

**ON THE NATURE OF THE FUNDAMENTAL ACTIVITY  
OF THE NERVOUS CENTRES; TOGETHER WITH  
AN ANALYSIS OF THE CONDITIONING OF  
RHYTHMIC ACTIVITY IN PROGRESSION, AND A  
THEORY OF THE EVOLUTION OF FUNCTION IN  
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*Introduction.* The spinal reflex holds such undisputed sway in thought as the fundamental activity—the “functional unit”—of the nervous system that the time appears an appropriate one for the examination of the foundations of its supremacy<sup>1</sup>.

The reflex is usually looked upon as consisting, first, in a centripetal process which passes towards the neuraxis in the afferent part of the arc and is there reflected by the mechanism of the grey matter into, secondly, a centrifugal process which travels in the efferent part of the arc.

What we term the “spinal reflex” is a conception in part morphological and in part functional. For it is an activity which is propagated

<sup>1</sup> Until comparatively recently the nerve-cell with its various morphological processes and the activities of this system were together regarded as the “functional unit” of the nervous system. Sherrington, in the “Integrative Action of the Nervous System” (1906), appears to have first defined the *reflex* as the functional unit.

in the animal from periphery to periphery through the mediation of the "reflex arc." That arc itself is usually looked upon as built up of various subsidiary morphological units—the receptive organ, the afferent neurone, one or more interposed neurones, the efferent neurone, and the effector organ—and the whole arc ministers to the functional unit only in as far as its constituents subserve the common function of the transmission of a state of changed activity from one end to the other.

Of course this conception is an artificial and a crude one. Every afferent path tends, in its activity, to activate many efferent paths; and every efferent path is activated by many afferent paths. But it is important to note that in the conception as it is usually accepted the afferent and efferent paths of the morphological arc, and the centripetal and centrifugal activities of the functional process, are given equal values.

With this conception of a functional and morphological unit as an instrument various speculations with regard to the evolution of the nervous system have been put forward; and various speculations have also been made concerning the manner in which its more complex activities—for instance that of progression—are built up.

Thus a difficulty in the problem of the evolution of the nervous system—a difficulty presented by the idea that the afferent and efferent portions of the arc have equal values—arises when it is attempted to account for the manner in which the afferent and efferent neurones appeared simultaneously in the course of that evolution; and, as is well known, it has been surmised that at first a mechanism similar to the neuro-muscular cell arose and that this unit—which performs the functions of receptor, conductor, and effector—became subdivided into more specialised constituent units each of which performed in the arc its own more specialised function. Opposed to this idea is that put forward by the Hertwigs that the effector cell, the receptor cell, and the intermediate ganglion cell evolved side by side and in their interdependent evolution at length attained to the complex reflex arc. But more recently G. H. Parker<sup>1</sup> has advanced the theory that the effector organ (primitive muscle cell) first evolved and was later joined by the receptor and by the intermediate neurone to which he gives the name "adjustor."

When we turn from the problems of functional evolution to those of functional analysis of the most complex activities evolved the dominance of the reflex idea is still apparent. Thus in such an activity as progression in the mammal it is evident that any one limb performs the

<sup>1</sup> *Proc. Amer. Phil. Soc.* L. p. 217. 1911.

acts of flexion and of extension rhythmically repeated. In the light of the view that the evolution of function in the nervous system has been upon the lines of the building up of complexes out of the fundamental units of activity—the reflex unit activities—what more natural than to attempt to analyse such a complex as that of mammalian progression in terms of the more simple reflex activities which may be investigated? Thus—in a crude formula—the act of progression in a limb consists in a rhythmic alternation of the activity which we know as the flexion-reflex and the activity which we know as the extension-reflex.

Granted the assumption that progression is compounded of the reflex activities of flexion and extension there are two species of these reflexes either or both of which might be the proper components—the extero-ceptive reflexes (those evoked by stimulation of the integumentary receptors) and the proprio-ceptive reflexes (those evoked by stimulation of the deeper receptors in the muscles, tendons, and joints).

Philippson, who was the first really to investigate the phenomenon of progression from its functional aspect<sup>1</sup>, emphasised the importance of the extero-ceptive reflexes, but Sherrington<sup>2</sup> has shown certain objections to this view and himself laid stress upon the proprio-ceptive mechanism in the act of progression.

The present author<sup>3</sup> was, however, able to demonstrate for the act of progression which may be evoked in the hind limbs on rapid division of the spinal cord in the decerebrate cat that it might appear even after destruction of the proprio-ceptive mechanism and of the extero-ceptive mechanism of both hind limbs. This experiment shows firstly, that if the act, as regards a hind limb, is compounded of reflex activities the afferent paths of these do not necessarily lie in the same limb, and secondly, that the rhythmic alternation of activities is not conditioned by afferent self-generated stimuli which have their origin in either hind limb—or for that matter in either fore limb.

In that same paper the author showed that the phenomena which follow this rapid division of the lower thoracic spinal cord enter with a state of maintained flexion and end in a state of maintained extension. In the intermediate phase—where there is a more or less equal balance of the two activities—the rhythmic act of progression occurs. As this experiment of necessity eliminates the possibility of a peripheral “Selbststeuerung” the problem of the nature of that rhythm at once

<sup>1</sup> *L'autonomie et la centralisation dans le système nerveux des animaux*, Bruxelles, 1905.

<sup>2</sup> *Journ. Physiol.* XL. p. 28. 1910.

<sup>3</sup> *Roy. Soc. Proc. B*, LXXXIV. p. 308. 1911.

arose and the suggestion was put forward that progression was conditioned during this state of "balance" of the two opposed activities (flexion and extension).

In another paper<sup>1</sup> it was found for another phasic phenomenon, that of "rhythmic rebound," that there was again evidence of the balance of two antagonistic factors; and later A. Forbes<sup>2</sup> and the author<sup>3</sup> demonstrated simultaneously that rhythmic reflex movements might be evoked during the synchronous application of two antagonistic reflex stimuli. The author showed that the antagonistic reflex stimuli must be nearly balanced, for graded relative increase in the strength of one was accompanied by gradual disappearance of the rhythmic phenomenon; that the phenomenon might be evoked in de-afferented preparations; and that it might occur in the low spinal preparation, and therefore that the rhythm was conditioned in the local lumbar centres. Sherrington<sup>4</sup> more recently has confirmed these observations that a rhythmic activity akin to the phenomenon of progression may be evoked on synchronous application of two nearly balanced antagonistic stimuli.

The problem of progression as it occurs in the mammal now resolves itself into this:—rhythmic progression is conditioned by an equal balance of two antagonistic central activities: are these fundamentally of peripheral origin?

It might thus be supposed that in normal progression the phenomenon is fundamentally conditioned by a nearly equal balance of the activities of peripheral flexion-producing stimuli and of peripheral extension-producing stimuli; but that the afferent neurones which condition these need not necessarily enter the cord in the same region (for instance, the lumbar) as that to which the limbs examined belong. Thus the phenomenon of progression evoked by rapid division of the lower thoracic spinal cord even after complete de-afferentation of the hind limb might be produced by the mechanical stimulation in the cord of descending fibres some of which give the flexion stimulus and some of which give the extension stimulus.

Or it might be supposed that the fundamental conditioning of the act is not of this nature but that a balance of these antagonistic activities may reinforce it; that the equal balance of the antagonistic stimuli reproduce in the centres a state similar to that which

<sup>1</sup> *Quar. Journ. Exp. Physiol.* iv. p. 331. 1911 (see p. 393).

<sup>2</sup> *Roy. Soc. Proc. B*, LXXXV. p. 289. 1912.

<sup>3</sup> *Ibid.* B, LXXXV. p. 278. 1912.

<sup>4</sup> *Ibid.* B, LXXXVI. p. 233. 1913.

fundamentally conditions the act, but that the fundamental condition is not the balance of peripheral activities.

The author<sup>1</sup> has already mentioned (but without detail) some experiments which throw light upon this problem. As they appear to have an important bearing not only upon this point but also upon some other problems of the nature of the activities of the nervous system, this paper is devoted to their description.

*Methods.* The phenomenon of progression here examined is that which sometimes occurs in cats while under the influence of a general anæsthetic—"narcosis progression." In this phenomenon walking, running, or galloping movements may occur in all four limbs. The phenomenon may commence in the stage of light narcosis and then the movements as a rule are of large amplitude. If the narcosis is gradually increased in depth the movements gradually decrease in amplitude until they finally disappear altogether. The phenomenon may also commence in the stage of deep anæsthesia and then the movements are of small amplitude. Further increase in the depth of narcosis makes them disappear as before, but if the depth of narcosis be decreased they gradually increase in amplitude and finally stop suddenly when at their full extent. The phenomenon usually occurs, if it occurs at all, shortly after the commencement of narcosis and is difficult to induce after the animal has been anæsthetised for more than half an hour.

The movements have been recorded both in the intact limbs and in the isolated muscles. The procedure is as follows:—

The cat is put under general narcosis and at once the skull is trephined for subsequent decerebration. The spinal cord is exposed in the lower thoracic region, a loose ligature is passed behind it, and the wound is closed. A tube is placed in the trachea and the carotid arteries are ligatured (sometimes the ligatures are not tied). All the muscles acting upon either hip-joint are then functionally destroyed by motor paralysis (division of their tendons of insertion, division of the ham-string nerve, division of the motor branches of the femoral nerve, division of the obturator nerve). This also destroys the muscles which act upon the knee-joints. In the left hind limb (that the muscles of which are not recorded) the great sciatic nerve is divided—thus destroying all the muscles of the leg and foot. In the right hind limb the muscles of the leg are destroyed by motor paralysis except tibialis anticus and gastrocnemius-soleus (or soleus alone) and the foot is amputated. The cat is then laid upon its back with its right thigh

<sup>1</sup> *Roy. Soc. Proc. B.*, LXXXVI. p. 150. 1913.

perpendicular to the table and its right leg pointing to the recording levers. That leg is fixed by means of steel drills through the lower end of the femur and through the lower end of the tibia. The retained muscles are attached to the recording levers by means of long threads, and tripolar electrodes are placed upon the two long saphenous nerves.

It is essential for the success of these experiments that this procedure be performed as rapidly as possible. With practice the whole preparation may be completed—and movements recorded—within 25 minutes of its commencement. In very favourable circumstances the time of preparation may be reduced below 20 minutes, but even then the phenomenon occurs with comparative rarity after the individual muscles have been prepared for recording.

When the movements occur the spinal cord may rapidly be divided by opening the wound in the back, drawing upon the loose ligature, and snipping the cord across with a sharp pair of scissors. Before this is done the rhythmic progression may be interrupted by peripheral stimulation (rapid faradic shocks) applied to the saphenous nerves.

Sometimes the movements may commence during the preparation of the animal. Clips attached by threads to the recording levers are kept in readiness, and so is a steel bar fixed in a stand so that it is parallel to the table at a height of about 4 cm. The cat is at once laid prone with a hot water bottle under the abdomen, the bar is slipped under the two ankles, and the clips are attached to the pads of the feet. The movements may thus be examined in the intact hind limbs within a few seconds of their first appearance; and later the movements may occur—and be recorded—after the preparation of the individual muscles.

To prevent any possibility of mistake it must be clearly stated that in all these experiments and for the whole of each of them the animals (cats) were completely unconscious and remained so until they were destroyed at their terminations. As the phenomenon of narcosis progression may persist through varying depths of narcosis I have used the terms "comparatively light narcosis" and "comparatively deep narcosis." The former means "a certain depth of narcosis at which, the cats being unconscious, the movements of narcosis progression tend first to appear as the depth of narcosis is gradually increased and at which these movements then exhibit their greatest extents in the flexor beats." The latter term means "that depth of narcosis at which the movements tend to be abolished when the depth of narcosis is progressively increased."

## I. EXPERIMENTS IN WHICH THE SPINAL CORD IS CUT.

In these experiments the movements were observed in the intact hind limbs alone and, except in one instance, not in the isolated muscles.

If the spinal cord be severed rapidly when the movements of narcosis progression are in being during "comparatively light narcosis" it has been observed that after one more "beat" there may occur complete cessation for a period of 12 seconds or more. But thereafter very small movements may again appear. In the experiment in which this was observed the narcosis progression was examined as it occurred in the individual muscles, and it was found that the slight movements after division of the cord were of a rate of about 0.8 "beats" per second—whereas the movements of large extent which were in being at the time of division of the spinal cord were of a rate of about 1.8 "beats" per second.

In another experiment the narcosis was also comparatively light at the time the spinal cord was cut. The movements of narcosis progression were rather irregular in their appearance—that is to say that for short intervals of time they disappeared. When they occurred with regularity their rate was one of about 0.9 "beats" per second. At the time at which the spinal cord was divided the movements were decreasing in extent, and the narcosis was probably becoming deeper. Division of the cord was followed by flexion movements in the two hind limbs. These were of small extent and duration and were immediately followed—1 second after the division—by movements of narcosis progression. The "beats" were greater in extent than before the division of the cord. At first they were of the same rate of rhythm. They increased in extent for about five seconds, and then their rate increased markedly until it was one of about 1.8 "beats" per second. About 28 seconds after division of the spinal cord the beats again became slower in rate and the phenomenon again became irregular. Cessation of the movements occurred abruptly and the final appearance of the record was in appearance similar to that before division of the spinal cord, with the exception that the movements were of greater extent.

In another experiment, where the depth of narcosis as judged from the extent of the "beats" in the narcosis progression phenomenon was deeper, similar results were obtained. Here division of the spinal cord was followed by a state of maintained flexion during which the movements of progression at first were abolished but later re-appeared. They were then of very much greater extent than before. Here the rate of

rhythm changed from one of 1.2 "beats" per second before division of the spinal cord to one of about 2.0 "beats" per second after that division.

In a fifth experiment the movements of narcosis progression were in being during deep narcosis. The spinal cord was divided and there occurred scarce a movement in either hind limb. The rhythmic movements were, however, abolished for a space of about 16 seconds. They then suddenly re-appeared and were then of greater extent than before but of about the same rate of rhythm—1.4 "beats" per second as compared with 1.2 "beats" per second. Here the movements gradually became smaller and finally faded away. The small movements which followed the rapid division of the spinal cord in this experiment were not of so great extent as that of the "beats" which were at the moment in being.

In a final experiment (Fig. 1) the narcosis progression phenomenon was in being at a very great depth of narcosis and the "beats" were of very small extent but at the same time were very regular in rate and extent. They were accurately alternating in the two hind limbs. The spinal cord was divided and the division produced scarce a movement in either limb. There was no interference with the rhythmic movements. There was a very slight slowing of the rhythm—from a rate of about 1.2 "beats" per second to one of about 1.1 "beats" per second. The "beats" became slightly greater in extent and lasted for about 75 seconds after the division of the spinal cord—gradually fading away. The slight variations in rate and extent of the "beats" in this experiment were not greater than those which may occur during records in which there is no interference with the spinal cord and in which the depth of narcosis probably is slightly varied.

These experiments seem to show that if the spinal cord is rapidly divided when the movements of narcosis progression are in being at a comparatively slight depth of narcosis, there is usually first a phase in which the phenomenon is abolished and then a phase in which the beats re-appear and are of greater extent and rate of rhythm than before.

They also seem to show that the movements may occur at a depth of narcosis at which the rapid division of the spinal cord produces little or no reaction, and that they may then persist almost unchanged.

At this depth of narcosis the phenomenon is therefore one which may be exhibited in the lumbar spinal centres alone, and is then not conditioned by the activity of higher centres.



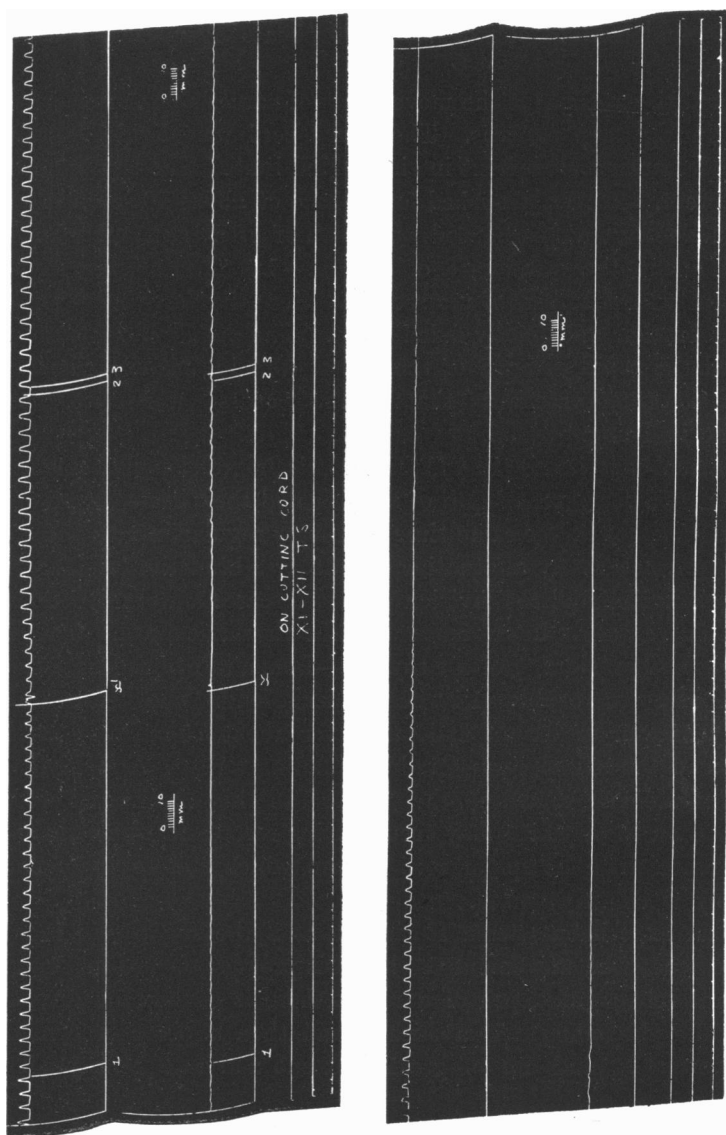


Fig. 1. Normal cat under deep narcosis, a record of the movements of "narcosis progression" in the intact hind limbs. Upper line registers the movements at the left ankle joint and lower line registers those at the right ankle. In either case the rise of the curve denotes flexion and the fall extension. Time in seconds. On the record a millimeter scale was drawn before varnishing, and is therefore

reduced in proportion with the record. The two parts of the figure are directly continuous.

The narcosis movements registered are of small extent. It will be observed that they are almost absent in the right limb. The movements of flexion in the two limbs are, however, seen to be alternate. At one point in the record ordinates have been drawn to illustrate this. These are numbered 2, and 3. It will be seen that between 2 and 3 there occurs a pause in the upper (left) curve and a movement of flexion-extension in the lower (right) curve.

At the point marked by ordinates  $x$ ,  $x'$  on the two curves the lower thoracic spinal cord was rapidly severed between segments *XI* and *XII*. This severe flexion-producing stimulus produces of itself little movement in the two curves. Thereafter the beats of the narcosis progression gradually increase in height but, after reaching a maximum, gradually decrease again and finally fade away.

This figure demonstrates in the first place that the phenomenon of narcosis progression may be one which occurs in the local centres of the lumbar segment of the spinal cord and does not depend upon impulses from the higher regions of the neuraxis. Secondly it seems to show that the phenomenon may appear at a depth of narcosis at which the spinal reflex is put out of action; for the stimulus of division of the spinal cord is usually a much stronger one than any peripheral flexion-producing stimulus, and here even it appears to be almost valueless.

As rapid division of the lower lumbar spinal cord is—in the decerebrate cat—one of the strongest, and probably the strongest, of flexion-producing stimuli it is probable that the phenomenon of narcosis progression may occur when the peripheral reflexes have been abolished by a general chemical narcotic.

## II. EXPERIMENTS IN WHICH THE PERIPHERAL REFLEXES ARE TESTED DURING NARCOSIS PROGRESSION.

Further to test the possibility that the phenomenon of narcosis progression may occur at a depth of narcosis at which the peripheral reflexes are abolished, the movements have been examined as they occur in the individual muscles of the leg and reflex stimuli have been then applied to afferent nerves of the same and of the contralateral hind limbs.

These stimuli should usually evoke the ipsilateral flexion-reflex and the contralateral extension-reflex respectively, but as a matter of fact it has been found that the contralateral extension-reflex has always been inexcitable at any depth of narcosis at which the movements of narcosis progression occur at all—and this even when the strongest stimuli which may be given with the coils in use are applied. In the same way it has been observed that extensor rebound (“extensor rebound contraction after inhibition”) in the flexion-reflex has been absent.

The ipsilateral flexion-reflex has been found to occur at the depth of "comparatively light narcosis" at which the phenomenon of narcosis progression is of great extent. This reflex then appears often to be peculiarly characterised by a tendency to flexor after-discharge. This tendency is greater than in the flexion-reflex of the decerebrate and low spinal preparations, and if the sudden terminal relaxation of the flexor muscles in the flexion-reflexes of these conditions be regarded as the reciprocal of the "extensor rebound contraction after inhibition," which is the most common positive terminal phenomenon in these reflexes, it seems by no means unlikely that the presence of this tendency to flexor after-discharge is associated with the absence of extensor rebound contraction in the state of general chemical narcosis.

In these experiments, although a contralateral extension-reflex has never been observed in the state of narcosis, the contralateral stimulus has not infrequently been observed to evoke the abnormal contralateral flexion-reflex. This has occurred in a greater proportion of experiments than that in which it is seen in the ordinary decerebrate preparation, and in the individual experiments in which it has occurred during chemical narcosis it has not seldom been found that later, when the preparation had been converted to the decerebrate condition and the effects of narcosis had been allowed to pass off, the contralateral reaction was the normal extension-reflex. These abnormal contralateral flexion-reflexes under narcosis have been followed by marked terminal flexor after-discharge.

This occurrence of an abnormal contralateral flexion-reflex in the state of narcosis is a point of interest. It might be argued that the disappearance of the extension-reflex, and perhaps also of the extensor rebound in the flexion-reflex, in chemical narcosis is due to a paralysis of those interconnexions between the two sides of the spinal cord which condition the related acts of the pair of hind limbs. That this might be so is also suggested by the observation that in the decerebrate preparation when one lateral half of the lumbar spinal cord has been removed the ipsilateral flexion-reflex shows a marked tendency to flexor after-discharge—often accompanied by the reciprocal "extensor rebound relaxation after inhibition<sup>1</sup>." But that the chemical narcotic does not act as it were by producing a longitudinal split of the two halves of the lumbar segment of the spinal cord is shown by this observation, that the abnormal contralateral flexion-reflex may occur although the normal contralateral extension-reflex does not; and by the additional observation

<sup>1</sup> *Quar. Journ. Exp. Physiol.* v. p. 233. 1912.

that even at a great depth of narcosis when the narcosis progression is occurring after division of the spinal cord in the lower thoracic region the movements of the two hind limbs are accurately alternate, and remain so for considerable lengths of time.

*Comparatively light narcosis.* When the movements of narcosis progression are of good extent and are in being when the depth of anæsthesia is "comparatively light" the ipsilateral stimulus evokes a reaction of flexion and this interferes with the phenomenon of progression. The flexor contraction in the reflex is then at first often of greater extent than the flexor contraction in the "beat" of the progression phenomenon. If the stimulus be prolonged in time the flexor contraction tends to die away and at the same time irregularities which correspond to the progression "beats" appear upon it. In other words, at first the reflex-flexion completely abolishes or masks the "beats" of the progression flexion, but later—as the reflex-flexion diminishes in value—the "beats" begin again to break through, or to be unmasked. If the reflex stimulus is of short duration in time there may persist a flexor after-discharge which has a similar appearance to that of the diminishing reflex-flexion described above. After such a reflex-flexion there appears sometimes to occur a quickening of the rhythm of the "beats" of the narcosis progression phenomenon.

When brief ipsilateral stimuli are applied at different points in the cycle during a period in which the phenomenon of narcosis progression is occurring steadily there appears to be evidence of a phase of relative refractability in each cycle, but there is no evidence of an absolute refractory phase when moderate stimuli are used.

While narcosis progression is in being in the stage of "comparatively light narcosis" the contralateral stimulus may give the same phenomena as the ipsilateral, and this even when the contralateral stimulus produces no response when the movements of narcosis progression are not in being. Very strong stimuli must be used in order to obtain the abnormal contralateral flexion effect.

Occasionally, however, when the narcosis is comparatively deep the effect of the contralateral stimulus may be to cause inhibition of the beats of the narcosis progression. A brief contralateral stimulus applied in the phase of flexor relaxation between two consecutive "beats" completely suppresses the second. The effect of this inhibition appears nevertheless to be transient, for the next "beat" in the series may be of the usual extent and the rhythm of the whole phenomenon is not "thrown out of step"—all that happens is that an individual "beat"

fails to occur. If, however, the contralateral stimulus be of longer duration one "beat" may be completely suppressed and the following "beat" may be delayed in its appearance.

*Deep narcosis.* When the phenomenon of narcosis progression is in being and the depth of narcosis is progressively increased the progression movements may continue at a depth of narcosis at which the animal is almost killed. At the stage at which the progression movements are finally abolished the respiratory centre may also be paralysed, but more commonly it continues to be active at a slightly greater depth of narcosis than that at which the progression movements cease.

At that depth of narcosis at which the progression movements are only just in being, and indeed at considerably less great depths of narcosis, the contralateral stimulus is ineffective even when the maximum strengths of stimuli are applied. There then occurs no change whatsoever in the rhythmic progression phenomenon.

The effect of the ipsilateral stimulus seems to persist at a greater depth of narcosis than does that of the contralateral stimulus, but it too appears to be inoperative at the greatest depths of narcosis at which the progression phenomenon occurs.

In one experiment (Fig. 2) the phenomena of narcosis progression were recorded for a period of about 370 seconds. They started in the stage of comparatively light narcosis and during the record the narcosis was gradually increased in depth until the movements were almost abolished. A contralateral stimulus of maximum strength was used throughout the series and its effect upon the rhythmic progression was tested at intervals. At first it appeared to inhibit the flexor "beats," but long before the progression had been reduced to its minimum the contralateral stimulus became completely ineffective.

In the early stages of the record the ipsilateral stimulus applied was a comparatively weak one. It was given in the same manner as the contralateral at intervals during the rhythmic narcosis progression phenomenon. As the depth of narcosis was increased the strength of ipsilateral stimulation was increased until it was maximal—a strength far greater than that which it is advisable to use in the normal decerebrate and low spinal preparations. While the extents of the "beats" of the progression phenomenon were still well marked although at a great depth of narcosis this great strength of ipsilateral stimulation, even when applied for periods of time as long as 5 seconds, gave scarce any evidence of interference. There was nothing corresponding to the flexor contraction of the flexion-reflex, and all that happened was

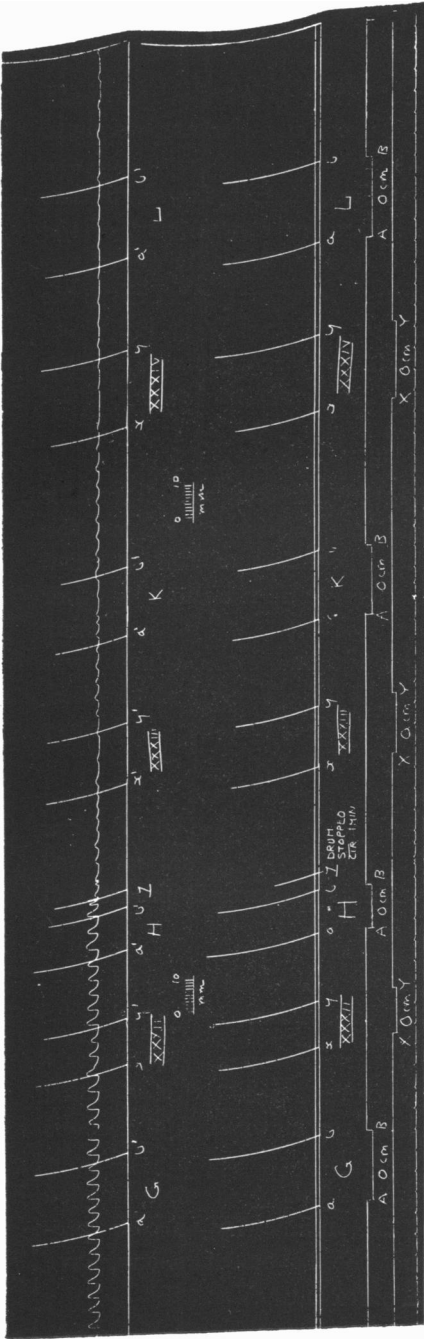


Fig. 2. Normal cat under deep narcosis. A record of the movements of right tibialis anticus (upper curve) and gastrocnemius-soleus (lower curve) in narcosis progression. The rise of either curve denotes contraction and the fall denotes relaxation of the recording muscle. During the record ipsilateral and contralateral long saphenous nerves are stimulated. The upper signal line gives the points of commencement and termination of contralateral (left) stimulation. These are denoted by the letters *A* and *B* and ordinates corresponding to these points have been drawn on the muscle curves (*a*, *a'*; *b*, *b'*). In a similar manner the lower signal line (*X*, *Y*) gives the temporal relations of ipsilateral (right) stimulation and the corresponding ordinates are marked *x*, *x'*; *y*, *y'*. The stimuli used are maximal. Time in seconds.

This tracing is the terminal portion of a long record. The first stimulus here reproduced (*G*) is a contralateral one and has no effect on the rhythmic beats of the flexor. The second stimulus (*XXXII*) is an ipsilateral one and during its application there appears to be a slight reduction in the extents of the flexor beats. At the point marked *I* (two ordinates are here drawn) the drum was stopped for a space of about 60". During this interval the afferent nerves were rearranged on the electrodes. The interval of rest and the rearrangement of the electrodes was performed to counteract as far as possible any "fatigue" effect. When the drum was restarted it will be observed that the movements of narcosis progression were smaller than before. The beats, as judged in the intervals between stimuli, are less regular than in the first part of the tracing here reproduced. The contralateral stimuli (*K* and *L*) are again apparently without influence. So too are the ipsilateral (*XXXIII*, *XXXIV*) with the exception that there appears to be a tendency for the beats to fail during ipsilateral stimulation. It will be observed that throughout no contraction of the extensor occurs. At the end of this record the movements fade away.

After the end of this record the ipsilateral stimulus was repeated at intervals of two minutes, and not for four minutes after the termination of narcosis (which coincided with the termination of this record) did a flexor contraction in response to this stimulation appear.

This figure illustrates a case in which it appears that the rhythmic phenomenon of narcosis progression continued at a depth of narcosis at which not only the contralateral extension-reflex but also the ipsilateral flexion-reflex was abolished even in response to maximal stimuli.

that occasionally a "beat" would fail. In fact, this great strength of ipsilateral stimulation appeared to be ineffective at the depth of narcosis which then obtained.

But repeated stimulation of an afferent nerve, as in this experiment, may produce a phenomenon of fatigue. In order as far as possible to eliminate this possibility the drum was stopped for a period of one minute during which no stimuli were applied, and at the same time the electrodes were moved to a fresh and more central part of the peripheral afferent nerve which was stimulated. When the record was resumed the state of narcosis was even deeper and the rhythmic movements of the progression phenomenon, although they still were in being, were very slight. It was then found that maximal contralateral and ipsilateral stimulation had no effect, and that the ipsilateral stimulus evoked nothing of the nature of a flexion-reflex.

The narcosis movements were then abolished by a further slight increase in the depth of narcosis and the narcotic was thereafter at once stopped. The progression did not again appear as the depth of narcosis gradually decreased. The effect of the maximal ipsilateral stimulus was then tested at different intervals of time after the cessation of the narcotic—that is, at different levels of decreasing narcosis. Two minutes after the cessation of narcosis the stimulus was inoperative. Four minutes later a very slight flexion-reflex was evoked, and then with decreasing depth of narcosis became ever of greater extent. The contralateral stimulus throughout was ineffective.

I should like to refer again here to an observation already published<sup>1</sup> on the effect of removal of one lateral half of the lumbar spinal cord. In one experiment the left lateral half of the lumbar spinal cord was removed in a cat and afterwards movements of narcosis progression occurred in the right hind limb.

### III. MOVEMENTS OF NARCOSIS PROGRESSION AFTER DE-AFFERENTATION OF ONE HIND LIMB.

In the paper just quoted<sup>1</sup> in which the movements of narcosis progression as they occur in the cat were described it was stated that after de-afferentation of one hind limb the movements of narcosis progression had not been observed. In these experiments the posterior spinal roots in the lumbar region of the spinal cord were divided immediately before the observation of the animal for narcosis progression and it is perhaps remarkable that the movements should have

<sup>1</sup> *Roy. Soc. Proc. B*, LXXXVI. p. 140. 1913.

occurred in either hind limb (they occurred in the hind limb which was not de-afferented) after this exposure of the cord.

In a more recent experiment the whole of the posterior spinal roots upon the right side of the lumbar spinal cord with the exception of the first post-thoracic root were divided about 15 months before the animal was examined under narcosis. When then put under the general chemical narcotic a phenomenon of rhythmic narcosis progression appeared in the left hind limb—that not de-afferented. The movements were therefore unilateral and remained so for a period of about 50 seconds. During this period there were no movements in the de-afferented hind limb. When the movements ceased in the left hind limb there shortly appeared similar movements in the right (de-afferented) limb, and these in their turn were unilateral. After they had persisted for a period of 20 seconds the movements of narcosis progression became bilateral and strictly alternate.

#### IV. THE GENERAL BEARING OF THESE EXPERIMENTS.

These experiments seem to indicate that the phenomenon of narcosis progression may persist in the hind limbs at a depth of narcosis at which the lumbar spinal centres respond neither to the excessively strong stimulus which a rapid division of the lower thoracic spinal cord inflicts upon them, nor to maximal peripheral stimulation of afferent nerves of the hind limbs.

But in this rhythmic activity of narcosis progression the lumbar efferent neurones are in action. The chemical narcotic therefore appears to affect the afferent path of the lumbar centres (or the first synapse) before it affects the efferent mechanism.

At this depth of narcosis it does not, however, affect the nice alternation of movement of the narcosis progression phenomenon. In all the depths of narcosis at which the phenomenon occurs it has been found that the extensor muscle plays no active part. But the movements of flexion and extension are still conditioned by contraction and relaxation of the active flexor muscle when it is made to work against some external agent such as gravity or the resistance of an elastic band.

We may therefore say:—these experiments seem to show that a certain complex rhythmic movement may occur at a depth of narcosis at which the peripheral reflexes (or at least the ipsilateral extero-ceptive flexion-reflex and its ally the contralateral extero-ceptive extension-reflex) are abolished: and therefore that the spinal efferent neurones may show some



degree of independence of the afferent neurones and some of the phenomena of reciprocal innervation when functionally separated from them.

If this thesis be sustained the experiments localise many of the functions of the spinal reflex arc in the efferent neurones—but not necessarily in the single neurone.

For in the first place the explanation of the rhythm in such acts as progression cannot be made by evoking peripheral centripetal impulses as the fundamental condition. The rhythm may best be explained as conditioned by some function of the interconnexion of efferent neurones<sup>1</sup>.

If this be the case it becomes likely that the explanation of reciprocal innervation may best be made on the same basis.

Again, and on the assumption that the more recent neural mechanisms are the more easily paralysed by a general chemical narcotic, these experiments seem to suggest that the most primitive activity of the spinal centres is that rhythmic one which we now see active in narcosis progression. This suggestion at once brings the fundamental activity of the spinal centres into close parallelism with that of the respiratory centre—another mechanism which is peculiarly resistant to the effects of general chemical narcosis.

The bearings of this theory will be noticed later, but it will be observed that it tends to displace the reflex as the unit of activity in the spinal centres and to put in its stead a mechanism composed of efferent neurones. Perhaps the simplest unitary mechanism is one formed of the efferent neurones to two antagonistic muscles; and as an artificial conception that of two such efferent “half-centres” (that is, two efferent neurones to antagonistic muscles) and their mutual interconnexions may be suggested.

#### V. ON THE FUNDAMENTAL CONDITIONS OF RHYTHMIC PROGRESSION.

When it was first shown<sup>2</sup> that mammalian progression may occur in the lumbar segment of the spinal cord after complete de-afferentation of both hind limbs, and after severance of the lumbar cord from the more oral parts of the neuraxis, it was observed that the phenomenon of progression which is obtained on rapid division of the spinal cord in the decerebrate cat is especially evidenced during a state of the balanced activities of antagonistic extension and flexion.

<sup>1</sup> *Roy. Soc. Proc. B*, LXXXV. p. 278. 1912.

<sup>2</sup> *Ibid.* B, LXXXIV. p. 308. 1911.

Later, when it was demonstrated that rhythmic movements of the same rate of rhythm as those of progression can be induced in the decerebrate and in the spinal cat when two antagonistic flexion-producing and extension-producing stimuli of a certain degree of equality are pitted against each other<sup>1</sup>, the inference was drawn that, as the one stimulus when applied "pure" gives an arrhythmic flexion-reflex and the other gives an arrhythmic extension-reflex but yet when applied together they give the rhythmic response, the rhythm is not an inherent function of the efferent neurone—that is, of the "half-centre"—but that it is a function of the interrelations of the "half-centres."

In other words, progression seems to be conditioned, by some function of their mutual relationship, during the equal and opposite activation of linked antagonistic "half-centres."

Sherrington<sup>2</sup>, who has endorsed these observations that a rhythmic phenomenon akin to that of progression may be evoked by the appropriate balance of antagonistic stimuli, in a paper lately published in this *Journal*<sup>3</sup> examines the question of the conditioning of these rhythmic phenomena. Dismissing the possibility of peripheral "Selbststeuerung" by stimuli—either extero-ceptive or proprio-ceptive—self-generated during the movements of the limbs, he discusses the following possibilities:—

In the first place it is possible "to regard, on the analogy of the respiratory centre, the rhythm of the step-reflex as of essentially intrinsic origin; a natural and native rhythmic reply of the nerve cells to an inner stimulus such for instance as the blood. This is a view to which T. Graham Brown inclines....It is a view that demands careful attention, but, as it seems to remove stepping from the category of reflexes except in so far as concerns regulation, the present argument which proceeds on the assumption that the forms of stepping here dealt with are reflex would be led too far afield by its consideration now."

From what has been said above it will however be noticed that the author does not in fact regard the rhythm of the phenomenon as conditioned by the native rhythmic reply of nerve cells but by a native rhythm which is a property of the interconnexions of antagonistic nerve cells and is set up during an equal and opposite activation of them.

In the second place Sherrington examines and accepts the possi-

<sup>1</sup> *Roy. Soc. Proc. B*, LXXXV. p. 278. 1912.

<sup>2</sup> *Ibid.* B, LXXXVI. p. 233. 1912; and *Quar. Journ. Exp. Physiol.* vi. p. 251. 1913.

<sup>3</sup> *Journ. Physiol.* XLVII. p. 196. 1913.

bility that the step-reflex may be conditioned by balanced antagonistic activation of the spinal centres. This "demands the presence of two separately placed peripheral stimuli which may be continuous, and it invokes the intracentral facts of 'rebound' and 'fatigue.' The two stimuli must be of opposed effect and...of closely balanced intensity in their action on the centre."

Sherrington therefore at present favours the view that the act of stepping is produced peripherally by balanced antagonistic stimuli in the presence of the intracentral factors of "fatigue" and "successive spinal induction."

But "narcosis progression" occurs when the peripheral reflexes have been abolished by a general chemical narcotic. Most certainly the effect of a contralateral stimulus (when the movements are examined in the individual muscles of one hind limb) is abolished at a depth of narcosis much more light than that necessary to abolish the progression movements. And the effect of the ipsilateral stimulus itself seems to be abolished while the progression movements still persist. There can be no possibility here of a balance of antagonistic peripheral stimuli.

And if the phenomenon of spinal "rebound" is ever seen in chemical narcosis it is never seen at the depths of anæsthesia at which the progression phenomenon occurs.

This phenomenon of progression is therefore not conditioned by peripheral stimuli, and the inference must be drawn that the fundamental conditions of progression are not of peripheral origin—progression is not fundamentally a "reflex" act.

But on the other hand, as has already been pointed out<sup>1</sup>, the phenomenon cannot be regarded as the fundamental property of the discharge of the single centre (that is, of the single nerve cell or "half-centre").

If so, how is the phenomenon of progression conditioned? The following suggestion may be put forward:—

The rhythmic phenomenon of progression is fundamentally conditioned by the balanced activation of antagonistic and linked efferent centres (or "half-centres"), but this activation is not necessarily of peripheral origin—it may, in fact, be produced by conditions similar to those of the "blood-stimulus" in respiration.

On the assumption that the rhythm is conditioned by some property of the interconnexions of these "half-centres" during this state, what explanation of the manner of its production may be given?

<sup>1</sup> *Roy. Soc. Proc. B*, LXXXV. p. 278. 1912.

The following explanation is suggested<sup>1</sup>:—

The efferent neurone may be supposed not only to activate its effector organ through the mediation of its axone but also, by means of some other branch-fibre or side-channel, at the same time reciprocally to depress the activity of an antagonistic efferent neurone; and similarly that antagonistic neurone may be supposed to depress the activity of the first neurone as well as to activate its own effector. There is some morphological evidence that the efferent neurones of the spinal cord send back from their axones a collateral branch soon after the axone leaves the cell-body. [For simplicity the consideration of interposed neurones in the arc is avoided.]

In such a system there would be a phenomenon of mutual inhibition. When one neurone ("half-centre") is activated it depresses the other synchronously with the activation of its own effector. But that other "half-centre" when active depresses the first, and when it is depressed its depression of the first "half-centre" will be diminished in value. Therefore the activation of the first will increase still further, and so on. This may be termed the "progressive augmentation of activation" by the process of mutual inhibition.

In theory, if this arrangement exists, the smallest stimulus which acts upon a centre if sufficiently prolonged should give a maximal activation of one of the "half-centres"—for the only limit set is that of complete depression of the other "half-centre." In practice this does not occur, and a limiting factor must be assumed.

Such a factor might be a process of "fatigue" in the collateral depressory connexions. There is some evidence that it exists. This "fatigue" may be termed the factor of "depreciation of inhibition."

If it be assumed that this depreciation of inhibition is proportional to the duration of the process of progressive augmentation of activation and proportional also to the value of that process, it is possible to frame a theory of the nature of the rhythmic phenomenon in the linked antagonistic "half-centres."

Thus when the two antagonistic "half-centres" are activated in equal degrees and with an extreme nicety of equality it might be supposed that no rhythmic phenomenon would occur. But if the balance was upset in the slightest degree to either side the process of progressive augmentation of excitation would set in. The activation of one "half-centre" would rise and that of the other would fall until the

<sup>1</sup> *Quar. Journ. Exp. Physiol.* v. p. 237. 1912; also, *Roy. Soc. Proc. B*, LXXXV. p. 278. 1912.

temporal process of depreciation of inhibition set a limit to the augmentation. When this point was reached the state of the activity of the centres would remain constant except for the hypothetical process of depreciation of inhibition which is assumed to increase with duration of time. This increase of the depreciation of inhibition would therefore tend to decrease the state of relative activation of one "half-centre" attained by the progressive augmentation of activation. There would therefore set in the opposite process—that is, progressive augmentation of activation in the other direction. This again would attain its maximum and the element of depreciation of inhibition, now acting in the opposite direction, would again tilt the process of progressive augmentation—and so the rhythmic phenomenon might be explained.

One point at first sight appears to present difficulty. How may it be supposed that the depreciation of inhibition—the "fatigue"—acts in opposite directions? This might be supposed to be conditioned in such an arrangement of the centres (or "half-centres") simply on the assumption that the depreciation was, in some degree, proportional to the strength of the inhibitory impulses. Thus if one "half-centre" is in maximal activity the process by which it inhibits the other "half-centre" will be subject in the greatest degree to the depreciation of its inhibitory impulses; but the process by which the second "half-centre" inhibits the first will be practically at rest in this relative state of the centres. As the process of progressive augmentation of activation sets in in the opposite direction depreciation will make its appearance and will gradually increase in value in the inhibitory branch of the second "half-centre" while it will gradually decrease and finally disappear in the inhibitory branch of the first "half-centre."

In this phenomenon of narcosis progression as it occurs at great depths of narcosis we are faced with the problem of how best we may explain the occurrence of the rhythm which is not conditioned peripherally and is not a native property of the cell-body. It seems to me that some such explanation as that offered above is the simplest and the most easy to accept.

It places the efferent neurone—or rather the linked pair of antagonistic efferent neurones or "half-centres"—in an independent position as the morphological substructure of the functional unit of the nervous system. Upon them and activating them may be supposed to play two kinds of stimuli. Of these the first and most primitive is that which corresponds to the "blood-stimulus" in respiration; and the second is the more recent stimulus conditioned by the afferent path of

what we know as the spinal reflex. In the light of this view the primitive activity of the linked "half-centres"—of the morphological unit—is supposed to be rhythmic; but the rhythm is not looked upon as conditioned in regard to its period by metabolic factors. It is rather regarded as conditioned by the periodic blocking and unblocking ("fatigue"), at a point (synapse?) in the path of "mutual inhibition" of inhibitory impulses which may have a much faster rate of rhythm of their own, and one perhaps conditioned by such metabolic factors. And again, in the light of this view it will be observed that a mechanism for reciprocal innervation is assumed to exist between the efferent "half-centres" and not in the (or is not necessarily assumed to be confined in the) afferent neurones.

In other words, the view here advanced is that the functional unit in the nervous system is not the activity of the reflex arc as is usually assumed, but that it is the activity of a unit which we may term the "half-centre"—or, perhaps, the centre composed of linked antagonistic "half-centres." There remains the question of the manner in which the peripheral reflex should be considered.

## VI. ON THE NATURE AND POSITION OF THE REFLEX.

One of the most fundamental properties of the spinal reflex is that of reciprocal innervation first described by Sherrington. Where one set of muscles in a reflex act is activated, the activity of a set of antagonistic muscles is reciprocally depressed.

The reciprocal innervation might be conditioned in the peripheral afferent neurones. For it is possible that stimulation of a mixed nerve trunk might set into activity some fibres which ultimately activate one set of muscles, and other nerve fibres which ultimately depress the other antagonistic set of muscles. Or, again, each nerve fibre activated might branch within the spinal cord and one branch might activate one centre while the other branch might reciprocally depress the other centre. This second view is that to which Sherrington inclines.

On the other hand the reciprocal innervation might be conditioned by some such process of mutual inhibition as that developed in the section of this paper immediately preceding the present one.

The phenomenon of narcosis progression demonstrates an alternation of antagonistic activities. Even although the extensor muscle does not demonstrate active movements, in the flexor muscle there occur phases of alternate flexor contraction and flexor relaxation—that is, flexion and

extension; and this phenomenon is seen even at the great depths of narcosis at which the afferent mechanism appears to be paralysed.

At this stage in the phenomenon it is therefore probable that although certain attributes of reciprocal innervation are exhibited there is yet no afferent mechanism in being to condition them. If this be the case it appears to be more probable that the conditioning is performed in the manner already set forth in this paper—and not essentially by processes of antagonistic and reciprocal activation and depression in the peripheral afferent neurones. It is not of course intended to state that such an arrangement is not present. All that can be said is that a peripheral afferent mechanism is redundant if present and if the manner here suggested is correct<sup>1</sup>.

The view here suggested therefore places the conditioning of reciprocal innervation, of rhythmic activity, and of the various central factors, in a mechanism of mutual inhibition which links efferent antagonistic “half-centres.” And it suggests that the fundamental

<sup>1</sup> During the correction of the proofs of this paper the following argument has suggested itself to me as a weighty one in connexion with the question of the manner in which reciprocal innervation is ordered: As I have shown, when two antagonistic stimuli of appropriate strengths are pitted against each other a rhythmic phenomenon is conditioned. The rhythm is evidenced in each of the two antagonistic muscles, *and their movements are then accurately reciprocal.* On the hypothesis of the ordering of reciprocal innervation by a mechanism of “mutual inhibition” between the antagonistic “half-centres” no difficulty is presented by the reciprocal relations of the rhythmic movements of the two antagonists. A difficulty is, however, presented if the attempt is made to explain the rhythmic phenomenon by the postulation of an interference which lies in a more peripheral point in the reflex arc. Thus in the ordering of the specific form of rhythmic activity here referred to it might be supposed that an influence which activates the flexor “half-centre” is interfered with by an influence which depresses it, and that the site of this interference is a common synapse between afferent neurones and efferent neurone. In a similar manner a similar interference might occur at another synapse for the extensor “half-centre.” The occurrence of such interference might well explain the rhythmic phenomenon which occurs in either “half-centre”; and if the rhythm is dependent in rate upon the relative values of activation and depression in each “half-centre,” the rates of rhythm in the specific phasic activity here examined would be alike in the two “half-centres”—in the two antagonists. But the movements of the two muscles—or the discharges of the two “half-centres” (efferent neurones)—*would not necessarily be reciprocal.* The difficulty here presented is a somewhat serious one, but it may perhaps be overcome by assuming that the discharges of the two antagonistic centres commence in opposite senses, and that then the rates of rhythm in the two “half-centres” are so accurately equal that the reciprocal relationship of the discharges is retained throughout the whole of the remainder of the period in which the two antagonistic stimuli are applied. But then, why should the first discharges be ordered reciprocally when the two antagonistic stimuli are synchronously commenced? In these circumstances the rhythmic movements of the two antagonists are still accurately reciprocal.

activity of this system is the rhythmic. In what light are we to regard the peripheral reflex?

One peculiarity of the spinal reflex is that under certain conditions the activity may change over into the opposite direction even during the application of a constant stimulus<sup>1</sup>. Thus a flexion-reflex may change over into one of extension during the application of an evocative stimulus.

Again, if the state of the centres be tested during a period of stimulation by means of the application of a brief antagonistic stimulus it may be observed that the "background" reaction has an ever less value as the period of activity is prolonged—even although it may not actually reverse in its activity<sup>2</sup>.

These and similar phenomena suggest that even in the peripheral reflex a process similar to the alternation of activity in progression occurs, although its period may be very much greater than the period of the rhythmic alternation in progression.

It is difficult to avoid the conclusion that the peripheral reflex is nothing more nor less than the distorted "beat" of the fundamental rhythmic phenomenon. On this hypothesis it might be supposed that the peripheral afferent stimulus, as it were, captures one side of the pair of linked "half-centres." As long as the peripheral centripetal impulses impinge upon the centre there occurs a constant elevation of the activation of one side of the unit system, and this may be sufficiently great to prevent an actual reversal of activity while the stimulus is in being. But nevertheless after the maximum of activity is attained there may occur a deterioration which is conditioned by the process of depreciation of inhibition, although the deterioration may be a slower phenomenon than that in the rhythmic phenomenon. When the peripheral stimulus is stopped there is withdrawn from the centres a factor which serves in part to neutralise the ordinary depreciation of inhibition. There then occurs the sudden reversal of activity which is seen in the most usual form of "rebound" phenomenon.

In short, the peripheral reflex may be regarded but as an exaggeration of one or other phase of the fundamental rhythmic activity. When the reflex stimulus is weak there occurs less distortion than when it is strong. There is then a less prolongation of the positive phase upon which the stimulus acts, and reversal of activity may even occur within the limits of stimulation. But when the stimulus is strong there occurs

<sup>1</sup> *Quar. Journ. Exp. Physiol.* v. p. 237. 1912.

<sup>2</sup> *Ibid.* vii. p. 245.



a greater prolongation of the positive phase and there may occur no reversal.

The peripheral stimulus may be looked upon as acting upon the centre in a manner similar to the action of what may be termed the "blood-stimulus" but in a more discriminating way. For whereas it is possible that such a factor as the "blood-stimulus" would act equally upon the two antagonised "half-centres," the peripheral stimulus may be looked upon as activating principally (if not entirely) one only.

If these suggestions are correct the peripheral reflex cannot be looked upon as the functional unit in the activity of the nervous system. The afferent path is only one of the manners in which the unit centre may be activated. The reflex is not the unit by the combinations of which such complexes as those of progression are built up; the afferent path merely selects for activation some of the activities of the more fundamental phenomenon of rhythmic action. If so, what part do the peripheral reflexes play in the normal activity of progression?

Sherrington<sup>1</sup> at one time suggested that perhaps the act of progression is conditioned by the interference of a constant activity through the mediation of peripheral impulses self-generated in the moving limbs, and of these he laid stress upon the proprioceptive impulses which are engendered by the active contraction of the activated muscles. Fascinating as this suggestion is it does not give the fundamental conditions, for progression occurs after such impulses are eliminated.

But there is of course no doubt that such impulses exist in the normal condition—as his work has so clearly shown. What is their effect?

One of their possible functions, as has already been suggested<sup>2</sup>, may be not to interfere with the maintained activation of the centres but actually to conserve it. And in this connexion Sherrington's recent observation<sup>3</sup>, that when the muscles are de-afferented it is less easy than in the normal condition to obtain a maintenance of the rhythmic phenomenon which is conditioned by balanced antagonistic stimulation, is of interest. It is indeed possible that the self-generated proprioceptive impulses serve to keep balanced the activities of the two linked "half-centres," and especially that they serve to maintain this balance where by the accidents of the environment the individual steps of mammalian progression have to be varied in order to carry the animal with accuracy over an uneven surface.

<sup>1</sup> *Journ. Physiol.* XL. p. 28. 1910.

<sup>2</sup> *Quar. Journ. Exp. Physiol.* VI. p. 246. 1913.

<sup>3</sup> *Journ. Physiol.* XLVII. p. 196. 1913.

## VII. ON EVOLUTION OF FUNCTION IN THE NERVOUS SYSTEM.

It is therefore possible to look upon the neuraxial unit as the efferent neurone and not as the reflex arc, and to regard as the primitive activity not the reflex but that rhythmic phenomenon of which there still remain examples in the acts of progression and respiration. On this basis it is possible to frame a hypothesis of the evolution of function in the nervous system on a more satisfactory foundation than that which is generally assumed when the reflex is regarded as the unit.

It must be clear that in the line of vertebrate evolution the first and most important activity is that of progression, for long before the presence of mechanisms for respiration became factors in the conservation of lines of descent a mechanism for changing the topographical relations of animal and environment played a part in that conservation.

Thus it is in the first place possible to figure an animal in which respiration took place as a direct interchange between cell and environment; and to picture it with a primitive locomotory mechanism which consists in an efferent neurone, the cell-body of which is directly exposed to the environment, and a primitive effector organ.

When the geographical relations between animal and environment remained too long unchanged there would occur a local asphyxia (in its widest sense—"starvation") of the efferent neurone—the primitive centre—and an activation of the effectors, even if incoördinate, would serve to drive the animal somewhere—anywhere—to a new region in which the deficiency of nutritive materials, and the surfeit of waste materials, would be compensated. In this primitive arrangement the discharge of the centre may be looked upon as prolonged in an "after-discharge" which lasts as long as the asphyxiation of the centres continues—unless indeed there occurs "fatigue" by the burning up of the molecules the katabolism of which subserves the activity of the centre. And the environmental stimulus may be regarded as the primitive "blood-stimulus."

The next stage in the evolution of the nervous system might be the primitive coördination of antagonistic effectors by means of the appearance of the process of mutual inhibition. It is possible to suppose that the primitive efferents in some lines of descent became able to inhibit efferent cells which activated muscles antagonistic to their own. When local asphyxiation then played upon the system the activity conditioned would not be the former incoördinate individual

activity which was characterised by "after-discharge," but a coördinate rhythmic activity—the primitive progression.

As evolution of the type proceeded, and the primitive nervous system became enclosed, the local asphyxia of the environment no longer would directly affect the nerve centres and its place would be taken by the "blood-stimulus" similar to that which we may suppose to-day acts in even the highest forms. The general hunger of the animal would now set into activity its mechanism of progression by activation of linked and antagonistic centres (or "half-centres") and thus it would be driven into fresh regions of the environment.

But, still later, mechanisms of protection and attack and mechanisms for the perfection of progression became factors of importance in the conservation of lines of descent. These might arise with the appearance of the peripheral afferent mechanism. Neurones which conveyed a state of raised activity towards the enclosed centres might make their appearance and might condition the activation of the centres by producing a state similar to that evoked by the "blood-stimulus." At first these might activate the linked "half-centres" equally, just as the "blood-stimulus" may be supposed to do; but later they might condition a greater and finer selection, so that one "half-centre" alone might be activated.

Thus finally the peripheral reflex as we know it in the mammal might be produced as a modification of the primitive neural activity first seen in its coördinate form in the "beat" of rhythmic progression.

#### SUMMARY.

1. In this paper are described experiments which demonstrate that the phenomenon of "narcosis progression" in the cat may occur at a depth of narcosis at which the spinal reflexes are abolished, and at which even so great a flexion-producing stimulus as rapid division of the thoracic spinal cord is apparently without effect.

2. At this depth of narcosis the phenomenon of "rebound" also is abolished.

3. Previous experiments have demonstrated that rhythmic phenomena are conditioned during the balance of equal and opposite activities in the antagonistic centres (or "half-centres"); but as these centres when activated from a single side demonstrate arrhythmic activity it has been pointed out that it is not justifiable to assume that the rhythm is conditioned in the individual cell-body or "half-

centre." The inference has been drawn that the rhythm is conditioned by properties of the mutual interconnexions of the "half-centres," and that it occurs during their equal activation.

4. But that this activation of the antagonistic linked "half-centres" is not necessarily of peripheral origin is shown by the present experiments.

5. It is therefore suggested that the equal and opposite activation of the linked antagonistic "half-centres" may be fundamentally conditioned by a stimulus equivalent to the "blood-stimulus" in respiration—although in normal circumstances this may be aided by the peripheral impulses. That asphyxia may affect the phenomenon of progression has already been shown.

6. But when the peripheral reflexes are abolished during the occurrence of "narcosis progression" there are still evident in that phenomenon many of the attributes of reciprocal innervation.

7. The inference is therefore drawn that a mechanism for that reciprocal innervation may exist between antagonistic efferent neurones (antagonistic "half-centres") without necessitating the presence of afferent neurones. Arising out of this conception a theory is given to account for the manner of the conditioning of rhythmic activity.

8. The experiments seem to show that the fundamental unit of activity in the nervous system is not that which we term the spinal reflex. They show the independence of the efferent neurone, and suggest that the functional unit is the activity of the independent efferent neurone; or rather, that it is the mutually conditioned activity of the linked antagonistic efferent neurones ("half-centres") which together form the "centre": and they also suggest that the primitive activity of the nervous system is seen in such rhythmic acts as progression and respiration.

9. In the light of this view it is suggested that the spinal reflex is of the nature of a distorted "beat" of the rhythmic progression phenomenon.

10. On the basis of the suggested functional independence of the efferent neurone or "half-centre" a theory of the manner of the evolution of function in the nervous system is sketched. It is supposed that at first the "half-centre" was directly exposed to the environment and that a state of "local asphyxia" then acted as the equivalent of the "blood-stimulus" in activating it and thus producing movements of the effector. Such rough movements might serve to change the immediate surroundings of the animal. Then the primitive coördination arose

in the appearance of a system of mutual inhibition between "half-centres" which innervated antagonistic effectors. At this stage rhythmic activity became possible, and with it a more efficient locomotion of the animal. With the enfolding of the nervous system the primitive environmental direct stimulus was replaced by the indirect "blood-stimulus"; and a peripheral afferent nerve mechanism, the function of which was to perfect the movements of progression and to give reflex movements of attack and defence, arose.

11. In other words, the general bearing of these experiments is to throw doubt upon the spinal reflex as the unit of function of the nervous system and to emphasise the possibility of a more fundamental unit of activity conditioned in independent "half-centres" by stimuli equivalent to the "blood-stimulus."