which the eyes are of unequal size, Gottsche states that the optic lobes are unequal, and are related in size to each other, as the eyeballs are. Still, as Serres has remarked, the quadrigeminal tubercles probably perform some other office besides that which refers to vision; inasmuch as the absence, or extremely diminutive size, of the optic nerves in some animals (the mole for instance) does not materially affect that of these bodies.*

Flourens found that destruction of either of these tubercles on one side was followed by loss of sight of the opposite side, and consequently that the removal of both deprived the animal altogether of the power of vision, but did not affect its locomotive or intellectual powers, nor its sensibility, except to light. In these experiments the action of the iris was not impaired if the tubercles were only partially removed; as long as any portion of the roots of the optic nerves remained uninjured, the iris continued to respond to the stimulus of light, but the total removal of the tubercles paralysed the irides. If the lobes of the brain and cerebellum were removed, leaving the tubercles untouched, the irides would continue to contract. These experiments leave no room to doubt that the optic tubercles are the encephalic recipients of the impressions necessary to vision, which doubtless are simultaneously felt by means of the optic thalami; and that they are the centres of those movements of the iris which contribute largely not only to protect the retina, but likewise to increase the perfection of vision. The optic nerve is at once the nerve of vision, and the excitor of motor impulses which are conveyed to the iris by the third nerve, which takes its origin very near to the optic tubercles. It is interesting to add, that irritation of an optic tubercle on one side causes contraction of both irides:—this is quite in accordance with the well-established fact, that, if light be admitted to one eye so as to cause contraction of its pupil, the other pupil will contract at the same time. So simultaneous is the action of the two centres; so rapid must be the transmission of the stimulus from one side to the other.

When the injuries inflicted on these tubercles were deep, more or less general convulsive movements were produced; if one tubercle were injured, the opposite side only was so affected. These convulsions were due to the lesion of the central parts of the medulla oblongata, with which the optic tubercles are intimately connected. A remarkable vertiginous movement was likewise caused, the animal turning to the side from which the tubercle had been removed. It does not appear that this rotation could be attributed to any special influence of the medulla oblongata, but rather to a state of vertigo induced by the partial destruction of vision; for Flourens found that the same effects could be produced in pigeons by blindfolding one eye. The movements, however, were not so rapid, nor did they continue so long. And Longet saw the same movements in pigeons in which he had evacuated the humours of one eye.*

It may be remarked, that deep injuries to the quadrigeminal tubercles are very likely to affect the only commissural connection between the cerebrum and cerebellum *(processus cerebelli ad testes)*, the integrity of which must doubtless be essentially necessary to ensure harmony of action between these two great nervous centres.

There are many instances on record in which blindness was coincident with pathological alteration of structure in one or both quadrigeminal tubercles. In some of the cases where the lesion extended to parts seated beneath the tubercles, disturbed movements were observed, as in the experiments above related.

We are ignorant of the object of the extensive connections of the optic tracts with the tuber cinereum, the crura cerebri, and the corpora geniculata; but these points are highly worthy of future inquiry, especially with reference to the office of these last-named bodies, which is at present involved in much obscurity. Many of the fibres of the optic tracts are undoubtedly commissural between the corresponding points of opposite sides, and exist when those which form the optic nerves are deficient.

We see, then, in the quadrigeminal tubercles, centres, which, whatever other functions they may perform, have a sufficiently obvious relation to the optic nerves, the eye, and the sense of vision. This is clearly indicated by anatomical facts, especially by those of comparative anatomy, by the results of experiment, and by the phenomena of disease. These bodies may, therefore, be justly reckoned as special ganglia of vision; and we are led to seek for similar centres in connection with the other senses. The olfactory processes seem very probably to perform a similar office in reference to the sense of smell. Their structure, their relation to the olfactory nerves, and their direct proportion of bulk to that of these nerves, and to the developement of the olfactory apparatus, place this question beyond all doubt. It is not so easy to determine the special ganglia of hearing; but the olivary *bodies*, or the small lobules connected with the crura cerebelli called by Reil *the flocks*, may be referred to as bearing a sufficient close anatomical relation to the

* Vid. OPTIC NERVES.

* Flourens' experiments have been amply confirmed by those of Hertwig and Longet.

auditory nerve to justify our regarding either of them as well calculated to perform this function. And, with respect to touch, the ganglia on the posterior roots of the spinal and the fifth nerves may perhaps be considered in the same light; for this sense being diffused so universally, in various degrees, over the whole surface of the body, and being seated in a great number of different nerves, would need ganglia in connection with all those nerves which are adapted to the reception of tactile impressions. The analogous sense of taste has its ganglia in those of the glosso-pharyngeal and the fifth.*

The upper and posterior part of the mesocephale has already been referred to, as being most probably that part of the brain which is most directly influenced by emotional excitement. Dr. Carpenter appears to localize the seat of emotional influence more specially in the corpora quadrigemina, and refers to certain fibres, which he considers terminate in those bodies, as channels of emotional impulses. Although I am compelled to differ from this able writer in this limitation of the centre of emotion (so to speak), and am far from admitting the existence of a distinct series of fibres for emotional acts, I nevertheless think that the arguments he advances are most applicable to that view which refers the influence of emotion to the grey matter of this entire region, which is brought into connection with the spinal cord by the fibres of the anterior pyramids, as well as probably through the continuity of the olivary columns and the posterior horns of the spinal grey matter.

Every one has experienced in his own person how the emotions of the mind, whether excited by a passing thought, or through the external senses, may occasion not only involuntary movements, but subjective sensations. The thrill which is felt throughout the entire frame when a feeling of horror or of joy is excited, or the involuntary shudder which the idea of imminent danger or of some serious hazard gives rise to, are phenomena of sensation and motion excited by emotion. The nerves which take their origin from the medulla oblongata, mesocephale, or crura cerebri, are especially apt to be affected by emotions. The choking sensation which accompanies grief is entirely referable to the pharyngeal branches of the glosso-pharyngeal and vagi nerves, which come from the olivary columns. The flow of tears which the sudden occurrence of joy or sorrow is apt to induce may be attributed to the influence of the fifth nerve, which is also implanted in the olivary columns, upon the lachrymal gland; or of the fourth nerve, which anastomoses with the lachrymal branch of the fifth. The more violent expressions of grief, sobbing, crying, denote an excited state of the whole centre of emotion, involving all the nerves which have connection with it, the portio dura, the fifth, the vagus, and glosso-pharyngeal; and even the respiratory nerves, which take their origin from the spinal cord, as the phrenic, spinal accessory, &c. And laughter, "holding both his sides," causes an analogous excitation of the same parts of the central organ and of the same nerves. The very different effect produced by the excitement of the same parts must be attributed to the different nature of the mental stimulus.

As the passing thought—the change wrought during the exercise of the intellect—may excite the centre of emotion, so this latter may exert its influence upon the general tenor of the mind, and give to all our thoughts the tinge of mirth or sadness, of hope or despondency, as one or the other may prevail. We say of one man, that he is constitutionally morose; of a second, that he is naturally gay and mirthful; and of a third, that he is a nervous man, and that he is never likely to be otherwise. One man allows his feelings to hurry him on to actions which his intellect condemns; whilst another has no difficulty in keeping all his feelings in entire subjection to his judgment. "Of two individuals with differently constituted minds," remarks Dr. Carpenter, "one shall judge of everything through the medium of a gloomy morose temper, which, like a darkened glass, represents to his judgment the whole world in league to injure him; and all his determinations, being based upon this erroneous view, exhibit the indications of it in his actions, which are themselves, nevertheless, of an entirely voluntary character. On the other hand, a person of a cheerful, benevolent disposition, looks at the world around as through a Claude-Lorraine glass, seeing everything in its brightest and sunniest aspect, and, with intellectual faculties precisely similar to those of the former individual, he will come to opposite conclusions: because the materials which form the basis of his judgment are submitted to it in a very different form."* Such examples abundantly illustrate the important share which the emotions take in the formation and developement of character, and how all things presented to the mind through the senses may take their hue from the prevailing state of the feelings. If a certain part of the brain be associated with emotion, it is plain that that part must be in intimate connection with the seat of change in the operations of the intellect, in order that each may affect the other; that the former may prompt the latter, or the latter excite or hold in check the former. And this association of the emotions with a certain portion of the brain explains the influence of natural temperament, and of varying states of the physical health, upon the moral and intellectual condition of individuals. We may gather from it how necessary it is to a well-regulated mind that we should attend not to mental culture only,

* It may be urged against this conjecture respecting the functions of the ganglia of the spinal nerves and the fifth, that the analogy between these bodies and the quadrigeminal tubercles is incomplete, inasmuch as the optic nerves are probably *implanted* in the latter, but the nerves of touch merely *pass through* the former. But, in truth, we know so little of the positive relation of the nerves in question to the ganglia, that no argument, either for or against the above view, can rest upon such imperfect information.

* Carpenter's Physiology.

but to the vigour and health of the body also; that to ensure the full developement of the *mens sana* we must secure the possession of the *corpus sanum*.

Certain diseases are evidently associated with disturbed or excited states of emotion. In such cases, the nerves most affected are those connected with the mesocephale and medulla oblongata, denoting an excited state of these portions of the encephalon. Of these diseases the most remarkable are *hysteria* and *chorea;* both of which may be induced either by a cause acting primarily upon the mind, or by functional disturbance of the body, as deranged assimilation, in persons of a certain character of constitution. In hysteria, the globus, the tendency to cry or laugh, the disturbed breathing, the variously deranged state of the respiratory acts, all denote affection of most, if not all, the nerves coming from these segments. In chorea the frequent movements of the face and eyes, the peculiar and very characteristic mode of protruding the tongue, the impaired power of articulation, are dependent on an altered state of that part in which the portio dura of the seventh pair, the third, fourth, and sixth, and the ninth nerves are implanted. In both diseases the principal central disturbance is in the mesocephale; and this may be caused either by the direct influence of the mind upon it, or by the propagation of a state of irritation to it from some part of the periphery. Chorea, even of the most violent and general kind, is very commonly produced by sudden fright; and it is well known how frequently mental anxiety or excitement developes the paroxysm of hysteria.

There is no part of the cerebro-spinal centre which appears to exercise such extensive sway over the movements and sensations of the body as this portion, *the mesocephale*, which may be regarded as the centre of emotional actions. Its influence extends upwards to the cerebral convolutions—backwards to the cerebellum—downwards to all the nerves of sensation and motion. Through its connection with the posterior horns of the spinal grey matter, it can excite the sensitive as well as the motor nerves of the trunk. Hence it is not to be wondered at that a highly disturbed state of this centre is capable of deranging all the sensitive as well as motor phenomena of the body and even the intellect. Hence we may explain the extraordinary movements in hydrophobia and general chorea, in both of which diseases this part of the nervous centre is doubtless affected. It has often been remarked how much more powerful are the voluntary actions when prompted by some strong emotion, than when excited only by an effort of the will. Rage, or despair, is able to magnify the power of the muscles to an incalculable degree. This may be due to the increased stimulus derived from the influence of the centre of emotion being conjoined with that of the centre of volition.

The intimate connection of the olivary columns with the grey matter of the cord, and through that with all the roots of the spinal nerves, illustrates the power of emotional changes upon the organic processes. How often does the state of the feelings influence the quantity and quality of the secretions, no doubt through the power of the nerves over the capillary circulation! Blushing is produced through an affection of the mind, acting primarily on the centre of emotion, and through it on the nerves, which are distributed to the capillary vessels of the skin of the face.

The sexual passion must be ranked among the mental emotions. Like them, it may be excited and ministered to by a certain line of thought, or by particular physical states of the sexual organs. It seems, therefore, more correct to refer this emotion to the common centre of all, than to a special organ—according to Gall's theory; and it may be remarked, that great developement of this part of the brain is just as likely to produce great width of cranium in the occipital region as a large cerebellum.

Of the functions of the cerebellum.—All anatomists are agreed in admitting, in the whole vertebrate series, (the amphioxus, perhaps, excepted,*) the existence of a portion of the encephalon which is analogous to the cerebellum. This extensive existence of such an organ indicates its great physiological importance, as a special element of the encephalon. The cerebellum exhibits much difference both as regards size and complexity of structure in the different classes; and although, upon the whole, it increases in its developement in the same ratio as the hemispheric lobes, it exhibits no constant relation of size to those parts.

The large size and complicated structure of this organ in the higher vertebrate animals, and its distinctness from the cerebrum,—for its commissural connection with that segment of the encephalon is not extensive,—have excited the interest and curiosity of speculative physiologists; and, accordingly, we find no part respecting which a greater variety of hypotheses have been suggested, most of them being entirely devoid of foundation. The experiments of Flourens have, however, thrown more light on this subject than any previous observations; and his hypothesis appears nearer the truth than any which has been proposed.

The facility with which the cerebellum may be removed or injured, especially in birds, without involving the other segments of the brain, renders it a much more favourable object for direct experiment than them. A skilful operator may remove the greater part or the whole of the cerebellum without inflicting any injury on the hemispheres or other parts.

Flourens removed the cerebellum from pigeons by successive slices. During the removal of the superficial layers there appeared only a slight feebleness and want of harmony in the movements, without any expression of pain. On reaching the middle layers an almost universal agitation was manifested, without any sign of convulsion: the animal performed rapid and ill-regulated movements; it could hear and

* The observations of Quatrefages render it doubtful that even the amphioxus can be regarded as forming an exception. Ann. des Sc. Nat., 1846.

see. After the removal of the deepest layers, the animal lost completely the power of standing, walking, leaping, or flying. The power had been injured by the previous mutilations, but now it was completely gone. When placed upon his back, he was unable to rise. He did not, however, remain quiet and motionless, as pigeons deprived of the cerebral hemispheres do; but evinced an incessant restlessness, and an inability to accomplish any regular or definite movement. He could see the instrument raised to threaten him with a blow, and would make a thousand contortions to avoid it, but did not escape. Volition and sensation remained; the power of executing movements remained; but that of coordinating those movements into regular and combined actions was lost.

Animals deprived of the cerebellum are in a condition very similar to that of a drunken man, so far as relates to their power of locomotion. They are unable to produce that combination of action in different sets of muscles which is necessary to enable them to assume or maintain any attitudes. They cannot stand still for a moment; and, in attempting to walk, their gait is unsteady, they totter from side to side, and their progress is interrupted by frequent falls. The fruitless attempts which they make to stand or walk are sufficient proof that a certain degree of intelligence remains, and that voluntary power continues to be enjoyed.

Rolando had, previously to Flourens, observed effects of a similar nature consequent upon mutilation of the cerebellum. In none of his experiments was sensibility affected. The animal could see, but was unable to execute any of the movements necessary for locomotion.

Flourens' experiments have been confirmed by those of Hertwig in every particular, and they have been lately repeated with similar results by Budge and by Longet. The removal of part of the cerebellum appears capable of producing the same vertiginous affection which has been already noticed in the case of deep injuries to the mesocephale. After the well-known experiments of Magendie, of dividing either crus cerebelli, the animal was seen to roll over on its long axis towards the side on which the injury was inflicted.

The effects of injuries to the cerebellum, according to the reports of the experimenters above referred to, contrast in a very striking manner with those of the much more severe operation of removing the cerebral hemispheres. "Take two pigeons," says M. Longet; "from one remove completely the cerebral lobes, and from the other only half the cerebellum; the next day, the first will be firm upon his feet, the second will exhibit the unsteady and uncertain gait of drunkenness."

Experiment, then, appears strikingly to favour the conclusion which Flourens has drawn, namely, that the cerebellum possesses the power of coordinating the voluntary movements which originate in other parts of the cerebro-spinal centre, whether these movements have reference to locomotion or to other objects.

That this power is mental, *i. e.* dependent on a mental operation for its excitation and exercise, is rendered probable from the experience of our own sensations, and from the fact that the perfection of it requires practice. The voluntary movements of a new-born infant, although perfectly controllable by the will, are far from being coordinate: they are, on the contrary, remarkable for their vagueness and want of definition. Yet all the parts of the cerebro-spinal centre are well developed, except the cerebellum and the convolutions of the cerebrum. Now, the power of coordination improves earlier and more rapidly than the intellectual faculties; and we find, in accordance with Flourens' theory, that the cerebellum reaches its perfect developement of form and structure at a much earlier period than the hemispheres of the cerebrum.

It may be stated as favourable to this view of the mental nature of the power by which voluntary movements are coordinated, that, in the first moments of life, provision is made for the perfect performance of all those acts which are of the physical kind. Thus, respiration and deglutition are as perfect in the new-born infant as in the full-grown man; and the excitability of the nervous centres to physical impressions is much greater at the early age, partly perhaps in consequence of the little interference which is received at that period from the will.

That the cerebellum is an organ favourably disposed for regulating and coordinating all the voluntary movements of the frame is very apparent from anatomical facts. No other part of the encephalon has such extensive connections with the cerebro-spinal axis. It is connected slightly indeed with the hemispheres of the brain, by the processus cerebelli ad testes, but most extensively with the mesocephale, the medulla oblongata, and the spinal cord. Now it is not unworthy of notice that its connection with the brain proper is more immediately with that part, which may be regarded as the centre of sensation; namely, with the optic thalami. This connection of the cerebellum with the centre of sensation may probably have for its object to bring the muscular sense to bear upon the coordination of movements, in which the individual experience of every one shows that that sense must materially assist.

The cerebellum is brought into union with each segment of the great nervous centre upon which all the movements and sensations of the body depend; through the restiform bodies it is connected with the medulla oblongata and the spinal cord; by the fibres of the pons with the mesocephale, and thus with the anterior pyramids and corpora striata; and through the processus e cerebello ad testes with the optic thalami. What can be the object of these extensive connections? It would be difficult to conceive any function for which so elaborate a provision would be more necessary, than that of regulating and coordinating the infinitely complex movements which the muscular system is capable of effecting; more especially when it seems highly probable that the antero-lateral columns of the cord, and the anterior pyramids and olivary columns supply all the anatomical conditions necessary for the developement of acts of sensation and volition.

It thus appears that Flourens' views respecting the office of the cerebellum derive considerable support both from experiment and from anatomy. When we come to collect the evidence on this subject which has been furnished by the effects of disease, we obtain very little information of a satisfactory kind. A superficial lesion of either cerebellar hemisphere or of the median lobe does not cause paralysis, but may produce delirium or convulsions, as a superficial lesion of either cerebral hemisphere may; but a deep-seated lesion of the cerebellum involving the central white substance which is continued from the crus cerebelli causes hemiplegia on the opposite side. This similarity between the effects of cerebellar and of cerebral disease is a remarkable and highly interesting fact, but one which considerably increases the difficulty of obtaining from pathological phenomena any contribution to the solution of physiological questions. It may be explained thus:—the transverse fibres of the pons passing through the mesocephale would propagate to this segment the morbid influence of any deep-seated lesion of the cerebellum, and thus affect the adjacent pyramid, which again would affect the opposite half of the body just as if the morbid influence originated in the cerebral hemisphere. It is, then, this secondary affection of either pyramidal body which obscures the proper signs referable to cerebellar lesion.

A few cases, however, have been put on record, in which a tottering gait, like that of a drunken man, and a defective power of coordination existed in connection with a diseased state of cerebellum. A striking instance of this occurred under my own observation: a young surgeon, who had recently received an appointment in the medical service of the army, was in attendance in the military hospitals at Chatham, preparatory to his nomination to a regiment. It was observed that as he walked he staggered to so great a degree that he was suspected of drinking to excess, and was put under arrest on this account. It was soon, however, found that he was suffering under symptoms of diseased brain, and he was sent up to town and placed under my care. I found that his principal symptom was extreme difficulty in the coordination of his movements, accompanied by a sense of giddiness in the head. He could neither stand nor walk, yet there was no distinct paralysis, for while he was in the recumbent posture he could move about his limbs freely. After a time he became amaurotic and comatose. The post-mortem examination revealed softening of the left crus cerebri and a patch of yellow softening on the corresponding restiform body: there was in addition a recent deposit of lymph at the base of the brain around the optic commissure.

I must now notice two other hypotheses as to the office of the cerebellum; the first is that of Foville; the second that of Gall. Foville supposed that the cerebellum is the centre of sensation, "the focus of sensibility." The objections which appear fatal to this hypothesis are derived from anatomy and from pathological observation. The cerebellum wants that general connection with *sentient nerves*, (direct as well as indirect,) which might be expected if it performed the office in question. Not one of the nerves of pure sense has any connection with it. Moreover the diseased states of cerebellum do not give rise to any privation of sensibility such as might be expected where the centre of sensation was the part involved.

The most celebrated view of the office of the cerebellum is that put forward by the distinguished Gall. He supposed that the instinct of propagation has its seat in this organ, and therefore referred to it as the source of all sexual and generative impulses.

Gall's view rests on two assumptions; first, that the instinct of generation or of reproduction is "the most indispensable and most powerful of all the instincts;" and, secondly, that great width of the occipital region of the skull and thickness of the back of the neck indicate great developement of the cerebellum.

It is by reason of the assumed transcendant importance of the generative instinct that so large a portion of the encephalic mass (an eighth or ninth part of the whole) has been assigned by Gall to exercise an exclusive influence over it.

This first position taken by Gall seems to me untenable. Can we separate the sexual instinct from the emotions, from those especially which are clearly instinctive in their nature? I apprehend not. The same part of the brain would probably exercise its influence upon all the emotional actions. But even if the sexual instinct were separable from the other instincts, it seems very questionable whether it is of that paramount importance as to need a separate organ of great magnitude, of complex structure, and of extensive connections with the rest of the cerebro-spinal centre. If we compare it with the instinct of self-preservation, as manifested in providing either for the wants of the body or for defence against assault, it certainly cannot be admitted to have a superior influence to this the most pressing of all. Yet, even to this instinct, a separate seat has not been assigned in the brain.*

The second position which Gall assumes,

* This argument was used, nearly *totidem verbis*, in Mr. Bowman's and my Physiology in discussing this subject. It and other objections to Gall's doctrine, which we made, have been criticised by Mr. Noble, of Manchester, a most zealous phrenologist, who, like many of that school, is impatient of the slowness of belief of those who do not completely embrace the opinions which he advocates. Mr. Noble seems to think that the existence of a surmise of Spurzheim's, of a single recorded observation of Dr. A. Combe, which led him to *suggest* that a certain large convolution, seen by him in the brain of a lady who had great *fear of death*, who evinced "perpetual anxiety about her own *death*," should be assigned as the seat of a faculty to be called "*love of life*," and some observations of Dr. Vimont, which Mr. Noble does not value so much as the *single* observation

and which is certainly necessary to the validity of some of the premises upon which his doctrine rests, is, I think, likewise open to strong objection. I cannot understand that great width of the occipital region and thickness of the back of the neck should necessarily indicate a great developement of the cerebellum. I do not mean to assert that a large cerebellum would not give rise to a large occipital region, but I do assert that great developement of the mesocephale may give rise to the very same external indications. This latter segment of the encephalon is of considerable size, and, as I have shown in a former part of this article, of complex anatomical structure, and contains all the elements of a distinct centre, while it possesses extensive connections with the cerebral hemispheres, the cerebellum, and the medulla oblongata. The largest portion of it, however, is independent of the cerebellum, and it is this portion which contains the greatest abundance of vesicular matter, and which has most distinctly the characters of a separate centre of nervous influence. Now the position of the mesochephale, in front of and between the hemispheres of the cerebellum, is such that a great developement of it would push the hemispheres to each side, and thus, notwithstanding a small size of the hemispheres themselves, the occipital region would become expanded.

The great and pre-eminent size of the cerebellum in the human subject would warrant the belief that the sexual instinct in man far exceeded that of other animals, if Gall's doctrine were correct. Yet this seems by no means to be the case; for, although in man this instinct is more frequently in operation, it cannot be said to influence the whole system to the same extent as in many of the inferior animals. Surely this instinct is not more powerful in man than in the feline class, both male and female;—the common cat, for instance, in which the lateral lobes of the cerebellum are very imperfectly developed! There are other animals, likewise, peculiarly distinguished by the strength of this instinct and the remarkable extent to which it influences their entire functions. I have already referred to the extraordinary state of polar tension to which the spinal cord of the male frog, or a portion of it, is liable during the state of sexual excitement. Yet in this animal the cerebellum is very small; nor does it at this period acquire any increase of size; and, moreover, there is no appreciable difference between the cerebellum of the male frog and that of the female, which exhibits no indication of increased excitement at this period. In fishes the instinct is in all probability strong; and the generative impulse, unaided as it is by sexual commerce, would seem to be dependent, more than in cases where copulation occurs, on the change which may take place in the nervous centre in accordance with the manifestation of that instinct; yet the cerebellum is by no means large in these animals. Dr. Carpenter refers to the kangaroo as affording a good instance of disproportionate developement of the cerebellum to the generative instinct. He says, " a friend who kept some kangaroos in his garden, informed the author that they were the most salacious animals he ever saw, yet their cerebellum is one of the smallest to be found in the class (Mammalia). Every one knows, again, the salacity of monkeys; there are many which are excited to violent demonstrations, by the sight even of a human female; and there are few which do not practise masturbation when kept in solitary confinement; yet in them the cerebellum is much smaller than in man, in whom the sexual impulse is much less violent."

According to Gall and most of his followers mutilation of the genital organs or their decay in the advance of age is attended by marked effects on the cerebellum. If one testicle be destroyed, a distinct diminution, according to Gall, takes place subsequently in the cerebellar hemisphere of the opposite side. The kind of evidence upon which phrenologists rest their views of this matter will appear from the following specimens: 1. Dr. Gall relates that at Vienna he was consulted by two officers who had become impotent in consequence of blows from fire-arms, which had grazed the napes of their necks. 2. " Baron Larrey," says Gall, "sent to me a soldier who, in undergoing an operation for hernia, had lost the right testicle. Several years afterwards his right eye became weak. He began to squint with the diseased eye, and could scarcely any longer distinguish objects with this eye. I examined the nape of his neck, in presence of the two physicians who had brought him, and I found *the occipital swelling of the left side much less prominent* than that of the right side. The difference was so perceptible that the two physicians were struck with it at first sight." 3. Baron Larrey's cases:—*a*. An artilleryman received a wound from a musket-ball, which traversed from side to side the insertions of the extensor muscles of the head, grazing and dividing the two inferior occipital swellings which correspond to the hemispheres of the cerebellum. This individual experienced *a diminution in the size of his testicles, which fell into a state of atrophy*. *b*. A light horseman, of very amorous disposition, received a sword-cut, which divided the skin and all the convex portion of the occipital bone through to the dura mater. The right lobe of the cerebellum was seen through the opening of the dura mater, and the slightest pressure upon this organ

of Dr. Combe, justify him in charging us with ignorance in making this assertion. Mr. Noble likewise dignifies our argument with the title of " nonsense." I am content to repeat the argument and to leave it to persons of calmer judgment to decide whether it is of sufficient weight. Mr. Noble has been so courteous and so complimentary in his remarks generally, that I cannot allow myself to believe that he *intended* offence by the use of this term. I hope, however, that he will excuse me for observing that it is much to be regretted that the advocates of particular views should allow their zeal so far to outrun their judgment as to lead them, in the sober seriousness of print, to make use of terms which they would hardly venture upon in the less premeditated colloquial argument.—See Noble on the Brain, p. 142.

caused giddiness, fainting, and convulsive movements. The patient loses sight and hearing of the right side, experiences acute pain in the course of the dorsal spine, and *tingling in the testes, which in fifteen days were reduced to the size of a bean.* The patient dies of tetanus, with loss of the functions of sight, hearing, and generation.* On dissection there was great loss of substance at the occiput, *the medulla oblongata and upper part of the spinal cord were of dull white, of firmer consistence, and reduced in size one-fourth.* The nerves arising from these parts were likewise wasted. *c.* A chasseur received a sabre cut, which divided the skin and *external protuberance of the occipital bone,* and the extensor muscles of the head *as low down as the sixth vertebra.* This man gets well, but Larrey states that he declares "that he has been deprived of his generative powers ever since that wound." 4. Gall caused rabbits to be castrated, some on the right side and others on the left. Having had them killed six or eight months afterwards, he finds diminution of the cerebellar lobe opposite the removed testicle, and flattening of the corresponding occipital swelling. Vimont, however, found no diminution of the opposite lobe of the cerebellum in four rabbits on which castration had been effected on one side, and which had been kept *eight* months; but in four other rabbits, similarly treated, but kept *eighteen* months, a very perceptible diminution in the opposite lobe of the cerebellum was found.†

The results of mutilation of the generative organs, as obtained by the researches of M. Leuret, are far from being favourable to Gall's theory. M. Leuret took the weight of the cerebellum both absolutely, and, as compared with that of the cerebrum, in ten stallions, twelve mares, and twenty-one geldings. The following table shows the results of the absolute weights.

	Average.		Highest.		Lowest.
Stallions..	61	..	65	..	56
Mares....	61	..	66	..	58
Geldings..	70	..	76	..	64

Thus the remarkable result is obtained, that castration tends to augment the weight of the cerebellum, and not to reduce it, as Gall and his followers affirm.

What is further very remarkable in these researches is that the *cerebrum* in geldings is on the average less in weight than that in stallions; and the fact gives great confirmation to the results of weighing the cerebella, rendering it in the highest degree improbable that the excess of weight in the cerebellum was accidental.

The general expression of the facts obtained by Leuret is this, that in horses, mutilated as regards the principal generative organs, the cerebellum is heavier than in horses and mares not mutilated in the generative organ; and he compared twenty-one of the former with twenty-two of the latter.

* I apprehend the loss of the generative function is not uncommon in tetanus!

† Quoted from Mr. Noble on the brain.

Compare these observations with those above quoted from Gall by Mr. Noble, a most ardent phrenologist, and I think most unprejudiced persons will admit that in the number of observations, in the exactness with which those observations were conducted, and in their freedom from sources of fallacy, the researches of M. Leuret have greatly the advantage over those upon which Gall rests his conclusion.

Yet Mr. Noble, while he unhesitatingly accepts the few and very feeble instances quoted and adopted by Gall, is at great pains to depreciate these observations of Leuret; first, because they are not sufficiently numerous; secondly, because Mr. Parchappe found that, in comparing the cerebra and cerebella of a certain number of mad men and women with those of sane men and women, a very slight advantage existed in favour of the former; and, thirdly, because the author of the observations is an opponent of phrenology.

I must say, however, upon this point, that, while I do not reckon myself among the opponents to phrenology, but rather among those who are anxiously looking for and desirous of promoting a truly scientific phrenology,* I cannot but regard the facts brought forward by M. Leuret as of the greatest interest and importance, and not to be affected by any such arguments as those of Mr. Noble; nor are they to be met at all, save by similar weighings, in the same, or still better, in double the number of animals.

The last point to be noticed with regard to Gall's theory of the office of the cerebellum is that it certainly derives no support from pathological observations. The few cases quoted by Gall, in which the injury in the neighbourhood of the cerebellum seemed to affect sexual instinct are far from being conclusive, for they might apply equally, if it were assumed that the seat of the instinct were in the posterior lobes of the cerebrum, in the medulla oblongata, or in the spinal cord. Indeed Baron Larrey's second case is much more favourable to the localization of the generative impulse in the centre of emotions, than in the cerebellum. For the latter organ was free from disease, whilst the medulla oblongata was indurated. And, further, the assumed connection between

* The following passage from Dr. Holland's valuable "Medical Notes and Reflections" expresses so well the true position of phrenology, that I am glad to quote it as an excellent expression of my own creed relative to this point. "In the present state of our knowledge of the brain," says Dr. Holland, "and of its relation to the mental functions, an impartial view of phrenology requires, not that the doctrine should be put aside altogether, but that great abatement should be made of its pretensions as a system. To say the least, it is chargeable with what Lord Bacon has called 'an over-early and peremptory reduction into acts and methods,' and with the adoption of various conclusions not warranted by any sufficient evidence. But on a subject thus obscure in all its parts, and where our actual knowledge is still limited to detached facts or presumptions, there is enough to justify the opinion being kept before us, as one of the outlines to which future observations may apply; not fettered, as they now are, by the trammels of a premature arrangement." P. 517.

the generative instinct and the cerebellum, from the occasional existence of an abnormal erection of the penis, is not justified by the facts. This symptom is far from being constant in cerebellar disease—indeed it occurs in but a very small number of cases—and, as a symptom pointing to lesion of a particular portion of the cerebro-spinal axis, it is much more indicative of disease of the medulla oblongata or of the cervical portion of the spinal cord.

Office of the cerebral convolutions.—The great sheet of vesicular matter which forms the cortex of the human brain, is of such vast extent that it is forced to assume the convoluted form in order to its being packed within the ordinary compass of the cranium. A little consideration will shew that the *convoluted form* can be regarded no otherwise than as a convenient mode of packing, and that the *number* and *depth* of the convolutions are the best indications of the superficial extent of this expanse of vesicular matter. In certain cases a slow and gradual accumulation of water within the ventricles of the brain, causing a corresponding enlargement of the cranium, expands the matter of the cerebral hemispheres, by which the ventricles are enclosed, and the convolutions become unfolded. We thus obtain a distinct demonstration of the true arrangement of this part of the hemisphere, which must be regarded as a nervous centre, consisting of a vast mass of the potential vesicular matter freely supplied with bloodvessels from a vascular surface on its exterior (the pia mater), and giving rise to an infinite multitude of nerve-fibres, which pass from its internal surface to the corpora striata and optic thalami, the centres of volition and sensation. The name which Mr. Solly has given to this expanse of nervous matter, *hemispherical ganglion*, is very expressive, not only of its true character as a centre of nervous power, but likewise of the *unity* of the organ on each side, consisting as it does of an uninterrupted layer of vesicular matter with its emerging or immerging fibres, and not of a great number of different organs, as the term convolutions would imply.

This vesicular surface with the fibrous matter which connects it with the optic thalami and corpora striata forms by far the largest portion of the encephalon in the higher classes of animals. This fact alone ought to stamp it with great physiological importance. But, further, it is a well-proved fact, that *the complexity of the convolutions in the animal scale is in the direct ratio with the advance of intelligence.* At the same time it must be remembered that the complexity of the convolutions is in part determined by the size of the head and the capacity of the cranium. If, for example, the habits and mode of life of the animal require a small head and at the same time a certain degree of intelligence, the brain would exhibit a greater number and complication of convolutions than would be found in an animal of corresponding intelligence, but which required and possessed a larger head. Hence neither the *size* nor the *weight* of the brain, whether absolute or in relation to the body, affords any certain criterion of the extent of the convoluted surface. Highly complicated convolutions may exist along with a brain both absolutely and relatively small. Thus, the ferret, as shown by Leuret, whose habits require a small head, has several well-marked convolutions on each hemisphere, and a brain no larger than that of the squirrel, which has no convolutions at all, and which wants even the few fissures which mark their first developement in the rabbit, the beaver, the agouti, &c. And the last-named animals have the brain both absolutely and relatively larger than that of the cat, the pole-cat, the roussette, the unau, the sloth, and the pangolin, all of which possess convolutions.

At the early periods of human life, in infancy and childhood, the convolutions of the brain are very imperfectly developed, but their increase of size goes on simultaneously with the advance of mental power. If the former be arrested, or if some congenital fault prevent the further growth of the convolutions, the mental powers are of the lowest and feeblest kind, but little or not at all above those of the brute with imperfect convolutions. In all idiots the brain is not only small, but its convoluted surface is extremely limited.

Anatomy points to the conclusion that the office of the convolutions is connected with the functions of the mind. Perception, memory, the power of abstraction, judgment, imagination, all possess, as instruments of corporeal action, these folds of vesicular matter. And it seems not improbable that the phrenological view which assigns to certain convolutions a special office connected with some particular faculty or faculties is true. This is strongly supported by the fact of a regular disposition of certain primary convolutions in the various classes of animals, so that each form of brain has its proper convolutions, and that in tracing the convolutions from the most simple to the most complex, indications are found of the persistence of the primary and fundamental convolutions in the midst of many secondary and superadded ones.

It may be here mentioned that Gall was by no means the first to assign this function to the convolutions. Our countryman, Willis, in the seventeenth century, distinctly advanced this opinion, and conjectured that the various gyrations were intended for retaining the animal spirits "for the various acts of imagination and memory" within certain limits.

It is important to ascertain the endowments of the fibres which connect the vesicular surface of the convolutions to the corpora striata and optic thalami. They might be supposed to possess similar endowments to those of sensitive and motor nerves, if we adopted the views of those who hold that all the nerves are continued up into the brain. This point, however, has been settled in the most decisive manner by experiments, dating as far back as the time of Lorry.* Mechanical injury to them excites

* Mém. de l'Acad. des Sciences, 1760.

neither pain nor disturbance of motion. Even the electric current passed through them produces no sensible effect (Matteucci). We are led, therefore, to the conclusion that these fibres have endowments quite distinct from those of sensitive and motor nerves, (a fact, by the way, quite irreconcileable with the doctrine which makes the brain the concourse of these fibres,) and that they are internuncial between parts which are beyond the *immediate* influence of the ordinary physical agents, and which have no direct connection with muscular organs. The proper stimulant of these fibres is the mind on the one hand, or the nutrient changes in the brain on the other. But, under the influence of a continued morbid irritation, they may excite either pain or convulsion, or both, as is frequently the case in disease of the cerebral meninges; this, however, is effected through a change produced in the corpora striata and optic thalami, and propagated thence to the origins of motor and sensitive nerves, or through irritation of the nerves of the meninges, which affect the centres of motion and sensation, just as the nerves of other parts do.

The experiments of Flourens and of Hertwig show that removal of the cerebral hemispheres produces a state of stupor, and, to use Flourens' expression, as it were condemns the animal to perpetual sleep, but deprives it even of the faculty of dreaming. There is, however, no paralytic state produced by these mutilations. It is evident, then, that the effect of these experiments is *psychical*, and it may be adduced as confirmatory of the view which associates the functions of the cerebral convolutions with the operations of the mind.

Pathological anatomy affords interesting confirmation to this view. Inflammation of the membranes of the brain, more especially of the pia mater, is invariably attended by disturbance of the mental faculties, as manifested by more or less delirium. It appears that any material alteration of the circulation in the grey matter of the convolutions is capable of giving rise to delirium; in the instance above quoted, the circulation in this part is affected in consequence of the inflammation of the pia mater, the bloodvessels of the one being distinctly continuous with those of the other; but in other instances of violent delirium, such, for example, as delirium tremens, the vesicular matter of the convolutions is found after death to be bloodless, as if its wonted supply of blood had been cut off or abstracted from it. We find this state in the delirium after great operations, after puerperal floodings, in the delirium of rheumatic fever, and in that of gout, and likewise in that which occurs in the more advanced stages of fever.

We learn from the most trustworthy reports of the dissections of the brains of lunatics that there is invariably found more or less disease of the vesicular surface and of the pia mater and arachnoid in connection with it, denoted by opacity and thickening of the latter with altered colour or consistence of the former.

From these premises it may be laid down as a just conclusion that the convolutions of the brain, in other words, that vast sheet of vesicular matter which crowns the convoluted surface of the hemispheres, constitute the *centre of intellectual action*, as distinguished from the *centre of volition* and the *centre of sensation* (corpora striata and optic thalami). It is essential to the perfection of cerebral action that these centres should be connected, and that the *centre of intellectual action* should be capable of exciting or of being excited by the centres of volition and sensation. This connection and mutual influence is effected through the innumerable fibres which pass from the one to the other.

To determine the precise connection which exists between the mind and the brain is beyond the reach of our means of observation and experiment. All we are justified in affirming is that the mental acts are associated with this portion of the brain, which I would call *the centre of intellectual actions*; and that the integrity of this part is necessary to the perfect exercise of the mind; that, in the language of Cuvier, this centre is the sole receptacle in which the various sensations may be as it were consummated, and where all sensations take a distinct form and leave lasting traces of their impression, serving as a seat to memory, a property by means of which the animal is furnished with materials for his judgment.

The actions of the convoluted surface of the brain, and of the fibres connected with it, belong altogether to the class of *mental* nervous actions; that is, they either excite or are excited by mental change. The physical changes in these parts give rise to a corresponding manifestation of ideas, and every thought is accompanied by a change in this centre. Modifications in its nutrition, or interruptions to it, produce corresponding effects on the mind. An increased activity of nutrient change causes a rapid developement of ideas, which, being generally uncontrollable by the will, and therefore undirected, assumes the form of raving or delirium. The shock of concussion so far checks the organic changes of the vesicular surface, and perhaps also of the fibrous matter, as to interrupt for a time those conjoint actions of the mind and the brain which are necessary for perfect consciousness. The condensation of the substance of the hemispheres, which is produced by an apoplectic clot, or by the effusion of some other foreign matter, prevents a similar consent of action, and thus gives rise to the phenomena of *coma*, a state in which all mental nervous actions are destroyed or suspended, and which, if continued long enough, will annihilate the physical nervous actions likewise.

It will be observed that, in this description, the workings of the mind are not viewed as mere functions of the brain. The term Mind expresses the mode of action of the Soul, an entity which both reason and revelation assure us is essentially different from the Body,* being incorruptible and indestructible, in the sense in which we suppose that both corruption and destruction may affect material things. To

* *Ens incorporeæ prosapiæ*, Prochaska.

will, to feel, to perceive, to think, are so many states of Soul or acts of Mind.

Mind is, then, the mode of action of the Soul, as Life is the mode of action of the Body. The latter we distinguish as *material*, and the phenomena of life as specially belonging to organized matter; the former we denominate *immaterial*, to mark its essential difference from the body, admitting, however, that it exists in a mysterious union with the nervous system of the body in a manner so intimate that in a state of health the smallest change in either readily affects the other.

Such is the doctrine which seems most consonant with reason and experience, and, above all, with revelation. But there are those who maintain that not only are certain states of mind preceded by certain states of body, but that all our ideas, our sensations, our volitions, are the result of, and as it were generated by, certain organic changes.

This view, which is that of materialism, while it necessarily tends to destroy our hopes of a future life, by denying even the very existence of a Soul, and not its immortality only, is opposed by the consciousness which we possess of a power inherent in the mind to direct and control the actions of the brain, and by the knowledge that the mind will rise superior to the fatigue and exhaustion of the body, and will survive, unimpaired, even its wreck.

There are, moreover, some excellent persons, who, while they admit the existence of an immortal soul distinct from the mind, nevertheless regard the phenomena of the mind as functions of the brain, resulting from the changes which are continually taking place in that organ. The mind, they say, is "the aggregate of the functions of the brain," and is entirely dependent on its integrity. But the adoption of these views involves the advocate of them in as great a difficulty as that from which he flatters himself he has escaped. If there be a soul, what is its relation to the mind? What is its office? Is it simply associated with the body without being affected by it or affecting it in turn? Surely it must have some office, and if it be admitted to be capable of exercising any influence, either on the mind or on the body, then the whole matter in dispute vanishes. If the soul can affect the mind, it must do so according to these views through the body; and, if this be admitted, why make a difficulty about admitting that the will, as a faculty of the soul, can influence some portion of the brain?

On the other hand, if it be denied that the soul can affect either mind or body, then must we come to the conclusion that the soul is inert, or else an entity totally distinct from the body, a looker-on as it were, which watches the corporeal functions and the mental phenomena, but takes no part in them, and has no true sympathy with them.*

An acute and ingenious writer, Dr. Wigan, who has advocated with great zeal and ability the docrine of the duality of the mind, seems to think that the progress of mental philosophy and of cerebral physiology is much hindered by the views of those who advocate the spiritual

* I beg the reader to peruse with attention the following passage from Bishop Butler:—"Human creatures," says this profound thinker, "exist at present in two states of life and perception, greatly different from each other; each of which has its own peculiar laws, and its own peculiar enjoyments and sufferings. When any of our senses are affected or appetites gratified with the objects of them, we may be said to exist or live in a state of sensation. When none of our senses are affected or appetites gratified, and yet we perceive and reason and act, we may be said to exist or live in a state of reflexion. Now, it is by no means certain that any thing which is dissolved by death is any way necessary to the living being in this its state of reflection, after ideas are gained. For though, from our present constitution and condition of being, our external organs of sense are necessary for conveying in ideas to our reflecting powers, as carriages, and levers, and scaffolds are in architecture, yet when these ideas are brought in, we are capable of reflecting in the most intense degree, and of enjoying the greatest pleasure and feeling the greatest pain by means of that reflection without any assistance from our senses; and without any at all, which we know of, from that body which shall be dissolved by death. It does not appear then, that the relation of this gross body to the reflecting being is, in any degree, necessary to thinking—to our intellectual enjoyments or sufferings; nor, consequently, that the dissolution or alienation of the former by death will be the destruction of those present powers which render us capable of this state of reflection. Further, there are instances of mortal diseases which do not at all affect our present intellectual powers; and this affords a presumption that those diseases will not destroy these present powers. Indeed, from the observations made above, it appears that there is no presumption that the dissolution of the body is the destruction of the living agent from their mutually affecting each other. And, by the same reasoning, it must appear too that there is no presumption that the dissolution of the body is the destruction of our present reflecting powers from their mutually affecting each other; but instances of their not affecting each other afford a presumption of the contrary. Instances of mortal diseases not impairing our present reflecting powers evidently turn our thoughts even from imagining such diseases to be the destruction of them. Several things, indeed, greatly affect all our living powers, and at length suspend the exercise of them; as for instance drowsiness increasing till it ends in sound sleep; and from hence we might have imagined it would destroy them, till we found by experience the weakness of this way of judging. But, in the diseases now mentioned, there is not so much as this shadow of probability to lead us to any such conclusion as to the reflecting powers which we have at present. For, in those diseases, persons, the moment before death, appear to be in the highest vigour of life. They discover apprehension, memory, reason, all entire; with the utmost force of affection; sense of character, of shame and honour; and the highest mental enjoyments and sufferings, even to the last gasp; and these surely prove even greater vigour of life than bodily strength does. Now what pretence is there for thinking that a progressive disease when arrived to such a degree, I mean that degree which is mortal, will destroy those powers which were not impaired, which were not affected by it during its whole progress quite up to that degree? And if death by diseases of this kind is not the destruction of our present reflecting powers, 't will scarce be thought that death by any other means is." See the admirable chapter, "*Of a future Life*," in Butler's Analogy of Religion, natural and revealed.

nature of the mind.* But no doubt his fears are unfounded; for if we hold that a connection subsists between soul and brain so intimate that every change in either affects the other more or less, surely the strongest inducement is held out for the minutest investigation of the organ which can exercise so wonderful an influence on the immortal part of our nature.

I would, then, lay it down that the proper function of the brain is to generate the nervous force, and that that force affects the soul and excites its action for the developement of mental phenomena. On the other hand, the action of the soul affects the brain, exciting it to the developement of nervous force, and directing that force for the production or regulation of other corporeal phenomena.

Taking this view of the nature of the mind, and of the relation of mind and body, we may, with advantage, arrange the principal mental states into two classes, according as they are preceded by certain states of body, or as they precede and are capable of exciting certain states of body.

In the first class I would place *sensation*, and such mental states as are immediately associated with or produced by sensation, as the emotions and the passions. To this class I would likewise refer that peculiar power which is, with the highest probability, exercised by the cerebellum, and to which we must give the name of balancing or coordinating power. It is a power which, like the emotions and passions, is exercised without any previous train of thought or intellectual process, and seems simply to be evolved as an immediate consequence of certain sensations, which are developed under the influence of impressions made upon the organs which are to be submitted to its regulation. Thus, in locomotion, the exercise of the muscles produces the sensation upon which the evolution of this mental power depends, which reacts upon the same muscles with an intensity proportionate to the exciting impulse. In the exercise of this power there is much analogy with the ordinary reflex acts; but while the latter are purely physical in their nature, the former may be clearly shown to be mental. The proofs of this are derived, 1, from its being never accomplished without consciousness; 2, from its being always associated with volition; 3, from the curious differences in the mode of its exercise in different individuals, according to differences of mental and physical constitution, one man being expert and precise in all his movements, another awkward and clumsy; 4, from the marked improvement which may be effected in it by instruction and duly regulated practice.

In the second class I would place volition and attention. In these the mind has clearly the initiative, and is capable of inducing certain states of body, either to move certain organs (voluntary motion), or to concentrate one or more of the inlets of sensation upon some external objects (attention). The power of abstraction, imagination, and all purely intellectual processes, are obviously associated with these.

The symmetrical disposition of the parts of the encephalon on each side of the median plane has been recognised by all anatomists. This symmetry is so complete that we may, with perfect correctness, speak of two brains, a right and a left brain, which are united to each other by transverse commissures. The right brain corresponds exactly with the left, just as much as the right eye corresponds with the left. This doubleness of the brain, no doubt, accords curiously with the doubleness of all the organs of sense, and very probably is rendered necessary by the existence of the double set of inlets to sensation. It is remarkable, however, that a perfect symmetry of the convolutions is not found in the higher races of mankind, and in individuals of high intellectual powers; and that the greater the mental power, the less symmetrical are the convolutions. In the inferior races, on the other hand, as Tiedemann has well shown, the symmetry of the convolutions is exact.

Upon the proved existence of two brains, as thus explained, Dr. Wigan, adopting the materialist view of mental phenomena, rests the theory that the mind is dual; that we have two minds; that each brain performs its own mental functions, which are in perfect harmony, if the two brains harmonise in quality, structure, and action.

It cannot be doubted that two brains, thus symmetrical in structure, must have a tantamount symmetry of function, if I may be allowed the expression; and that, therefore, in order to insure harmony of action between them, and to prevent the actions of one from interfering with or neutralising those of the other, some such organic connection between them is necessary as that which exists between the two retinæ, and which converts the separate and in some degree dissimilar physical impressions made on each of them into one sensation.

And as any interference with the organic conditions necessary to secure single vision with two eyes produces double vision, so it is not unreasonable to expect that an analogous imperfection in the organic union between the two brains may occasion doubleness of mental impression and action. Such a conclusion, as Dr. Wigan has ingeniously suggested, gives the clue to the explanation of such phenomena as states of double consciousness, delusions, irregular volitions, and some forms of insanity; and, if fairly worked out by physiological psychologists, may solve other obscurities connected with the phenomena of the mind. While, therefore, I admit that great practical interest and value attach to Dr. Wigan's views respecting the action of two brains, I am not prepared to infer the existence of two minds from that of two brains; no more than I can assume a duality of our visual sense from the existence of two eyes. The two cases, indeed, are strictly analogous. The organic change in each retina developes a

* Wigan on the Duality of the Mind. Lond., 1844.

corresponding sensorial impression; and from the connections which subsist between the retinæ, and still more from that between the centres of sensation, these impressions become fused into one. In like manner the organic changes in the two brains developing nervous force in similar modes and proportions, each being capable of affecting the mind similarly, although perhaps not identically, are yet so united in their action that the double organic affection acts on the mind as one. But if, through default of the connecting media of the two brains, or through lesion of one, the organic changes in each do not harmonise with those in its fellow, then it is plain that two separate and distinct mental affections will result, and more or less of confusion must ensue. I can see no ground for inferring the existence of two minds from such a supposition. The confusion results from the want of simultaneous affection of the same mind by two distinct and separate brains. If, in vision, each centre of sensation affected only its own mind, or, in other words, developed only its own mental phenomena, as Dr. Wigan's theory would compel us to assume, then each mind would perceive a different perspective projection of the object presented to the eyes, and an elaborate and complex mental process would be required to combine the two sensorial impressions. How much simpler is the view of this process which assigns the combination of the double impression to a physical union in the brain of each physical change in the retina; so that, in truth, but one impression, different from each of its excitant ones, reaches the mind. So also, in the normal intellectual action, the organic changes of the two brains are united by the various transverse commissures, so that but one physical stimulus affects the mind and excites but one train of thought. Not so, however, when from any defect in the brains themselves, or in the commissures, the physical conditions necessary for the organic states of the two brains cannot be fulfilled.

Dr. Wigan's theory is inconsistent with the acknowledged fact of the existence of an imperfect symmetry of the convolutions in persons possessing the highest order of mind. If the two brains always act in harmony, there ought to be perfect symmetry. But if we admit that the mind may have the initiative, then it is easy to understand how one brain may be used more than another.

That a power exists of using one brain more than another, seems probable from the more frequent and more perfect use of one hand; and the existence of such a power implies also a capability of keeping one brain in suspense while the other is acting, under particular circumstances, just as we can suspend the use of one arm or one finger or one eye, although the exercise of its fellow prompts greatly to its simultaneous action.

Sleep is an affection of the centre of intellectual action, a condition rendered necessary by the incessant working of the mind. It is indicated by the cessation of all mental nervous actions. In deep sleep the body is given up to the physical nervous actions only, without which the functions of breathing, circulation, &c., could not be carried on. *Dreaming* occurs only in imperfect sleep,—often, if not always, just before waking,—and serves to show how the organic changes of the centre of intellectual action, when uncontrolled, may produce the most rapid trains of thought, recalling events or impressions that have passed away, and which we may have thought had been forgotten.

Coma is sleep of the profoundest kind, a paralysis, indeed, of the centre of intellectual action, as well as of sensation and volition. It occurs under states of disease, which induce *compression* of the brain, or under states of shock, which suspend or greatly diminish its natural changes, as in concussion. Or it may be induced by the influence of certain poisons of the sedative or narcotic kind, as opium and belladonna, which, if given in too large a dose, paralyse first the centres of mental nervous actions, and ultimately those of physical nervous actions.

Somnambulism must be regarded as a state of intense dreaming, in which the person is prompted to the performance of certain acts. Talking in one's sleep, the curious changes of position which are made under the influence of nightmare, and even the most complex actions, as walking, or taking things from one place to another, or holding a long conversation, are all induced by the same state, a morbid condition of the centre of intellectual action, generally produced by deranged assimilation or great previous disturbance of mind. The somnambulist, in short, is one who dreams and acts in his dream as if he were awake, and as if all the phenomena of which he takes cognizance were real.

Delirium is a condition very analogous to dreaming. The organic changes in the centre of intellectual action are too rapid to be controlled by the will, or the influence of the centre of volition is impaired. The ravings of a delirious patient generally take place unconsciously, as if the centre of sensation were impaired likewise. In most instances, however, the patient may be roused; a strong stimulus, as in addressing him with a loud voice, will affect his centre of sensation, and he either controls his thoughts for a brief space, and directs his attention to what is going on, or the effect of the stimulus is to direct his ravings into some new channel. The incoherent and unconnected manner in which thought follows thought in the delirious state is sufficient proof that the centre of intellectual action requires the controlling power of a will for perfect trains of thought, as much as any particular set of muscles requires the same influence for the accomplishment of definite action.

Delirium, indeed, may be viewed as a *subjective* phenomenon of the centre of intellectual action, just as *tinnitus aurium* or *ocular spectra* are subjective phenomena of the centre of sensation.

In analysing the fibres of the centrum ovale we find that a large number of them is commissural, but that the greatest proportion of them serves to establish a communication between the centre of intellectual action, and the centres of volition and sensation. It is through this connection that the intellect and the will are capable of mutually affecting each other, the intellect prompting or exciting the will; and the will, on the other hand, controlling or applying the powers of the intellect. The faculty of attention, and, therefore, in a certain degree, that of memory, are dependent on the influence of the centre of volition upon the centre of intellectual action. Every one is sensible of a power which he possesses of fixing his attention on any given subject, as distinct as that by which he can contract any particular muscle. The association of the intellectual centre with that of sensation is necessary to ensure the full perception of sensitive impressions. The experience of each individual can supply him with numberless instances in which, while the mind was employed upon some other object of interest, an impression was made upon some one of the organs of sense, and indistinctly *felt*, but not fully perceived. When the mind has become disengaged, the fact that an impression had been made is recalled, without any ability to recollect its precise nature. And in many lunatics the centre of intellectual action is so impaired as to destroy or greatly reduce the power of perception, whilst there is abundant evidence to shew that the affections of the organs of sense make a sufficient impression on the centre of sensation, although in such cases this centre may likewise participate in the general hebetude.

Perfect power of speech, that is, of expressing our thoughts in suitable language, depends upon the due relation between the centre of volition and that of intellectual action. The latter centre may have full power to frame the thought; but, unless it can prompt the will to a certain mode of sustained action, the organs of speech cannot be brought into play. A loss of the power of speech is frequently a precursor of more extensive derangement of sensation and motion. In some cases the intellect seems clear, but the patient is utterly unable to express his thoughts; and in others there is more or less of mental confusion. The want of consent between the centre of intellectual action and of volition is equally apparent in cases of this description, from the inability of the patients to commit their thoughts to writing.

The hemispheres of the brain, as has been already stated, are insensible to pain from mechanical division or irritation; in wounds of the cranium in the human subject, pieces of the brain which had protruded have been removed without the knowledge of the patient. Nevertheless, pain is felt in certain lesions of the brain, even when seated in the substance of the hemispheres, or in the optic thalami or corpora striata. This results from the morbid irritation extending to other parts with which nerves are connected, as the medulla oblongata; or in which nerves are distributed, as the membranes. The nearer a cerebral lesion is to the membranes or to the medulla oblongata, the more likely is it to excite pain. Headaches, of whatever nature, must be referred to irritation, either at their centres or at their periphery, of those nerves which are developed in the dura mater or in the scalp. The branches of the fifth pair, of the occipital nerve, and the auricular branch of the cervical plexus, are those most frequently affected.

Certain sensations are referred to the head which may occur from a morbid state, or may be produced by changes of position in the body. Such are vertigo, a sense of fullness, or of a weight in the head, a feeling of a tight cord round the head. These are, no doubt, truly subjective, arising from altered states in the distribution or in the quality of the blood sent to the brain. A sensation of a rushing of blood to the head is often consequent upon excessive hemorrhage, or accompanies a state of extreme debility from any cause. This is, doubtless, owing in great part to the feeble tone of the arteries, resisting imperfectly the flow of blood to the head, and allowing it to impress the nervous matter too much. It is well known, that, by turning round quickly on one's own axis, the sense of vertigo may be produced; a confused feeling in the head, and an inability to maintain the balance of the body, accompanied by an appearance as if external objects were revolving. If the eyes be kept shut, the uneasy feeling of the head will take place, but no true vertigo. To obtain this feeling perfectly, the eyes must be open, and objects presented to them. And Purkinje has shewn that the direction in which external objects appear to revolve is influenced by the position of the body and of the head while turning round, and by the position of it afterwards, when the experimenter has ceased to move round. If the experimenter have kept his head in the vertical position while moving round, and afterwards when standing still, the objects appear to revolve in the horizontal direction. If the head be held with the occiput upwards while turning round, and then erect when standing still, the objects seem to rotate in a vertical plane, like a wheel placed vertically revolving round its axis.* It is highly probable that these sensations, as well as those which arise spontaneously, are due to some irregular distribution of blood to various parts of the brain. A sense of giddiness frequently precedes fainting, and is attributable to the temporary deficiency in the supply of blood to the head. If the horizontal position be immediately adopted, or the body be laid with the head inclined downwards, the faint may be prevented. The sense of giddiness which is experienced upon rising from the horizontal position after illness, is doubtless of the same kind. Anæmic patients experience this feeling of giddiness even in the horizontal position; and both it and the headache and delirium, which accompany this state of bloodlessness, may be relieved by placing the patient on an inclined plane with the head downwards.

The mind possesses a remarkable power of exciting and of exalting painful sensations in various parts of the body. If the attention be

* Müller's Physiology, by Baly, vol. i. p. 848.

directed very strongly, and for some time, to any part, it may become the seat of pain, for which the most effective remedy is to engage the thoughts as much as possible on some other object. In many instances, where pain has been excited by a physical cause, there can be no doubt it has been continued long after the cessation of its exciting cause, by the attention of the patient having been directed to it. It is probable, that in such cases the *perceiving* parts of the brain (so to speak) become habituated to a certain condition of the centre of sensation, produced by the original exciting cause of the pain. And, on the other hand, pain, at first excited by the mind, may be rendered permanent by habit; a certain physical alteration in some part of the centre of sensation being induced by the frequent repetition of the mental act in reference to a particular part of the body.

Those parts of the brain which are capable only of mental nervous actions, that is, of actions by which the mind is immediately affected, or which the mind can develope, have no nerves implanted in them. Such are the convolutions, the corpora striata, the optic thalami, and the cerebellum. The only apparent exceptions to this statement are the olfactory and optic nerves: these nerves, however, have in truth no immediate connection with any of the parts above mentioned. The former are implanted in the olfactory lobe; the latter in the chiasma, which is formed by the junction of the optic tracts, and these ought no more to be regarded as portions of the optic nerves, than the olfactory lobes should be considered as nerves.

Functions of the commissures.—The anatomy of the parts which we call commissures indicates that the name by which they have long been known is not misapplied, inasmuch as they seem to unite particular portions of the nervous centres with each other. The most obvious object of such an union would be to ensure the harmonious cooperation of the parts thus united. And this view of their function is strengthened by the fact that the principal commissures bear a direct ratio in point of developement to that of the parts they unite, and that, when these parts are absent or defective, the commissures are deficient or wholly wanting. Thus the corpus callosum and the hemispheres are developed together; the fornix and the hippocampi, the pons Varolii and the cerebellar hemispheres.

In Stilling's experiments on the spinal cord it was found that when division of that organ was made along the median plane, a stimulus applied to one leg caused only reflex actions of that leg, and not at all of the other side of the body. The power of transmitting organic change from one side of the cord to the other was destroyed by the section of the commissure.

The anatomy of the corpus callosum is favourable to the hypothesis that it is the bond of union to the convoluted surface of the hemispheres, and that it is in all probability the medium by which the double organic change is made to correspond with the working of a single mind.* There is nothing in the recorded observations of morbid change or congenital defect of this part to militate against this idea; but as all these cases are accompanied with lesion or defect of some other parts, and of the convolutions themselves, it is impossible to gather from them what is the precise consequence of the defect of the corpus callosum. This commissure is defective in the marsupiate class, as was shown by Professor Owen, and likewise in birds; but we have yet to learn whether there is any psychological character in either of these groups of animals, which would give us material assistance in our search into the nature of its function.†

Direct experiments upon the corpus callosum yield only negative results. Longet and others found that mechanical irritation of it did not cause convulsions; and Longet states that injury to the corpus callosum in young rabbits and dogs did not appear to disturb voluntary movements; and that when he incised this body in its whole length in rabbits standing, they continued to maintain that position, or, when urged on, ran; and that no convulsive movement whatever, nor any sign of pain, was manifested. Such effects are not unfavourable to the view above taken, as the connection of the centres of intellectual action is probably in no degree necessary to locomotion, which function would no doubt be as well performed without a corpus callosum as with one.

The fibres of the fornix manifest the same insensibility to mechanical irritants, and their obvious anatomical connection with particular convolutions warrants but one conclusion, that they associate the actions of those parts. The connection of this commissure with the optic thalami and the corpora mamillaria indicates that it also associates these gangliform bodies with the convolutions at the posterior part of the brain, and with the hippocampi. A marked relation exists between these latter convolutions and the fornix; they bear, indeed, especially

* Mr. Solly and Mr. Grainger think that they can trace the fibres of the corpus callosum distinctly to the convoluted surface of the hemispheres. With the greatest respect for these able anatomists, I must express my doubts that all the fibres which they have represented can be regarded as fibres of the corpus callosum. See fig. 99 in Mr. Solly's work on the Brain, p. 251, ed. 1847. Although the anatomical views of these writers correspond with and confirm the physiology of the organ advocated in the text, I feel that great caution should be used in drawing conclusions from tracing the fibres of brains *hardened* in alcohol. By these means any speculative anatomist may make preparations to illustrate his views, as is, indeed, abundantly shown by what I must call the fanciful anatomy of the brain put forward by Foville.

† An excellent account is given by Mr. Paget of a case in which the corpus callosum and fornix were imperfect, in the xxixth vol. of the Med. Chir. Trans., accompanied by some very judicious remarks upon the office of those commissures, and an analysis of other similar cases. Mr. Paget refers to some oblique fibres as existing in the corpus callosum, and serving to connect the anterior convolutions of one hemisphere with the posterior ones of the other.

as regards the posterior pillars of the fornix, a direct ratio to each other.

Lallemand relates a case in which the symptoms were altogether limited to mental disturbance, without any affection of the sensitive or motor powers, and the fornix and corpus callosum were found in a state of complete softening without discolouration.

The fibres of the pons Varolii bring the cerebellar hemispheres into connection with each other, and with the vesicular matter of the mesocephale. Direct experiments on these fibres can yield no satisfactory result, because they are so intimately associated with the deeper seated parts of the mesocephale, and with the nerves of the fifth pair and others, that it is impossible to irritate them in the living animal without affecting these parts likewise. The anatomy of the fibres, however, sufficiently indicates that they belong properly to a double cerebellum: for when the cerebellum becomes single, as in birds, reptiles, and fishes, no such fibres are found in the encephalon. Morbid lesion of the pons is productive of very serious results from the number and importance of the parts in its neighbourhood, the pyramids, the medulla oblongata, the quadrigeminal tubercles; so that the symptoms it produces cannot be referred solely to the injury to the commissural fibres. It is very probable, however, that the crossed effect of deep-seated disease of either hemisphere of the cerebellum may be accounted for by the influence of these commissural fibres upon the adjacent anterior pyramids, which again would influence the opposite side of the spinal cord.

Having thus brought to a termination our review of the physiology of the encephalon, I may now sum up the principal conclusions which our examination of this difficult and important subject leads to; and these are embraced in the following propositions.

1. That the encephalon consists of a series of centres, each of which has its proper influence in the exercise of the mental and bodily functions. These are the centre of intellectual actions, the centre of volition, the centre of sensation, the centre of the coordination of muscular movements, the centre of emotion, and the centre of respiration and of deglutition.

2. That the cerebral convolutions, with the fibres which connect them to the corpora striata and optic thalami, constitute the centre of *intellectual action.*

3. That the centre of *volition* consists primarily of the corpora striata; the inferior layers of the crura cerebri, which are continuous with the anterior pyramids, connect these gangliform bodies with the vesicular matter of the crura (locus niger), with the vesicular matter of the mesocephale, medulla oblongata, and with that of the spinal cord (the anterior horns), all of which with the corpora striata probably form the dynamic nervous matter in the impulses of volition for nerves implanted in them respectively.

4. The optic thalami, which by the extension of the olivary columns through the mesocephale and medulla oblongata to the posterior horns of the vesicular matter of the spinal cord, become continuous with those parts, constitute the centre *of sensation,* having implanted in it or connected with it less directly all the sentient nerves of the body.

The nerves of the higher senses probably have each special ganglia or centres, which, however, are connected with the general centre; as the olfactory lobes for smell; the retina, corpora geniculata, or corpora quadrigemina for vision; the vesicular matter in which the auditory nerves are implanted or the flocks of Reil for hearing; the ganglia of the fifth, glosso-pharyngeal, and posterior roots of spinal nerves for taste and touch.

5. The cerebellum constitutes the centre of the coordination of muscular movements, both in locomotion and in all the complicated movements of the frame.

6. The upper and posterior part of the mesocephale, including probably the greatest portion of the corpora quadrigemina, constitutes a special centre of actions referable to the emotions, among which may be reckoned sexual impulses. This centre connects itself with the medulla oblongata by the olivary columns, and through the same channel with the posterior horns of the spinal vesicular matter.

7. The medulla oblongata constitutes the centre of respiration and deglutition, but it cannot be considered as wholly devoted to these functions, inasmuch as it consists likewise of continuations of the centres of volition, of sensation, and of emotion.*

Of the functions of the ganglions.—That ganglions are small nervous centres we are bound to believe, from the existence in them of a considerable quantity of vesicular matter mingled with fibrous matter. And the views which we have already expressed respecting the dynamic character of the vesicular matter warrant the assumption that wherever a special accumulation of that form of nervous matter is found, there must be a special source of nervous power.

* I have great pleasure in referring the reader to a very able essay on the physiology of the brain, (which I did not see until this article was at press,) in which very similar views to those expressed in the text are advocated, based on comparative anatomy. The author, who in justice to himself ought not to withhold his name, is evidently hampered by his adhesion to the excito-motory doctrines. I allude to the Review of Noble on the Brain in Dr. Forbes's Journal for October, 1846. I had already put forward similar opinions respecting the subdivision of the brain and the uses of its parts, in the section headed "*An hypothesis of the action of the brain,*" in the article NERVOUS CENTRES, published in 1845, and subsequently republished in a volume entitled "The physiological and descriptive Anatomy of the Brain, &c." chap. xii., and the same views were expressed in Mr. Bowman's and my "Physiological Anatomy and Physiology of Man," part ii. 1845, p. 291 and p. 374. I may add that the review to which I refer contains a very complete and masterly exposition of the weakness of the present system of phrenology.

There are certain facts connected with the larger nervous centres which strongly indicate the correctness of this assumption. Thus, the existence of special accumulations of vesicular matter connected with them, where any particular developement of the nervous force is needed, is much in favour of this view. As instances, we may cite the special electrical lobes in the electrical fishes, the ganglionic enlargements on the medulla oblongata of the gurnard, the median lobe, occupying a similar position to the electrical lobe above referred to, which is found in the remora or sucking-fish, and from which nerves are supplied to the suctorial disc on the head of that animal. Allied to these is the remarkable fact pointed out by Professor Sharpey, that the arms of the cuttle-fish contain ganglia which furnish nerves to the suckers which exist upon them in great number. Furthermore, the anatomy of the nervous system in some of the Mollusca, the Conchifera for example, in which a separate *ganglion* appears to exist for each function, for respiration, for locomotion, for deglutition, &c., is beautifully illustrative of the office of ganglia.

When, however, we come to inquire into the office of the particular ganglia which exist in Man and the Vertebrata, it is, in some instances, difficult to determine what object can be gained by a special evolution of nervous force by some of them. It may be inquired what is the function performed by the ganglia on the posterior roots of spinal nerves, on the large root of the fifth, on the glosso-pharyngeal, on the vagus nerves? Can it have reference, as already suggested in a former part of the article, to the part which these nerves perform in connection with tactile sensibility or with the sense of taste, as in the fifth and glosso-pharyngeal, in analogy with the ganglia attached to the olfactory and optic nerves, and probably with the auditory? Or have these ganglia anything to do with the nutrition of the parts among which their nerves are distributed, as Dr. M. Hall suggests, in which case they would present an obvious analogy, and might be classed with the sympathetic ganglia?

The data which would assist in coming to a right conclusion upon this subject are so few, that, with our present knowledge, it is impossible to form anything like a distinct hypothesis regarding it. I would remark with reference to the last-mentioned conjecture that it would receive great support if gelatinous nerve-fibres were found to take their rise from the ganglia and to follow the course of bloodvessels.

With regard to the use of the ganglia of the sympathetic, the proved existence of gelatinous fibres, peculiar to these ganglia and taking their rise from them, distinctly indicates that they are the seat of a special developement of nervous power, whether spontaneously arising in the nutrient changes of ganglia, or by the reflexion of a change propagated to them by afferent nerves implanted in them. The various facts which show that the sympathetic system enjoys an existence and power independent of the cerebro-spinal axis also confirm this view.

But we must enquire further what is gained by the passage of certain nerve-fibres through these ganglia, as is the case with most if not all the tubular fibres connected with them? It may be that in their passage through the ganglia the tubular fibres acquire an arrangement in new sets or fascicles in a manner analogous to that which occurs in the plexuses. But this can scarcely be the only object of this connection. Do these fibres associate the cerebro-spinal centres with the ganglionic system? or do they themselves in passing again through vesicular matter experience some modification in their vital endowments? These questions cannot be satisfactorily solved in the present state of our knowledge.

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(R. B. Todd.)