

The Action
of
the Spinal Nerve Centres
in
Health and Disease;

with special reference to
the Functional Diseases
of the Spinal Cord.



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Preface

The investigation pursued in the following dissertation deals with a branch of the physiology and pathology of the Spinal Cord.

The subject was suggested by two circumstances occurring about the same time :-

(1) I was called to see a case of paralysis of which the aetiology was at first obscure; but which was ultimately traced to a source of peripheral irritation causing reflex inhibition of a spinal centre.

(see page 97)

(2) The whole subject of nerve-centres and their functions was reviewed shortly afterwards in an elaborate address by Sir Hughlings Jackson at the meeting of the British Medical Association in Leeds.

(14 Aug. 1889)

6.

The present enquiry is limited in scope to the mode of action of the Spinal nerve centres; —

first as observed in experiments on the lower animals:

then clinically as noted in cases of organic disease of nervous tissues in man.

Lastly the functional diseases (to which group the above-mentioned case belonged) are examined in some detail.

G. A. B.

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1.

The Action of the Spinal Nerve Centres in Health and Disease.



The exact diagnosis of a case of nervous disorder is often a matter of extreme difficulty. The symptoms during life may not conform to any known type: and no physical changes may be found in the tissues after death, to account for the morbid phenomena. Yet most of the common methods of classification follow one or other of those lines of enquiry.

The object of this essay is to trace all nervous diseases, in the first place to an altered function of some part of the nervous mechanism; and then, (from investigation of the mode of action of each part under normal and

abnormal conditions,) to reach deductively the cause of the disorder.

But the subject thus stated is too large for adequate treatment in an essay of moderate length. Hence the only diseases included for consideration are those which are related, more or less directly, to morbid conditions of the Spinal Cord.

Of these, again, disorders of the nerve-centres will be specially selected for investigation: — those dependent on organic changes in the nervous structures being briefly alluded to; while the so-called functional diseases are treated more in detail.

A preliminary inquiry into the physiological constitution and function of those centres will first be made.

Part I.

A
erve-Centre

The term "nerve-centre" is applied to a definite portion of nerve-tissue which subserves a certain function. This function may range from the simplest to the most complex: hence the tissues composing a centre may vary from a few cells to large tracts in both cord and brain.

Consider, first, one of the least complicated.

The anatomical basis of a simple nerve centre is one or more cells from which several nerve-fibres proceed in various directions. One of these may be traced to the skin or other sensory surface; and one to a muscle or gland.

The function of such a centre is inferred from observation to be alluded to presently: meantime it

may be stated that the function of the majority of centres in the spinal cord is to bring about the contraction of a muscle, or at least some fibres of a muscle.

(1)

The mode of action of such a centre is as follows:-

One fibre conveys to the nerve a stimulus, which may be termed the sensory impulse. On receipt of this, the cell discharges a certain amount of nerve energy, which passes along another fibre and, reaching a muscle or gland, throws it into a state of activity. This may therefore be called the motor impulse.

(2)

This statement, however, applies to a centre artificially isolated. There are few centres separated so completely from the influence of neighbouring ones. Hence in these the mode of action is more complex. From the nerve-cells composing the centre,

fibres may be traced to other cells in the cord. Along these the sensory impulse may travel, and stimulate more centres than one. From each, an efferent impulse may be discharged and thus an extensive and more or less co-ordinate reflex act takes place.

(3) A third mode of action occurs when the original stimulus comes, not from a sentient surface, but from another nerve centre in cord or brain. In this case the effect may be to rouse to action the subordinate centre, or to modify or check any discharge of energy which may at the time be going on.

Summary. Thus every action traceable to the influence of nerve-centres must belong to one of three groups

- (1) It is either a simple reflex - an afferent or sensory stimulus

giving rise to an efferent or motor impulse.

(2) Or it is a co-ordinate reflex where neighbouring centres in the cord are also called into activity.

(3) Or, lastly, it is completely subordinate to the command of a higher centre — perhaps the very highest in the whole nervous system; and so this group includes all acts of will.

(proof.)

The proof of these statements must now be given. It rests mainly on two series of investigations:-

(1) The complete action of each centre takes place if the essential elements are present and healthy.

(2) If any part of the system be wanting or functionally disabled, then the action cannot be perfectly performed and is either greatly modified in character or altogether absent.

(1)

The simplest method of determining the essential factors of a purely reflex act is to study it in the case of a frog.

First pith the animal, and so isolate the lumbar centre from the rest of the cord. If, after a certain time has elapsed, some stimulus (such as a drop of dilute Sulphuric Acid) be applied to the skin of one leg, — at once that leg will be drawn up. This proves that no part of the central nervous system above the lumbar enlargement is required for the performance of this action.

Let a number of frogs be similarly treated, and it will be found that each reacts to the stimulus as the first did.

But now, in one frog, let the nerves conveying sensory impressions from the leg to the spinal cord

be severed: and if the stimulus be reapplied, no response is given.

Again, let the motor nerves of another frog be cut: here also the muscular reflexes in the affected leg are abolished.

Lastly let the lumbar centre in the cord be destroyed in a third frog; and here no response whatever is given to the application of a stimulus.

These experiments prove that for the accomplishment of a simple reflex act, a definite series of nerve structures is essential, namely:-

- (1) One nerve to conduct the sensory impulse to the spinal cord:
- (2) a nerve-centre there; and
- (3) another nerve to convey the motor impulse to the muscle which is caused to contract.

(2) But mere continuity of nerve structure

is not sufficient to allow of a reflex action taking place. Each part of the circuit must be functionally active. The proof of this statement is furnished by an examination of the power of various chemical substances to suspend for a time, or permanently, the function of some part of the nervous mechanism.

Chloroform and Ether are found (a) to affect the sensory nerves specially; and in an animal placed deeply under the influence of these drugs, reflex action cannot be produced by any form of peripheral stimulus.

Curarin, on the other hand, affects the motor nerves as is proved by the following experiment. Let a few milligrammes of a watery solution of curarin be injected into the dorsal lymph sac of a frog, whose spinal cord has been divided. Any stimulus applied to the skin

(a) Landois and Stirling's Physiology pp 920 & 1158.

of the frog's leg now produces no response: and, when each part of the nervous circuit is examined, it is found that the terminations of the motor nerve in the muscle have been so affected by the poison that their function is entirely suspended. (b)

Lastly many drugs (such as methyl-conine and Morphine) are (c) found to act principally on the nerve-centres in the cord, — reducing or abolishing their function for a time.

[Other influences also affect the excitability of the nerve centre and alter the intensity of the resulting act, but these will be referred to in detail presently (p. 14)].

The above experiments may suffice to show that the essential elements engaged in the performance of a complete reflex act are a nerve cell and two nerve-fibres

(b) Experiment of Claude Bernard.

(c) Lauder Brunton's *Textbook of Pharmacology*, p. 172.

forming a circuit, every part of which must be functionally active.

But it may be stated as an objection to this conclusion, that sometimes acts are observed which seem to prove the existence in the nerve centres of a power of spontaneous action. After a long period of rest, the centres in some animals become specially excitable, and some observers assert that the excitability may reach a point at which the centres discharge motor impulses independently of all external stimuli — i.e. act automatically.

Two experiments in particular are cited in support of this view.

If the spinal cord of a cat be severed in the dorsal region, and if in addition all the sensory nerve roots be cut, so as to exclude all external sources of irritation;

Spontaneous
Activity
of nerve-
centres?

if now dyspnoea be produced, there will presently occur muscular spasms in the hind limbs.

Again, in the case of a dog, if the cord be divided in the dorsal region, the hind limbs are noticed after a time to be subject to constant jerks and spasms. (d)

Yet in each case it is impossible to prevent the action of internal stimuli, and in the first experiment, at least, the presence of venous blood in the cord would form a powerful stimulus to the nerve-cells.

In a few animals, certainly, the spinal centres have no automatic action. For example if a frog, whose spinal cord has been divided, be placed in a position of equilibrium, and protected from all perceptible external stimuli it will remain motionless till it dies.

(d) Michael Foster's Physiology page 543.

Hence it may be inferred that the functional activity of the spinal nerve centres in the lower animals is generally roused by some stimulus, either directly applied to the nerve-cell or indirectly through a nerve-fibre: but it must be granted that in some, under certain circumstances, those centres shew signs of spontaneous activity.

Before the various forms of stimulation are considered, let a passing reference be made to the essential function of a nerve centre.

Function
of a
nerve centre.

If attention be directed to a single centre, such as that constituted by a few nerve-cells in the anterior cornu of the cord, whose normal function is to cause contraction of muscular fibres in part of one of the fore-limbs, — it is found that, however diverse the nature of the afferent

impulse, the resulting action of that centre is always the same in its essential nature and varies only in the amount of energy displayed.

A similar statement will be found to be true of all the other centres; (whose individual functions will be given in detail later. page 32).

Each centre has a definite function to perform; but the extent to which it is performed depends on the degree and nature of the stimulation to which the centre is subjected.

Attention must therefore now be directed to those conditions which have considerable influence in modifying the extent of the reflex act.

They may be arranged in two great classes according to the importance of one of the following elements:—

Conditions
modifying
the reflex
act.

- (1) The intensity and persistence of the stimulus applied.
- (2) The degree of excitability of the nerve fibres and cells called into action.

(1)

As to the first of these conditions little need be said. It is proved in the case of a frog that the application of a drop of **strong** Sulphuric Acid will bring about a more violent reflex than when weak acid is employed.

Further the persistence of the stimulus has an important influence on the reflex act. This is well shown in an experiment on a frog. Let one of its legs be allowed to hang into a vessel containing very dilute Sulphuric Acid, which fails to cause any immediate reflex movement; yet after a certain time has elapsed, the leg is drawn up.

This example of the "summation of stimuli" belongs perhaps to an intermediate class, since the persistent stimulus leads to an increased excitability of the nerve-centre affected. This is proved by the further observation that if the same experiment be repeated soon after, the reflex act takes place when a shorter interval has elapsed.

(2)

But the second group of conditions which modify the action of a nerve-centre is of more importance and demands careful investigation.

The excitability of any part of the nervous mechanism may be either depressed or excessive.

Consider the former condition first.

The functional activity of the nerve-fibres (both afferent and efferent) is reduced by subjecting them to

continued severe pressure or stretching, or by the application of cold to the extent of $+5^{\circ}\text{C}$. (e)

Many drugs have a similar influence — for example, curarin in affecting the terminations of the motor nerves, and aconitin those of the sensory fibres. (f) (g)

The nerve-cells also have their excitability reduced by various circumstances. If the blood supply be greatly reduced, or if there is a marked deficiency of oxygen in it, their functional activity is diminished: so also if a current of galvanic electricity be caused to pass along the spine from above downwards.

Many drugs have a similar action on the nerve-centres, and among these may be mentioned Chloroform,

(e) Landois and Stirling loc. cit. p 779 & 905
 (f) Landois and Stirling loc. cit. p 698
 (g) Lauder Brunton loc. cit. p 833.

Picrotoxin, Chloral, Bromide of Potassium, (h)
Chloride of Ammonium, and Morphine.

Lastly the excitability of the centre is rapidly exhausted by a series of stimuli evoking energetic reflex acts.

On the other hand, the functional activity of the reflex arc is increased by a variety of circumstances. The moderate application of pressure, stretching or cold is found to raise the excitability of the nerves. And the centres are similarly affected by many drugs such as Strychnin, Caffein, Carbonic Acid and Atropin.

In the case of strychnin, the excitability of the centres is so greatly increased that a slight stimulus suffices to bring about an energetic and extensive reflex act.

(h) Landois and Stirling loc. cit. p 907.

But this experiment compels one to extend the field of observation.

Up to this point the only elements under consideration have been a single nerve-centre comprising a nerve cell and two nerve fibres — those engaged in a simple reflex act.

All the circumstances affecting such a centre have been referred to.

Now it will be of advantage to study the combined action of adjacent centres; and then the mutual influence of all the centres in the cord.

adjacent centres:

their combined action.

The co-ordinate reflexes resulting from the action of more than one centre may best be studied in a frog. Let the spinal cord be divided in the cervical region, and then let a series of stimuli of gradually increasing intensity be applied to its right foot.

A weak stimulus may cause the right foot to be drawn up. If, after an interval, a stronger stimulus be applied, both legs will now be withdrawn. An excessive stimulus may bring about contraction of the muscles in the trunk and fore-limbs as well.

A similar series of results may be obtained, if, instead of increasing the stimulus, one were to increase the excitability of the nerve-centres in the cord by suitable doses of strychnin.

The anatomical basis for those phenomena is the presence in the anterior cornua of the cord of numerous multipolar nerve-cells connected to one another by nerve-fibres. And the physiological explanation of the actions observed is that a stimulus reaching one nerve-centre may (owing to its own intensity or

the unusual excitability of the centre itself) be passed on to other centres in the vicinity; and thus bring about an extensive reflex.

Yet apart from an excessive stimulus or excessive irritability of nerve elements a peculiar kind of co-ordinate reflex may be observed in a frog and other animals, — one which implies the activity of centres at a distance from each other.

Centres at a distance: their action.

For example, let a piece of blotting-paper soaked in acetic acid be applied to the left flank of a "pithed" frog: presently the left leg will be raised to remove it, and usually succeeds in doing so.

This so-called 'purposive' act can be explained in one of three ways:—

- (1) The sensory impulse may have spread to all the centres in the cord: but only a few of these responded.

(2) It may have passed readily to the few centres only whose co-operation was required to effect the required movement.

(3) Lastly it may have passed to a higher centre in the cord, — one whose function had to do with movements and not with muscles, — i.e. one which had the power of calling into activity certain groups of nerve cells, whose united action brought about the contraction of the muscles required and in such a way as to effect the removal of the irritant.

The last of these affords the best explanation of the facts. We thus reach in theory the first indication of what Sir Hughlings Jackson calls the "hierarchy of nerve-centres," — which (j) it is one object of this essay to investigate, and whose mode of action in health and disease is so deserving of study.

(j) British Medical Journal 1889 Aug 17. p 361

The proof of the anatomical existence of these centres in the cord is not complete; but the exact locality of similar centres in the brain is well-known; and analogy lends this theory a great measure of probability.

The centre may be supposed to consist of a few nerve-cells situated in the grey matter of the cord, and connected by means of nerve-fibres with multipolar cells in both anterior and posterior cornua.

The function of such a centre would be to receive impulses from the sensory ganglion and to discharge impulses to special motor ganglia whose action will call the required muscles into activity.

While lower centres have only power over individual muscles, this centre can regulate the action of a group of muscles. It can

thus preside over movements.

By a slight extension of thought it may be expected that there are as many of those reflex higher centres as there are varieties of movement capable of being accomplished by the spinal cord alone. And, as many simple movements are frequently associated in one complex action, those centres would be subordinate again to others.

Thus all the centres in the cord might be arranged according to function, in a series commencing with those which have to do with the management of a single muscle, — and ending with those which superintend the execution of the most complex and co-ordinate movements, traceable to the unaided action of the spinal cord.

(Proof)

A few examples will make clear the physiological basis of this theory. Consider first some which shew a positive action of these centres.

(1)

In a dog let the spinal cord be severed in the dorsal region; and, after an interval has elapsed, let the skin in the posterior half of the animal be tickled at one spot, — say, the left gluteal region. At once the left hind leg will be raised to scratch the spot, — an action requiring the co-operation of centres at some distance from one another, and moreover a delicate adjustment of the amount of energy discharged by each.

Similarly, the complex acts of micturition and defecation can be brought about in such an animal by a variety of stimuli.

Yet there is a limit to the quality and quantity of the stimulus, for the irritant must be applied to a sentient surface, and must not be excessive. If the stimulus be applied to the trunk of a nerve, a more or less extensive reflex of a simple nature may be elicited, — but not the peculiar form of reflex at present under consideration.

Further, if the stimulus be excessive in degree, — even though applied to a sentient surface such as the skin, — an entirely different result is produced. The expected reflex does not occur; or, if it were at the time in process of accomplishment (eg. micturition), it is at once checked.

2) As an example of this curious effect, the following experiment on a frog may be referred to. If the frog be pitted, and a stimulus

be immediately afterwards applied to the skin of one leg, — no reflex occurs. Nor can any be elicited till some time after, when the shock produced by section of the cord has passed off.

(k)

And even then, if the sciatic nerve of one leg be kept in a continual state of excitement by a strong current of faradic electricity, — the application of a moderate stimulus to the other leg will be followed by no reflex whatever.

In these cases a reflex act is prevented by a previous and persistent stimulation: but after it has been started it may be suddenly checked by some acute irritation of the skin. For example, after micturition has been begun in a dog, (whose spinal cord has been divided,) a sharp pinch applied to the skin of one leg will at once arrest the act.

(k) Michael Foster loc. cit page 542.

In each case it is noticeable that the amount of stimulation required, either to produce or to check a certain reflex act, must reach a minimum intensity, — otherwise the result does not follow. And to obtain this, ^{sometimes} a combination of stimuli is required. For example let the spinal cord of a dog be divided in the dorsal region. Some time afterwards when the bladder is nearly full, let the anus be gently sponged, and the reflex act of micturition will be at once elicited. Later, when the bladder is nearly empty, let the anus be sponged as before and this time no reflex is produced: but as soon as the amount of the combined stimuli reaches the minimum required to rouse the nerve-centre to action, — micturition is started.

Similarly, a combination of acute stimuli, — each sufficient merely to modify the energy of the reflex act, — when occurring at the same time, may succeed in checking it altogether.

Inhibition.

These phenomena bring into view the great fact of *Inhibition*, which is so important an element in the influence of one nerve-centre over another. Its exact nature is unknown; but several hypotheses have been put forward with regard to it.

- (1) One is that a peculiar form of nerve energy is transmitted along a special nerve-fibre from one cell to another, and restrains the discharge of energy from the latter.
- (2) Another theory is that no special system of inhibitory cells and fibres need be postulated; but that the peculiar form of nerve energy

accompanies the normal impulse to the muscle and counteracts it, just as two waves of light do in phenomena of "interference." (l)

(3) A third explanation may be suggested, by comparison with the phenomena of "attention" in the higher centre in the brain.

Let that condition of a nerve-cell in the cord which leaves it open to the reception of a sensory impression and ready to respond to it, — in short, its excitability, — be termed "spinal attention"; and it is found that what is true of the brain is in this case true also of the cord.

When the "spinal attention" is not confined to any special part, all centres are excitable and any reflex is readily elicited.

If, however, a previous stimulus has drawn the whole "attention" to one spot, (as in the case of shock

(l) *Lauder Brunton loc. cit. p. 167.*

from severe localized injury,) the other centres are very slightly excitable, and reflexes fail to act.

Lastly, if a reflex movement be in process of execution, and a sudden sharp stimulus be applied, it withdraws all the spinal attention to another quarter, leaving the centre in question almost non-excitable, and so its motor impulses come to an end: the reflex act is checked.

Whether the second stimulus will be sufficient to check an action in process of accomplishment, — or modify it in any way, — will depend on two conditions:—

1. The intensity of the stimulus:
2. The amount of excitability remaining in the centre which it first affects.

Undoubtedly some phenomena are best explained by a mutual

counteraction of stimuli either in the nerve-cell, or in the motor nerve-fibre beyond. But other cases seem to be more readily explained by the reduced excitability of the centre itself.

The various conditions which modify the action of a given nerve-centre have now been considered. It remains, therefore, to glance at the various functions which are latent in the spinal nerve-centres, and only await a suitable stimulus to be realized in action.

These functions are motor, secretory, or atrophic in character

Of the motor ones affecting non-striated muscles, the following may be noted as well-defined examples:-

1. The cilio-spinal centre which has to do with dilatation of the pupil:

Functions
of
nerve-centres

(1)

2. The Ano-Spinal centre presiding over the act of defecation:
3. The Vesico-Spinal centre regulating the act of micturition.
4. Centres for erection, ejaculation and
5. parturition may also be mentioned.
- 6.
7. Further the non-striated muscular fibres surrounding the blood-vessels are also controlled from a series of spinal centres, which again are subordinate to the general centre in the medulla oblongata. Vaso-motor centres have been proved to exist in the cord: and vaso-inhibitory ones are believed to be present too. [The further investigation of this subject is deferred meantime: it will be referred to later in its relation to central and peripheral ^{nervous} centres.] (see page 40)

The voluntary muscles in trunk and limbs are immediately regulated by a series of centres in the anterior cornua of the cord, and these again are subordinate to higher centres in the cord and the brain.

(2)

Of the secretory functions, the chief regulates the secretion of sweat from the skin; and, as this is in some respects peculiar in its action, it deserves to be specially investigated.

The existence of a distinct centre and efferent nerves for this function is proved by the following experiment.

Let the sciatic nerve of a kitten's ^(m) leg be cut, and then let the animal be placed in a hot air chamber. Presently the three intact limbs will become bathed in sweat, while the other limb remains quite dry. But now let that limb be removed entirely from the body and a stimulus applied to the end of the sciatic nerve. At once sweat will be secreted all over it. This experiment also proves that the sweat-secreting apparatus can act quite independently of the vaso-inhibitory

(m) Landois and Stirling loc. cit. p 670.

system, regulating the supply of blood to the glands; and also independently of the system regulating the contraction of the non-striated muscular fibres round the sweat-glands.

Normally, however, the action of all these systems is combined and produces a greater effect.

The sweat-centre for trunk and limbs is found to be situated in the anterior cornua of the spinal cord. Afferent impulses reach it through the common sensory nerves, and efferent impulses pass along the nerves which accompany the motor strands, and so reach the glandular structures which they rouse to action.

The normal stimulus is the application of heat to the peripheral extremities of the sensory nerves in the skin; but irritation of the nerve-trunk itself will call forth

the reflex secretion. For example let the brachial plexus of a cat be divided and its central end be stimulated, — sweat will immediately be secreted on the foot of the opposite side.

The centre itself may be directly stimulated by various conditions.

If the blood be overheated, or deficient in oxygen, — or if one of the following drugs be administered:

Calabar Bean, Nicotin, Picrotoxin, (n)
Camphor, Ammonium acetate,
the centre is roused to action.

The efferent nerve may be excited by electrical stimulation, and by the action of pilocarpin or muscarin circulating in the blood. On the other hand, the function of the secretory nerves is completely abolished by the administration of Atropin.

Lastly all the sweat-centres

(n) Landois and Stirling loc. cit. p 962.

in the cord may be excited to action by an impulse from the higher centre in the medulla oblongata.

Other secretory centres may exist in the cord, — possibly controlling the sebaceous secretion and also that intra-cellular secretion termed pigmentation; but as yet nothing is known of the mechanism.

In the phenomena of pigmentation, at least, there are many indications that some central agency regulates the whole: and indeed such a centre would be intermediate in function between that of secretion and trophic influence — both of which are under central control.

(3) Only one function remains to be considered namely that of trophic influence.

The existence of this system is

proved by the following experiments.

Let one sciatic nerve of a growing animal be cut; and growth ceases in that leg, — the bones even becoming lighter than before the operation took place. But in another animal after the nerve has been cut, let a continuous source of irritation be applied to the peripheral end (e.g. by some threads dipped in sulphuric acid). The result will be a marked hypertrophy of all the structures of the leg. (o)

These experiments prove the existence of trophic nerves; and the following one demonstrates as conclusively the existence and situation of the trophic centre.

If the spinal cord of a kitten be divided in the dorsal region, the (p)

(o) Landois and Stirling loc. cit. p 838

(p) Brown Sequard, Experimental Researches p 14.

Two hindlegs will continue to grow exactly as the fore legs do. The trophic centre for the hind limbs must, therefore, be in the Lumbar enlargement of the Spinal cord.

Further investigation points to the grey matter as containing the centre in question, — the anterior cornua being concerned in maintaining the trophic condition of muscles and joints, while the posterior cornua are similarly engaged in influencing the nutrition of the skin and the remaining tissues. { Changes in particular tissues referable to altered function of this centre will be alluded to in detail when the morbid appearances observed in man come up for investigation. } (page 76)

Summary

To sum up, then, — the functions of the Spinal Nerve Centres may be classified in three groups:—

motor, secretory, and trophic. Each of these is capable of further subdivision; and each is subject to a great variety of modifying influences. Of these some act directly on the centres; others indirectly through sensory nerves, and some come from other centres in the cord. In each case the result is that a function, before dormant, may be roused to action; or if already in action it may be increased or reduced in intensity, or altogether checked.

Influence
of
a-Spinal
centres.

It now remains to consider the influence of centres outside the cord upon those within it.

For this purpose let one special system be investigated.

The existence of vaso-motor centres in the cord has already been referred to. (page 33)

The chief centre however is situated in the medulla oblongata. If this area in a frog be stimulated (g) by repeated induction shocks, the blood pressure is raised all over the body: and the same result is obtained even though the contraction of all voluntary muscles be prevented by the previous administration of curarin.

On the other hand, if the spinal cord be severed from the medulla, there is an immediate fall in blood pressure. In the former case the vaso motor centres in the cord were stimulated, in the latter temporarily paralysed.

Soon however, they recover their previous activity; for the blood pressure rises again to the normal: and if a sensory stimulus be applied to the hind foot, a reflex contraction of the arteries occurs.

(g) Landris and Sterling loc. cit. p 952.

But now let the whole of the spinal cord be crushed, — so as to abolish at once the function of all the spinal centres. An immediate relaxation of the arterial coats takes place, and the blood pressure falls.

Once more, however, after some time has elapsed, the arteries recover part of their tone; and the rhythmic movements, — normal in some animals, — reappear.

This phenomenon is explained by the presence and activity of peripheral ganglia situated along the course of the vessels, and capable of acting independently of all higher centres.

The action of those peripheral centres exactly resembles that of the higher ones in the cord.

A stimulus applied to the vessel wall, or venous blood reaching the centre itself brings about a

contraction of the fibres surrounding the vessel.

But even in the absence of all peripheral centres of a nervous kind, — the tissues have the power of producing changes in the vascular tone. This is proved conclusively by an experiment with an egg about the fourth day of incubation. By that time, vessels can be detected in the umbilical membrane, — but no trace of any nervous mechanism. Yet if a drop of nicotine be applied to any point in this vascular area, there follows at once an intense congestion.

An experiment on a frog may be cited in support of the action of the peripheral centres, or of the tissues themselves. If all the nerves in a frog's leg be cut, and a drop of nitric acid be placed on its

(r) Charcot Lectures on Diseases of Nervous System 1887 Ed. Soc. page 121.

foot, intense hyperaemia will follow. Whether the tissues or the peripheral nerve-centres have most to do with this result, it equally proves their independent power of action, — apart from the centres in the cord.

Influence of cerebral centres.

As to the centres in the brain only two kinds of influence need here be mentioned:—

- (1) Their power of calling into activity the lower centres in the cord
- (2) Their power of modifying or altogether arresting an action in process of accomplishment.

1. The former statement is proved by stimulating a motor area in the cerebral cortex of a frog, when at once a leg will be caused to move.

2. The latter fact is readily proved by the following experiment:—

Let the cerebrum be removed from a frog: if now the hind limb be stimulated, it will be withdrawn as usual. But let a crystal of salt be placed on the optic lobes, and the same stimulus reapplied: no reflex can now be elicited.

If the spinal cord be severed from the brain, and an interval be allowed to elapse, the repetition of the stimulus is at once followed by the usual reflex. The inhibitory influence of a cerebral centre on those in the cord was in the first case augmented, and in the second abolished.

The power of the higher centres does not, however, extend to all those in the cord, nor is it sufficient in all cases to inhibit an action in course of execution. [But these matters will be referred to more particularly

when the action of similar centres in man are under consideration.]

Summary

Meantime, it will be of advantage to summarize all the inferences that have been drawn, with reference to the action of centres in the spinal cord, from experiments on the lower animals.

Considered from a physiological point of view, the spinal cord is a great series of centres more or less intimately associated with one another. They control all action, secretion and growth in a large part of the body. They are normally excited to action by a stimulus applied to the skin, or by an impulse from some centre in cord or brain. But each centre has a certain degree of freedom to energise by itself;—

Though never perfect; and the degree to which a centre is roused to action depends on a great variety of conditions. These have been considered in detail; and the striking fact has been noticed that one centre may have the power of augmenting or inhibiting the activity of another.

Hence the spinal centres have been arranged in a series according to increasing complexity and range of function: and it has been shewn that while lower centres have only the power to call into activity muscle or gland, — the higher centres control the lower: (and these in turn are controlled by still higher centres in the brain).

Such is the hierarchy of nerve centres in the Spinal Cord as inferred from observations on the lower animals.

Part II.

Now the question presents itself:- Does the same arrangement of nerve-centres exist in the spinal cord of man?

From analogy we would expect it, and by observation the truth of it is conclusively shown.

Yet there are two well-marked differences which those observations reveal:-

(1) Those centres which have the highest function in the cord of the lower animals are in man transferred to the brain.

Hence the purely spinal reflexes in man are less complex and less co-ordinate than they are in the lower animals.

(2) Even those centres which remain in the cord in man are less independent than the corresponding

ones in animals. Indeed they cannot act without assistance from higher centres in the brain; as clinical observations show, — (which will presently be given in detail). (see page 70)

With these two exceptions, the mode of action of the spinal centres is very similar in both animals and man.

It is in the department of pathology, however, that the knowledge gained from observations on animals will be most serviceable, — by suggesting an explanation of morbid phenomena in man, and especially the most puzzling group of these, — the functional neuroses.

Consider first a simple centre such as that which calls into action the muscles of a limb.

Its anatomical position is in the anterior corner of grey matter

normal
section
of a
spinal
centre.

in the spinal cord; and its activity is normally aroused in one of three ways:—

- (1) Reflexly, by a sensory stimulus from the skin &c.
- (2) Co-ordinately, by an impulse from another centre in the cord.
- (3) Subordinately, by an impulse from higher centre in cord or brains

When all the essential nervous elements are present and functionally active, the application of an appropriate stimulus to the skin is followed by a movement of the limb or limbs in a measure proportional to the intensity of the stimulus.

For example

- (1) If the foot be tickled, the leg is drawn up.
- (2) If the stimulus be strong, both legs are withdrawn.
- (3) If the person wills to move his leg, that action follows.

Such are examples of the three kinds

of reflexes:— simple, co-ordinate and subordinate.

Abnormal action of a spinal centre.

But sometimes the reflex act is greatly modified in character, or altogether fails to appear.

The interpretation of such a circumstance is of great importance in the study of the abnormal action of the spinal centres.

the causes.

Hence a review of all the possible causes of such a result will now be made.

It may be traced to an altered condition of the nervous mechanism engaged; and first let that part of the reflex arc be briefly considered which lies outside of the spinal cord, — in other words, the sensory and motor nerves.

Altered condition of the nerves.

Alterations in these may be of a mechanical, chemical, or vital nature.

A. In the first class, the nerves

may be subjected to section, pressure or stretching; and on the extent of the irritation or destruction of the nerve will depend the degree of impairment of its functional activity.

Complete section of a nerve at once abolishes its power of conducting impulses; and so does extreme compression as by a large tumour, or in the familiar examples of so-called "crutch-paralysis" and "Sunday-morning paralysis", where the brachial nerves have been firmly compressed. A similar result follows over-stretching of the fibres as in the case of a child suddenly dragged or carried by means of one of its arms. The whole arm becomes presently paralysed, owing to the extreme stretching of the fibres in the brachial plexus.

But when these conditions are less complete, an entirely different series of phenomena is observed.

The partial section of a nerve leads to symptoms of great irritation among which may be mentioned acute Herpes Zoster and rapid atrophy (s) of muscles and bones.

Slow continuous pressure, (for example gluteal aneurism pressing on the sciatic nerve) leads to similar results: so also if the tumour stretches the nerve instead of compressing it. (t)

From these and other observations one may infer the results of a gradually increasing source of mechanical irritation. At first the excitability of the nerve—(both to sensory and motor impulses) is increased, as shewn by tenderness of the skin, and muscular twitchings. Gradually,

(s) Mitchell and Keen "Gunshot Wound" p 71.

(t) Fagge "Principles & Practice of Medicine" vol I p 425 & 483.

however, the power of conveying motor impulses is lost; and sensory impulses alone are passed along the nerve. Finally both sensory and motor paralysis is complete.

The importance of this fact will be seen when the results of compression of the cord itself come under discussion. (page 60)

B. Chemical influences to affect the functional activity of nerves.

Aconitin paralyses the peripheral terminations of the sensory nerves; and curarin those of the motor nerves, as observed in cases of poisoning by these drugs. But the trunk of the nerve too is affected by a poisonous environment. This was well shown in the case of a woman (v)

(v) Lauder Brunton loc. cit. p 833 & p 147

(w) Fagge loc. cit. vol I p 399.

who suffered from complete paralysis of sensation and motion below the knee in both limbs. The cause was found to be a large collection of pus in the pelvis surrounding and poisoning the nerves.

C. Lastly a combination of both mechanical and chemical irritants due immediately to vital changes in or near the nerve may seriously affect its functional activity. Such a condition is found in cases of peripheral neuritis. The nerve becomes swollen, and soon pressure symptoms appear, especially if the nerve has a dense perineurium or lies in a bony canal. At first the symptoms are those of irritation, but later both motor & sensory paralyses may supervene.

{ Other conditions of a more general nature, such as the quality of the blood supply, and the intrinsic vital power of the nerve under ordinary circumstances will be considered along with changes in the intra-spinal nervous tissue which is affected at the same time. }

(see page 68)

Altered
condition
of
endorgans

A passing reference must be made to the peripheral endorgans in skin and muscle. Their functional activity is greatly increased by moderate irritants, such as heat and friction. On the other hand, it is diminished or even abolished by extreme heat or cold, by various poisons, or by a crush sufficient to deprive the tissues of their vitality.

Thus, to sum up the inferences already drawn, the amount of energy displayed in a reflex act depends on:-

1. The intensity of the stimulus;
2. The excitability of the peripheral sensory organs;
3. The functional activity of the sensory nerves;
4. The condition of the centre itself;
5. The functional activity of the motor nerves;
6. The excitability of the peripheral motorial end plate and the muscles.

There remains, therefore, to be considered only the condition of the centre itself; - namely the group of nerve-cells and their branches in the cord, which together complete the reflex arc.

Altered
condition
of the
centre.

Here again the disturbing influences may be reduced to three classes:— mechanical, chemical and vital.

A.

Among the destructive mechanical conditions may be mentioned:—

- (1) Section of the cord, — as in cases of dagger wound of the back.
- (2) Compression from without as by tumour or dislocated vertebra; or from within as by tumour or effusion of blood in the cord.
- (3) Extreme stretching: but this apart from compression of the cord is rarely observed in man. (x)

In these cases there is complete suspension of the function of the tissues affected: and if the centre in question be situated at the spot, its action is at once abolished. No reflex acts of any kind can be elicited.

(x) See a case reported in British Medical Journal
5 April 1890 p 775.

If, however, the seat of lesion be above that centre, a different result is observed. At first, indeed, all reflexes are abolished; but after a few days they can again be elicited, and later they become very active. This is well seen in the case of fracture with displacement of a cervical vertebra. The explanation seems to be that the abolition of reflexes at first is due to the shock; and when that has passed off, the reflex activity of the centres in the cord returns, and, as all inhibitory influence of higher centres is now cut off, the activity of the former becomes exaggerated.

But if the section or compression be less complete, other peculiarities of function are observed. For example it frequently happens

that sensory impressions are perceived in the lower limbs long after paraplegia has become complete. This was well shown in the recorded case of an old woman who suffered from complete paraplegia, but still retained some degree of sensation in her legs. After death, the spinal cord was found enveloped and compressed in a dense arachnoid which sent thick septa into its substance. (3)

Consider now the effect of a localized lesion. When the posterior columns of the cord are enveloped in dense tissue and so subjected to compression as in cases of Locomotor Ataxia; — sensory impulses are seriously interfered with in transmission and sometimes arrested altogether. As a consequence, reflex action in the

(3) Fagge loc. cit. vol I page 494.

lower limbs is often entirely abolished. Most commonly the knee-jerk cannot be elicited, and the plantar reflex diminishes in proportion to the plantar anaesthesia. Yet in an uncomplicated case, there is no loss of motor power.

The quantity of energy discharged from the centre in the lumbar part of the cord is unaltered; but the quality of the resulting action is entirely changed. The reason is that the afferent sensory impulses which contribute to the co-ordinate^{movement} of the limbs are now in great measure checked on their way, and the centre thus crippled fails to act properly.

On the other hand, infiltration and compression of the lateral column (as in primary lateral sclerosis) is followed by very remarkable results. The reflex

mechanism of centres below is unimpaired; indeed their functional activity becomes greatly increased. The explanation is that impulses, — both motor and inhibitory, — are now prevented from reaching the centre in question. The fibres in the lateral columns were concerned in conveying those; but their function has been abolished by the undue compression to which they were subjected.

Another effect is produced when the nerve-cells in the anterior cornua are put out of existence in any way.

Sometimes the mechanical process, by which this is accomplished, is evident (eg. extension of chronic infiltration from the lateral or posterior columns): sometimes its nature is unknown: but in each case a very definite result follows.

The muscles supplied by them are at once paralysed; no contraction can be brought about either reflexly or by voluntary impulse. Moreover atrophy rapidly makes its appearance: yet sensation is unimpaired.

The simplest example of this condition is acute Infantile Paralysis or Poliomyelitis Anterior Acuta as it is called from its possibly inflammatory origin. In the subacute form of the same disease, a similar destruction of the nerve-cells leads to a similar series of symptoms varying only in the time and manner of invasion. In the chronic form (or progressive muscular atrophy) the same cells are attacked and slowly destroyed; but as healthy cells exist alongside of those, the symptoms are less evident. A certain amount, however, of paralysis and atrophy of the muscles, with a

corresponding diminution in the activity of the reflex actions is evident.

Thus the results of the mechanical changes in the Spinal Cord with respect to the centre under consideration may be summarized as follows:-

1. If an extensive lesion affect the part where the centre exists, — its function is at once abolished.
2. If it occur in some segment of the cord above this centre, its function may be abolished at first, but it soon returns and assumes even an exaggerated form.
3. If the posterior columns alone are affected, the simple reflexes may be abolished while those subordinate to voluntary impulses remain, — the same in force, but deficient in co-ordination.
4. If the Lateral (and anterior) columns are affected, the simple reflexes remain,

— indeed become exaggerated; while those subordinate to voluntary impulses become difficult, irregular, and at last impossible.

5. Finally if the nerve-cells in the anterior cornua be attacked, reflexes of all kinds are abolished. No amount of peripheral stimulation, — no force of central voluntary impulse, — can elicit the least response.

B. Now let the changes produced in the spinal cord by chemical means be investigated. Only the earlier stages of these lesions need be studied; for it is found that if the drug be long administered it invariably brings about the atrophy and disappearance of the nerve elements; — and then the symptoms are sufficiently explained by the physical changes.

With reference to the conducting functions of the cord, it may be briefly stated, that caffeine has a paralyzing influence on the sensory fibres; while chloroform and ether (at a certain stage in their action) paralyse the fibres conveying painful impressions.

(z)

The drugs, which act on the nerve-centres themselves, may be divided into depressant and excitant; but many of the former have a short preliminary exciting stage as in the case of alcohol; and others have a concluding convulsive stage, as belladonna. The chief example of a simple excitant is strychnin, and of a simple depressant is methyl-strychnin; while a mixture of both leads to a first stage of paralysis, followed by a period of convulsive seizures.

(a)

(z) *Lauder Brunton* loc. cit. p 160.

(a) ditto p 172.

Such are the typical changes produced by drugs on the functions of the spinal cord: but the action of any particular drug depends much on the quantity administered and in large doses every one may lead to paralysis of the centres in the cord.

Further, if the blood supplied to any part of the cord be greatly reduced in quantity, these centres have their activity diminished or abolished. Such an effect may be due to the absorption of digitalin and consequent contraction of the arterial walls, — or to a physical narrowing of the same for example by syphilitic endarteritis. In a case (b) of the latter, all functional activity of the lower limbs and all reflexes there were abolished in consequence of the anaemia produced in the lumbar enlargement of the cord.

(b) Fagge loc. cit. vol I p 465.

The presence of venous blood in the cord leads first to stimulation and consequent convulsions, and later to paralysis.

Extreme cold causes a rapid diminution in function of all the centres.

C. Lastly, in the absence of all direct irritants, it is evident that different cells in the cord have different degrees of functional activity. They vary in different men; and in the same man at different times. It may even happen that their functional activity may cease some hours or (in some cases) days before life is extinct in the rest of the body. Such a condition has been observed in the last stage of mercurial poisoning and of Paralysis Agitans, — the limbs previously in incessant

(c) Charcot loc. cit. page 149.

motion gradually passing into a state of rest. The vital energy of the nerve centres had vanished.

Automatic action?

Before proceeding to investigate the various functions which these modes of stimulation can rouse to activity, - I shall endeavour to answer a question which naturally presents itself here: -

Can any spinal centre act independently of all stimuli?

This cannot be settled directly, for it is impossible to exclude all internal stimuli. Still on reviewing a few cases the answer might possibly be affirmative; and analogy would lead one to expect that under certain circumstances the centres might act automatically.

But lately this belief has been entirely set aside by Dr Charlton Bastian (d) who has brought forward a number

(d) British Medical Journal 1/3/90 page 480.

of clinical observations in support of the fact, — that, in a complete transverse lesion of the spinal cord in the cervical region, the centres in the rest of the cord cannot be roused to action by any form of peripheral irritation. In other words, in the absence of cerebral aid, the spinal centres in man are entirely powerless.

This statement contrasts strongly with the commonly received opinions regarding reflex action. It is also contradictory to the inferences from experiments on animals. But analogy cannot be depended upon here, and the clinical observations all go to support the new opinion.

In twelve cases of injury to the spine causing a complete transverse lesion of the cord in the upper dorsal region and limited to that part, — the reflexes of

71

centres below were abolished at once and continued to remain absent for weeks.

No doubt partial lesions of the cord may affect the reflex activity of centres below the seat of lesion in various ways — (even sometime increasing it) — if some nerve energy can still be transmitted to these from the cerebral and cerebellar centres. But this is no disproof of the statement that when spinal centres are entirely cut off from assistance from higher centres, — their power of action is at once and permanently abolished.

It follows from this, that the purely automatic action of spinal centres in man is quite impossible.

Up to this point, only a simple spinal centre in man has been

under consideration; and all the possible modes of stimulation and degrees of excitability have been discussed. The only result of the action of such a centre, however, would be to discharge a motor impulse of a greater or less intensity, and bring about a more or less energetic contraction of a single muscle.

It now remains to review briefly the special kinds of function latent in the spinal centres, and ready for exercise on receipt of an appropriate stimulus.

As in the case of the lower animals these functions may be arranged in three groups, according as they bring about motor, secretory or trophic results. These again may be subdivided into the series previously enumerated; since the

functions
of
spinal
centres.

normal action of those centres in man corresponds very closely with that in the lower animals.

[The list need not therefore be repeated here.]

(see page 32)

But their abnormal action in man is very interesting, and demands a short notice.

- (1) Of the motor functions little need be said. The resulting contraction in a single muscle may be too feeble or too energetic, tonic or clonic in character. If, however, the function of the centre be to regulate a group of muscles; and any part of that centre be in an abnormal condition, an unusual alteration is observed in the resulting movement. Instead of being co-ordinate, it becomes quite irregular, even unrecognisable: yet on analysis it is found that the immediate

cause is the inaction of one or more muscles and the excessive activity of others. This will be found to apply to all the disorders of function of the higher motor centres.

A similar series of phenomena is observed in the action of the non-striated muscles. For example those of the bladder may be in a condition of tonic or clonic contraction or on the other hand persistently relaxed. The failure of co-ordinate movement here leads to the various forms of vesical colic and incontinence: but in this case again the immediate cause is excessive action of one group of muscles and inaction of others.

(2). Similarly in the case of the secretory centres, their chief simple variations in action are those of

excess and defect. But the disorders of co-ordination here lead to very peculiar results, — for example the secretion of coloured sweat, and of milk which proves at once fatal to the infant receiving it.

As observed in the lower animals, the sweat centres are distinct from the others (eg. the vaso-inhibitory) though these usually act together. In a paralysed limb the arterial walls may be widely dilated and yet no secretion of sweat occur there. On the other hand, the cold sweats, — frequently caused by emotion — occur when the arterial walls are strongly contracted. The centre for each function is distinct, though often co-operative.

(3)

The effects of the activity of the trophic centres are very striking.

(e) Ross. The diseases of the nervous system
vol I page 218.

At times they consist in rapid and excessive growth of tissues; (cf. the hair of the eyebrows during slight supra-orbital neuralgia.) But more frequently disorder of the function is in the direction of defect; and the result is the atrophy of all the tissues supplied from that centre. The skin becomes thin and glossy; hairs drop off; glands vanish; muscles atrophy and bones become brittle and light. Joints lose their articular cartilages and the ends of the bones gradually wear away.

These changes are usually slow; but sometimes they occur with great rapidity. In that case, herpes and pemphigous bullae may appear on the skin; and the joints may become acutely inflamed and distended with fluid and rapidly undergo disorganisation. {The explanation of

(f) Mitchell Morehouse and Keen
"Gunshot Wounds" page 71.

these changes will be referred to (page 80)
 presently.] Lastly, if the patient
 be a child, and the function of
 a trophic centre for a limb be
 entirely suspended, the further
 development of that limb is permanently
 stopped.

Some questions naturally present
 themselves for answer here.

1. Is this trophic function secondary
 to some other (e.g. that which
 maintains vascular tone); or
 may it act and be affected
 independently?

Two groups of cases prove its
 independence of neighbouring centres
 in the cord. In infantile paralysis
 the atrophy is marked and rapid;
 yet no vaso-motor disturbance is
 noticed, nor is the temperature
 of the limb at all raised.

On the other hand, cases of
 hysterical ischaemia occur in which

not even a drop of blood exudes on pricking the skin; yet no trophic disturbance of any kind occurs. (9)

2. Is this trophic influence conducted along a special set of nerves, or along nerves already subserving a definite function, (eg. conveying motor or sensory impulses) ?

Since the trophic function has been proved to be distinct from all others, it is natural to suppose it has a special set of efferent nerves as well as a centre. But the question is one of secondary importance here: though it has an important bearing on whether one nervous structure can discharge two functions; — its own and that of another which has been destroyed. [The subject however will be referred to again later.]

(page 86)

(9) Charcot loc. cit. page 115.

3. One important question remains:—
Is the maintenance of the normal
condition of the tissues entirely
dependent on trophic influence
from centres in cord and brain?

The answer must be in the negative.

There is indeed a close relationship:
but yet up to a certain point, the
normal condition of the tissues
can be maintained in the absence
of all trophic influence from a
distance. This was shown to
be the case in the lower animals;
and clinical observations on man
largely support it. But here
an important difference must be noted.

It is found in one set of cases
(eg. in simple section of a nerve) that
when the stimulating influence of
the higher centres is cut off from
the tissues, the latter maintain
their trophic condition for a
time and then slowly atrophy.

If, however, the nerve be torn, and so irritated, — an entirely different series of phenomena occurs. The tissues waste with great rapidity; — indeed become acutely inflamed and the skin ulcerates. (i)

These observations prove that up to a certain point, the tissues have the power of maintaining their own trophic condition. But when placed in circumstances of irritation, they require the aid of higher centres to maintain their normal condition: and if that be wanting they rapidly degenerate with signs of inflammation and ulceration.

Similar properties may be proved to belong to all the various tissues.

Every cell has the power of absorbing and excreting

matter, and so maintaining to a certain extent its own trophic condition.

Some have also the power to excrete a definite quality of matter and are hence termed secretory.

Others have the power of moving one part of the cell closer to another and are thus termed motor.

But such power in each case is very limited. It is increased and called into action and regulated by higher centres, through the medium of nerves.

Those centres again are subject to others, and this arrangement is found to exist up to the highest of all, — the centres of judgment and emotion and will.

Such is the "hierarchy of nerve-centres" in man.

Part III.

Having now considered fully all the causes which excite the spinal centres to functional activity, and all the results which are observed to follow; — both in the lower animals and in man, — we shall now turn attention to the essential nature and properties of those nerve-centres; with a view to reaching (if possible) an explanation of the phenomena observed in the so-called 'functional diseases of the spinal cord.'

From the facts already stated the following conclusions may be drawn:—

- (1) Each nerve-centre is powerless of itself to discharge any nerve impulse.
- (2) Each must be stimulated directly or indirectly before it can act.

(3) Each has a definite function to perform, - (i.e. its latent energy can be changed into a definite form of kinetic energy, - motor, secretory or trophic.)

(4) In man, a certain amount of influence from higher centres in the brain is essential, before any spinal action can take place.

The laws observed in the effects of various stimuli on those centres may be summarized thus:-

- (1) If the arriving sensory impulse is not sufficient to rouse the centre to action - (i.e. to liberate the latent energy) - no result whatever occurs.
- (2) If sufficient, (by prolonged application or increased intensity,) a quantity of latent is transformed into kinetic energy in the nerve-cell, and a definite result is produced.

Intensity
of
stimulus.

(3) If excessive, the latent energy may be entirely transformed into kinetic and then all action comes to an end for a time. (2)

Further, alteration in the quality of the stimulus modifies the result.

Nature
of
stimulus.

(1) If the sensory impulse be simple — such as might arise from irritation of a nerve trunk, — it may affect any centre in the cord.

(2) If peculiar, — such as is due to irritation of special nerve-endings in the skin or elsewhere, — it may affect higher centres, which have a co-ordinating function; and thus lead to a complex reflex act. (j)

(3) In man, however, these centres are not numerous in the cord; and hence the purely spinal actions are seldom complex.

(2) A good example of this is a case of D Budd see Fagge vol I p 438

(j) Striking examples are given in Fagge vol I p 439.

Excitability
of
nerve-
centres.

But the character of the stimulus is not the only element in determining the resulting action. The degree of excitability of the nervous structures is also an important factor.

- (1) If the excitability of a centre be slight, a vigorous source of stimulation is required to rouse it to activity.
- (2) If great, a delicate stimulus is sufficient for the purpose.

The function thus called into action must be either motor secretory or trophic in the lower centres. But in the higher ones there is an increased range of power; so that they can inhibit as well as excite each of these lower centres. [This fact is of the greatest importance in accounting for many obscure phenomena observed in the functional neuroses.]

The
pathological
action
of
centres

Such is a summary of the laws regulating the physiological action of the spinal centres. It will now be possible to review their pathology.

A. Consider first the case where one of a group of similar centres has been deprived of its functional activity.

- (1) If the centre is the only one concerned in effecting a given action, its destruction is followed by the entire absence of that action.
- (2) If, however, the centre is associated (even slightly) with others in accomplishing the action; — even when that centre is destroyed, its function may be performed to a certain extent by others. The reflex is still possible.
- (3) The more gradual the destruction of such a centre, — the more

perfectly will its function be transferred to others.

But now consider a case where the disabled centre belongs to a subordinate group.

B.

- (1) If its function be motor, some of the other centres usually endeavour to make up for the missing function, by performing their own to excess. Still the resulting action is always irregular.
- (2) If its function be sensory, the stimulus reaching the higher centre is imperfect and the resulting action is irregular, — sometimes impossible.
- (3) If the higher centre itself be destroyed the co-ordinate action of the lower centres is quite impossible.

But instead of being destroyed,

C. a centre may be in a condition of extreme excitability. This leads to another series of morbid actions.

- (1) If normally co-operating with other centres, it now greatly exaggerates one part of the movement, and so makes the whole very irregular.
- (2) If the centre be a superior one, the whole action is regular but very energetic.
- (3) As an inferior centre, however, it is of most interest pathologically. Normally the superior centre should control its activity: now it fails to do so. Thus the most various movements, — (formerly brought about by the will) — now take place without it, and sometimes in spite of it.

Practically it is found that excessive activity of one nerve centre is often associated with deficient

activity of another. In these cases the resulting morbid action is due to a combination of both those conditions; and it may be impossible to determine, in which the disorder originated.

The proof of the above statements is contained in the investigation which preceded them: but the position may still further be strengthened by shewing that the same principles of action occur in other arrangements of nature.

(1) The fact that the latent energy in a given nerve cell can only be transformed into a definite form of kinetic energy, — (motor, secretory or trophic as the case may be) has its counterpart in the chemical changes of all objects in nature. For example let a

Analogy
with other
operations
in nature.

piece of coal be heated in air — by whatever means, — and at length the carbon will unite with the oxygen and all the train of results — (termed combustion) follows.

So also with the various forms of physical energy: for example let a stone be in unstable equilibrium, it will remain so till a disturbing impulse of sufficient intensity affect it, — when the potential energy of position will be transformed into the kinetic energy of motion.

(2) The fact that certain forms of nerve energy affect only the higher nerve-centre has, also, its counterpart in the phenomena of nature.

If a bell, when struck, gives out a certain note, — it may be caused to vibrate by sound-waves of that pitch and by no other. Further if that note be produced among

a large collection of bells of all sizes, it will at once single out and put in motion that bell whose period of vibration is in unison with it.

(3) The fact of substitution in nerve-centres is a common one throughout the body. If the veins of the liver be slowly compressed by cirrhotic tissue surrounding them, the abdominal and other veins will gradually dilate and take up the function of the former, — so that no ascites occurs. If one kidney undergoes atrophy, the other by hyperactivity accomplishes the function of both; so that elimination of waste products continues almost unimpaired.

(4) The phenomena of inhibition are also strictly analogous with facts in nature. The same tube

that emits a musical note, — (a series of sound-waves), — also emits waves which by suitable arrangement may be made exactly to neutralize the first series and produce silence.

The rays of light reflected from the outer and inner surface of a soap-bubble may interfere completely, and no light is reflected at all.

(5) The last series of facts, — namely those of failure in part of a complicated mechanism, — is true of all complex machines whether material or vital.

It is this which Sir Hughlings Jackson has specially in view, when he compares the whole nervous system to a hierarchy of active powers, — some higher and some lower, — in which the failure of any one important member throws the whole of that department out of regular action.

Part IV.

Having thus established the exact mode of action of the spinal nerve-centre, — proved by a detailed examination of observations on animals and on man, — and supported by reference to a similar constitution and interaction of energies throughout nature, — we are now in a position to investigate the so-called functional diseases of the spinal cord.

The general conclusions, respecting the normal and abnormal action of nerve-centre, would lead one to expect that the causes of all derangements of spinal action should be looked for in three groups of circumstances; — (each of which is capable of further subdivision).

functional
diseases
of the
Spinal
Cord

- (1) Excessive stimuli applied to the peripheral terminations of the sensory nerves.
- (2) Deficient or excessive excitability of the spinal nerve centres.
- (3) Disordered action of the encephalic centres which influence those in the cord.

No doubt cases may occur where more than one of those conditions is present. Still it will be convenient to arrange them all in those three divisions, according as one or other condition predominates.

- (1.) The first group, containing those disorders which can be traced to the presence of an excessive irritant, has two well-marked subdivisions:—
 - (i) Cases where the reflex is of a positive nature; (eg. spasms).

(2) Cases where it is negative;

(eg. paralyses).

At first sight, it may seem strange that excessive stimuli should lead to results of so opposite a character. Yet it is found, that a stimulus, of slightly more than the usual intensity, is apt to cause a reflex spasm; while if it far exceed that limit, the result will be paralytic in nature.

A few examples will make this clear. It frequently happens that the presence of ascarides in the rectum of a child may lead to spasms of various kinds, and sometimes to general convulsions.

On the other hand in a case, (described in Guy's Hospital reports), a similar irritant led to just the opposite result. A girl was attacked suddenly with paraplegia. A few doses of oantonin were administered:

(k) Guy's Hospital Reports 1868
see also Fagge I p390.

with the result that a number of round-worms were discharged, and the paralysis disappeared a few hours after.

The forms of peripheral irritation leading to such results are very various. Among the most common are a displacement of the uterus, a stricture of the urethra, and (in surgical practice occasionally) ligature of haemorrhoids.

The experimental researches of (c) Lewis on the behaviour of frogs when subjected to sharp irritation agree with these results. For he found that forcible squeezing of the kidney or uterus produced paraplegia which vanished shortly after the pressure was removed.

In this connection, two facts frequently observed in practice may be mentioned. In some patients who become subject to a convulsive

(c) quoted in Fagge vol I p 457.

attack when a sensitive area of skin (eg. over left ovary) is gently rubbed, — forcible pressure on the same spot at once checks the attack.

So also in a patient whose limb is thrown into violent contraction by tickling the sole of the foot, — sharp flexion of the great toe suffices to relax the muscles at once.

The following case which I had the opportunity of observing in private practice is an excellent example of a functional disorder of this kind; but its aetiology was at first very obscure.

A child, about 12 months old, had completely lost the power of moving its right arm. This had happened suddenly one morning; and when I saw the child in the evening, it was lying on the nurse's knee, — its right arm hanging

powerless by its side, and even its right leg much feebler in action than the left. No accident was known to have occurred, and the only diagnosis that seemed likely to be correct was acute Infantile Paralysis. But there were some anomalous symptoms. The temperature was quite normal; and the child evinced a good deal of pain, when the arm was touched.

On further examination it was found that the humerus was fractured close to its upper extremity. So the paralysis of both arm and leg was reflex in origin.

(2.)

The second group of 'functional diseases' contains those which depend on the condition of the nerve-cells which compose the centre in the cord.

If they be found to shew signs

A. of degeneration, or have entirely vanished, — the disease may at once be placed in the organic class: and the symptoms are (so far) capable of explanation.

If, however, the cells are of normal appearance, the symptoms are not yet explained. Still a large number of such morbid conditions are traceable to a physico-chemical lesion of the nerve-cells, — too delicate (in recent instances) to admit of recognition under the microscope; but leading (always in old-standing cases) to well-defined physical changes.

A striking example of this is the condition observed in cases of lead-poisoning marked during life by paralysis of various muscles. If the case be recent, the multipolar nerve cells in the anterior cornua of the cord appear to be unaltered.

But if the case be old-standing, they are found to be greatly altered, — sometimes vitreous, sometimes atrophied, at other times entirely gone. (m)

A similar explanation holds good for all toxic nerve symptoms such as those due to strychnin, Bromide of Potassium, Mercury, &c.

The individual influence of each is distinct in character, but the general mode of action is the same for all.

But inorganic and vegetable poisons are not the only substances which affect the centres and interfere with their functions. The leucosmaines formed in man during digestion, and the ptomaines arising from the action of bacteria in the gastro-intestinal tract have been proved to be deadly poisons: and if permitted to pass through the liver unchanged, — (n)

(m) Vulpian quoted by Ross loc cit vol II page 960

(n) Brunton loc cit. page 401

they would paralyse all the nerve-centres in the body. These probably, when acting in minute quantity on the nerve-centres, are the immediate causes of the languor and weariness frequently experienced during hepatic torpor.

There is another series of morbid phenomena which may be naturally included in this group. The paralyzes and other nervous symptoms, observed during or after an attack of fever, may be, (without hesitation), traced to the action upon the nerve cells and fibres, of a poison developed by microbes or by the tissues during the course of the attack.

In support of this statement consider the case of 'Intermittent Spinal paralysis,' - a remarkable form of ague. Hertz, Romberg and

(b) Lauder Brunton: in Practitioner Oct + Nov. 1880
("Indigestion as a cause of nervous depression")

Hartwig have recorded cases of this disorder. The paraplegia rapidly develops, lasts a few hours, and disappears on the occurrence of a critical sweat. This is repeated every day or every second or third day according to the type of the ague. Further, quinine is usually successful in checking it completely. Here evidently the malarial poison is developed at regular periods and brings about the suspension of function of the spinal centre in the lumbar region. Once the poison is removed by the sweat or otherwise, the function is at once restored. (9)

A similar condition, no doubt, occurs in mild cases of post-diphtheritic paralyses for in severe cases definite inflammatory changes are found in the nerve cells and fibres functionally related to the

(9) Ross loc. cit. vol II page 343

muscles paralysed.

Such may also be the real explanation of "Landry's acute ascending paralysis" The centres, whose function is interfered with, lie in the anterior cornua of the cord: yet no trace of altered structure can be observed on microscopical examination.

The hypothesis, that the function of those cells has been suspended by some chemical poison, which selects that series of centres alone, — derives support from the fact that slight fever sometimes precedes the onset of the paralysis; and that the spleen is found afterwards to be enlarged. (5)

This whole group of diseases due to a chemical lesion of the nerve cells occupies an intermediate place between the purely functional and the admittedly organic disorders of the spinal cord. At first

(5) Westphal: quoted by Fagge vol I page 463.

producing merely a chemical change; they lead, in old-standing cases, to distinct physical alterations in the nerve-cells.

- C. [A third subdivision of this class — the purely functional — will be investigated presently.]

(page 106)

(3) The last class of disordered spinal actions may be traced to morbid activity of the higher centres in the brain. The chief types of these may be stated: but the study of their causes and effects lies outside the limits set in this dissertation.

- A. Cerebral haemorrhage by destroying the highest motor centre greatly diminishes the functional activity of the lower centres in the cord. Various co-ordinate reflexes are still possible, however, and cause movement in the paralysed limb.

Cerebral tumours, by irritating the higher centre may bring about a form of in-co-ordinate hyperactivity of the lower centres in the cord, — as seen in cases of Jacksonian Epilepsy.

B. Chemical depressants and irritants may affect the higher centres and so influence the lower in a similar manner.

C. A third subdivision of "purely functional" disorders of the highest centres may merely be mentioned. The influence of these on spinal centres is very potent: but the analysis of the conditions which cause them lies beyond the present enquiry.

Now, having considered all the disorders of spinal action which can be explained in any way by physical or chemical changes

The purely
functional
disorders

in the nervous mechanism, — we can turn attention to those for which no such explanation can be found. Those, indeed, are the only disorders which deserve the name of "purely functional;" and it will be found that they are closely related to actions, which are quite normal in other circumstances.

Take first the subdivision of those which show only spinal functions disordered. As an example of this class, consider the various kinds of Tremor observable, say, in the hand, — either when it is at rest or engaged in some action. Exclude all such as are traceable to physical changes (as in Sclerose en plaques); or to chemical alterations, (eg. from the influence of alcohol or mercury.) There still remain several common forms of the disorder.

One is frequent in the aged: another in the subjects of hysteria. It is marked in those who are convalescent from an exhausting disease; and indeed normally after severe bodily exertion or mental excitement, it is always present. Another form occurs if the temperature of the skin be much lowered. Rare cases are met with where the tremor is hereditary and occurs in members of a family through several generations. In all these cases, tremor is associated with weakness, either general or local; and in the latter condition, the fault may be traced to the large cells in the anterior cornua of the spinal cord, which shew a marked reduction of their functional activity.

Almost the reverse is true of another group of spinal functional disturbances, namely the "fatigue diseases"; of which writer's cramp is a typical example. Any occupation, however, which requires fine work and close attention may give rise to this disorder; — which consists in a failure of co-ordination in the action of a group of muscles.

Sometimes the prominent feature is spasm of one set; sometimes paralysis of another; occasionally it takes the form of tremor.

Pain is a common accompaniment and at times there is trophic derangement too.

The original cause of these disorders is certainly over-exertion and fatigue of some part of the neuro-muscular apparatus employed.

But the exact seat and nature

has been variously inferred by several writers.

Mitchell considers that there is a hyperactivity of the sensory centre, which receives impressions from the muscles. Gowers and Ross trace the source of the disturbance to changes in the brain itself. De Watterville believes the muscles to be the seat of the morbid changes. Bartholow and others, while thinking it may exist at first in the muscles whose action is impeded, — believe that in advanced cases there must be changes of

(r) Mitchell: "Functional Spasms" American Journal of Medical Science Oct. 1876.

(s) Gowers: Medical Times and Gazette 1877 II p536

(t) Ross: Nervous Diseases vol I page 468.

(v) De Watterville: "Cure of writers cramp" British Medical Journal 1885 I p323.

(w) Bartholow: Medical electricity.

a congestive nature in the spinal cord, — especially round the cells in the anterior cornua.

This opinion is borne out by a series of remarkable experiments made on men by Dercum and Parker. (x) A fixed attitude of hand and arm was maintained constantly for some time. Gradually a tremor commenced: this increased and spread to neighbouring groups of muscles till the whole body was thrown into convulsive spasms.

On repeating the experiment, the tremor and spasms were more rapidly brought on, — till the mere attempt to fix the muscles or the reception of a sensory stimulus was sufficient to induce a convulsive attack.

B. This experiment throws light also on the possible causation

(x) Polyclinic 1884 II p 95.

of those disorders which involve centres in the brain as well as those in the cord.

In "Neurasthenia Spinalis" there is great want of power in the motor centres of both cord and brain: and in "Spinal Irritation" the sensory apparatus shews the same weakness. All the reflexes are very active and readily elicited; but the amount of energy for any continued work is very small.

This irritability of the motor centres is also shewn in "saltatory spasm," where the patient cannot stand up without being jerked violently into the air: and this action is repeated so long as the Tendo Achillis is stretched. An exactly analogous symptom occurs in cases of Lateral Sclerosis; but there an organic change

is found to account for it.

In "Thomson's disease", a tonic spasm of a general nature occurs on first calling a muscle into action. Both in this disorder and in the previously-mentioned one, the reflex centres in the cord are too irritable and too much out of control of higher centres.

C.

The same may be said of a series of irregular nervous symptoms, — classed together under the name of Hysteria.

But in this case the spinal centres are not entirely — nor indeed principally — at fault: and the study of the action of the encephalic centres cannot be entered upon here.

Thus on reviewing all the functional diseases of the spinal cord, — we can set aside one group as due to mechanical changes in some part of the nervous mechanism, and include in it, the reflex disorders due to an excessive peripheral irritant.

We may also set aside those due to chemical changes in the nervous structures as a second group, which will include thus all the post-febrile paralyzes and the various forms of toxic nervous disorders.

Lastly those, which cannot be traced to mechanical or chemical changes in any part of the nervous mechanism, — will form a group by themselves, the purely functional neuroses. These are found to be closely

allied to conditions which are normal at other times. For if that condition of the spinal centres, which exists after a period of severe exertion, be imagined to be permanent in an individual, — that would give rise to just those symptoms which are observed in this group. All of them may be traced to irritable weakness of the spinal centres.

1. If the lowest centres only are affected, the symptoms of the disorder are those of tremor.
2. If higher centres of the cord are attacked, the result is:— marked inco-ordination of action in a group of muscles.
3. Lastly if the centres in the brain too are weakened, the inco-ordination is more pronounced and more extensive.

At times chiefly spasmodic in character, it is at other times paralytic: and by involving large tracts of the body or even the whole at once, — it renders regular voluntary action quite impossible.

Part V Conclusion.

The investigation of the action of the Spinal nerve centres in health and disease is now concluded.

It forms the foundation, — but no more than the foundation, — of a much larger study.

The spinal centres are so intimately related to the cerebral in man, that their action cannot be thoroughly understood without including a study of the cerebro-spinal

system as a whole. [This was indeed at first proposed as the subject of the present dissertation; but it proved too large for adequate treatment in a paper of moderate length.]

Even then, however, the investigation of the subject would have been incomplete.

For the purely cerebral centres have functions, whose action and influence on all lower centres form a most important part of the problem. Under the names of judgment and passion and will, they engage the attention of students of philosophy and psychology and jurisprudence.

The natural subordination of one centre to another has been proved in the spinal centres: it can be proved still more conclusively in the cerebro-spinal system; it is still evident in

The purely cerebral, whose function composes the very highest part of man's nature. But here a new law can be distinguished: for while, in any given man, the supreme centre, — whether its function be that of passion or of judgment, — can be readily stated, it is found that different men possess these faculties in various degrees: and that, which rules in one, assumes only a secondary place in another. Hence arise the sciences of sociology and politics.

One step more brings one to the limits of the enquiry.

It is found that in all men the centres, — even the highest of them, — are not self-existent nor are the functions discharged by them ever perfect or entirely harmonious. Hence the search that man has made

in all times, for some Being higher and more perfect than himself. In this relation we enter the spheres of religion and theology.

1. From one point of view, a man consists of many members.
2. From another and higher standpoint, men are members one of another.
3. From the highest of all, the whole of mankind are children of the one great Creator, in whom they live and move and have their being.

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