ON AXON-REFLEXES IN THE PRE-GANGLIONIC FIBRES OF THE SYMPATHETIC SYSTEM.

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THE purpose of this Paper is to give an account of the extent of the pilo-motor reflexes which are obtained on stimulating different portions of the sympathetic chain, to determine the mechanism by which the reflexes are produced, and to point out certain deductions which can be drawn from the facts, as to the arrangement of the pre-ganglionic nerve-fibres.

CONTENTS.

The observations have been made almost entirely upon the pilo-motor nerves of the cat, but the general deductions to be drawn from them may I think be applied to all classes of efferent nerves existing in the sympathetic system.

Anæsthetics. The animals were in all cases anæsthetized. In experiments on cats chloroform was first given, and then the A.C.E. mixture, or occasionally ether, by a tracheal tube. In operations on cats ether was given during the operation, and a $\frac{1}{4}$ to $\frac{1}{2}$ a gram of chloral hydrate per rectum immediately after it. In experiments on dogs morphia was first injected subcutaneously and then the A.C.E. mixture given by a tracheal tube.

Anatomy. Meaning of terms used. I have given earlier an account of the connections of the several ganglia of the trunk of the sympathetic[1]. Some knowledge of these connections is necessary for the proper understanding of the results described here.

With the exception of the compound ganglion stellatum, each ganglion of the sympathetic trunk sends the great majority of the fibres which arise from its cells, to the corresponding spinal nerve. These fibres form wholly or in very large part what is commonly called the grey ramus[2] of the ganglion. I use then the term grey ramus, unless otherwise mentioned, for the strand or strands of nerve-fibres which pass from a given sympathetic ganglion to the spinal nerve of the same body segment as the ganglion.

The nerve-fibres of the grey ramus accompany the spinal nerve in its course to the periphery and innervate the autonomic (visceral) structures of an area of the skin which lies within the area of the afferent cutaneous fibres of the spinal nerve. The skin areas of successive grey rami are themselves successive, and as a rule two adjoining areas do not overlap by more than one or two millimetres.

So far the connections are simple. A complication is introduced by the not infrequent additional connections of the ganglia. A ganglion may send a few post-ganglionic fibres to the spinal nerve of the segment above its own, or to the spinal nerve of the segment below its own, or to both of these (cp. *op. cit.* p. 201). And from about the 11th thoracic to the 6th lumbar ganglia, each ganglion usually sends a few fibres to the spinal nerve above that of its own segment, by way of the white ramus of that nerve. Thus the area of skin supplied by a ganglion is usually more extensive than the area of skin supplied by what we speak of as the grey ramus of the ganglion.

EXTENT OF PILO-MOTOR REFLEXES IN THE LOWER PART OF THE SYMPATHETIC CHAIN.

In 1894 it was found by Dr Anderson and myself[3] that stimulation of the sympathetic trunk below any one of the lumbar ganglia in the cat caused the hairs of the back to become erect in the dorsal skin areas of two to four grey rami immediately above the point stimulated. We found that the effect of stimulation was abolished by injecting

[1] This *Journal*, XV. p. 176. 1893.

[2] If a more precise term is required, this grey ramus might be called the homo-segmental grey ramus. It commonly consists of two strands anastomosing on the artery (intercostal or lumbar) before they join the spinal nerve.

[3] This *Journal*, XVI. p. 435. 1894.

nicotine into the circulation, so that the impulses set up on stimulation must pass through nerve-cells. We pointed out that the hair movement could not be due to ascending pre-ganglionic fibres, since descending fibres only are present in this part of the sympathetic. We considered that an action brought about under such conditions would properly be spoken of as a reflex action, until it had been shown to be produced in some other way.

Method of experiment. In these experiments it is essential to cut the hairs short—a length of 2 to 3 mm. is perhaps best—otherwise much time will be wasted in determining the exact limits of the several areas. It saves time also to know where to look for a movement of hairs on stimulating a given point of the sympathetic; to this end the positions of the vertebral spines should be noted. The grey ramus of the 5th lumbar ganglion—or with an anterior plexus that of the 4th lumbar ganglion—in nearly all cases supplies the skin over the lower part of the sacrum. The successive ganglia above this supply successive patches of skin, each of approximately the length of a vertebra.

In exposing the sympathetic chain, the viscera are covered with warm flannels frequently renewed. There is perhaps less interference with the blood-flow in experimenting with the left, than with the right sympathetic.

Stimulation of the lumbar sympathetic causes normally reflex movements of the body, and twitchings of the skin. These interfere with the observation of the hairs. There are several ways in which this movement can be prevented altogether, or diminished so as to be unimportant. (*a*) A large excess of anæsthetics may be given; in this case there is of course the possibility of a reflex action on the hairs by way of the central nervous system (cp. below, p. 377). (*b*) The spinal cord may be cut, best about the 10th thoracic vertebra; a less excess of anæsthetics is then required to reduce the body reflexes to insignificance. (*c*) The spinal cord from the 10th thoracic to the 3rd lumbar segment may be removed, or the corresponding nerve-roots cut on the side to be stimulated. Except as showing that the hair reflex does not involve the spinal cord, this method is less advantageous than the preceding. (*d*) The white rami of the lumbar sympathetic may be cut, and the trunk also cut above the uppermost severed white ramus. This method is the best for the region stretching downwards from, and including, the 3rd (or perhaps 2nd) lumbar ganglion. In isolating the sympathetic at about the 1st lumbar ganglion, the pleura will almost certainly be punctured; in this case it is advisable to use artificial respiration.

The preparatory dissection having been made, the animal is turned on its side, the hind leg on the side to be observed drawn up by a cord and fastened to a stand; the back is moved to the edge of the warm water-bag so that the skin of the mid-line of the back is well seen. Hooks are passed from the body wall upwards over a rod fastened to a stand, and arranged so that the sympathetic chain is readily accessible. The viscera are arranged so that as little tension as possible is put upon the lumbar vessels; unless this is attended to the circulation in the ganglia and in the skin is apt to be unduly interfered with.

Two persons are required to carry out an experiment, one to stimulate the sympathetic, the other to mark the areas in which the hairs become erect on each stimulation. It is advantageous to have two persons observing the hairs, one noting the upper limit of movement, the other, the lower limit. The limits are marked by cutting the hairs still closer to the skin in a narrow line. Each line is painted with a pigment dissolved in alcohol; thus the effect of a given stimulation can be entered in the notes taken, as extending from red to green, or blue to green, or red to yellow, and so on. Whether the movement of hairs takes place in the whole of an area, or in a part only must be noted.

In stimulating the sympathetic trunk, the electrodes may be placed under the trunk mid-way between two ganglia, but this is not desirable unless certain points in addition to the reflex are to be observed, for on stimulating in this way there is some danger of an escape of current to one of the adjoining ganglia, and there is a risk of injuring the nerve by too great tension. It is best to proceed from below upwards, tying the sympathetic immediately above each ganglion in succession, cutting below the ligature and stimulating immediately above it; thus 1·5 to 2 cm. of nerve may be obtained below each ganglion, and there is greater surety that the electric currents do not spread to the ganglion.

In all careful observations, the sympathetic should be stimulated several times in succession at intervals of about a minute. I have repeatedly found that the movement of hairs is given in the notes of an experiment as less extensive in the earlier stimulations than in the later ones; this is partly due to the difficulty of seeing a slow and slight hair-movement unless the attention is fixed upon the particular hairs; but in part I think it is due to the response being stronger in the later stimulations. On the other hand, on exposure and diminished circulation of blood, fatigue may be easily induced by too frequent stimulations.

Finally the ganglia which send their grey rami to the portion of the skin in which hair movement has been observed must be ascertained. This is most readily done by stimulating each ganglion in succession after severing all its connections except its grey ramus, and noting the patch of hairs which thereupon becomes erect. (For other methods, cp. this *Journal*, xv. p. 184, 1893.)

The results of the experiments upon the greater part of the lumbar region are given in Table 1. In this and in other similar Tables, the numbers placed in the columns under each Exp. indicate the areas of the skin in which the hairs stood on end in consequence of the stimulation. Thus in Exp. 2. stimulation of the sympathetic trunk below the 3rd lumbar ganglion caused the hairs to stand on end in the areas of the skin which received pilo-motor fibres by way of the grey rami of the 3rd, 2nd, and 1st lumbar ganglia.

In the experiments, more or less attention was given to the rapidity and extent of the hair movement. I have indicated some of the results in the Tables by putting figures in black type (**3**) when the movement was noted as prompt and complete, and in italics (*3*) when the movement was noted as slight or as occurring in a part only of the area. The stimulus used in these cases was moderate in strength, viz. that produced by interrupted shocks distinctly felt on the tip of the tongue (1 Daniell, du Bois Reymond's induction coil, index of secondary coil at 9 to 10cm.).

A point of some importance not shown in the Table, is that when the strength of the stimulus is decreased to a certain extent, the effect produced in the several areas decreases from below upwards.

The results given in the Table, taken together with those already given by Anderson and myself, and with those which will be considered later in this Paper, show that on stimulating the lower lumbar sympathetic, a movement of hairs always occurs in the regions governed by the grey rami of two successive ganglia above the point stimulated.

In some cases the region affected is more extensive, and may include three or even four grey ramus areas. But it will be noticed that this wider effect is far more frequent when the white rami are intact than when they are cut, and we may conclude that the implication of more than two areas is in the main due to post-ganglionic fibres passing from a ganglion to the spinal nerve of the segment above by way of the white ramus of that nerve (cp. p. 365). In one only of the four experiments in which the white rami were cut were three areas affected; and the effect in the uppermost of the three areas was but slight. The results then are that on stimulating any point of the lower lumbar sympathetic, a reflex pilo-motor effect is obtained from two, and occasionally from three, successive ganglia above the point stimulated; in the latter case the effect from the uppermost ganglion is but slight.

I have shown earlier (*op. cit.*) that the 6th lumbar ganglion very rarely sends pilo-motor fibres to its grey ramus. And in none of the

TABLE 1. *Extent of sympathetic reflex in the lower lumbar region.*

Place of stimulation of sympathetic trunk	Grey ramus areas affected									
	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10
Below III. L. gang.	3 . 2 . 1	3 . 2 . 1	3 . 2				– . **2**			**3** . – . –
Below IV. "	4 . 3 . 2	4 . 3 . 2	4 . 3 . 2	**4 . 3**			**4** . –	**4 . 3**		**4** . . –
Below V. "	5 . 4 . *3*	4 . 3		**5 . 4** . 3	**5 . 4** . 3 . 2		**5 . 4**	**5 . 4**	**5 . 4**	**5 . 4** . *3*
Below VI. "	5 . 4 . *3*			**5 . 4** . *3*	**5 . 4** . 3 . 2	**5 . 4** . *3*	**5 . 4**		**5 . 4**	**5 . 4** . *3*
Below VII. "							7 . 5 . *4*		7 . *5*	**7 . 5** . *4*
	White rami uncut						White rami cut			
		No pilo-motor nerves in 5th lumbar grey ramus Plexus-Ant.					Grey ramus of 3rd L. gang. cut		Symp. trunk cut just below 3rd L.gang.	Symp. trunk cut a little below 2nd L. gang.

Exp. 1. Spinal cord removed from 12th thoracic to 2nd lumbar segments inclusive; 1st and 2nd lumbar nerves cut just peripherally of the posterior root ganglion.

Exp. 2. Spinal cord cut above 13th thoracic nerve.

Exp. 3. Spinal cord cut below 11th thoracic nerve, and the part below removed. The sympathetic was stimulated on both sides and the results were the same.

Exp. 5. Exp. 10. Stimulation below the 5th lumbar ganglion had a stronger effect than stimulation below the 6th ganglion.

experiments mentioned in Table 1 did stimulation of the 6th lumbar grey ramus have any pilo-motor effect. Since stimulation below the 3rd, 4th, or 5th ganglion affects the areas of the two ganglia which are *immediately* above the point stimulated, we might expect that on stimulating below the 6th ganglion a similar rule would hold, but that as the 6th grey ramus has no pilo-motor fibres, a reflex effect would be obtained from the 5th ganglion only. It is a striking fact that this is not the case (cp. Table 1). Stimulation below the 6th ganglion gives rise to a reflex from the 4th as well as from the 5th lumbar ganglion. The rule then only holds if we regard a ganglion which has no pilo-motor fibres in its grey ramus as non-existent.

The general result may be stated thus: the usual arrangement of the nerve-cells and nerve-fibres in the lower lumbar sympathetic trunk is such that on stimulating any point of it, the hair-muscles contract in the grey ramus areas of the first two of those ganglia above the point stimulated which send pilo-motor fibres to their corresponding spinal nerve.

This generalization does not however include the whole of the facts. Although the 6th ganglion very rarely sends pilo-motor fibres to the 6th lumbar spinal nerve, it not infrequently sends a few to the 5th. This occurs usually, if not invariably, when the 5th lumbar nerve has a white ramus, and it has a white ramus when the arrangement of the nerves is median or posterior[1]. In such case, when the sympathetic trunk is cut above the 6th lumbar ganglion without severing the connection of the 5th lumbar white ramus with the trunk, stimulation of the sympathetic below the 6th lumbar ganglion causes a movement of hairs in the area of the 5th lumbar grey ramus. The movement is usually feeble and usually in a part only of the area of the 5th lumbar grey ramus. If ·5 p.c. nicotine be brushed on the ganglion, stimulation below it has then no effect (cp. below p. 378). It follows from this that in most cases although stimulation below the 6th lumbar ganglion causes a movement of hairs in two grey ramus areas only (4th and 5th lumbar), it nevertheless excites nerve-cells in three ganglia (4th, 5th, and 6th).

We have seen that stimulation below the 6th ganglion, and below the 5th ganglion, affects the same area of the skin, but it is usually obvious on employing a weak stimulus, that the effect is stronger when the stimulus is applied below the 5th ganglion than when it is applied

[1] Cp. Langley. This *Journal*, XVII. p. 296, 1894; Langley and Anderson, *ibid.* XIX. pp. 77—95, 1895, XX. p. 372, 1896.

below the 6th. Taking into account the fact that the 6th ganglion commonly sends a few pilo-motor fibres to the 5th lumbar nerve, a law of the reflex which is broadly, though not strictly accurate may be formulated as follows: The difference in the pilo-motor reflex effect of stimulating above and below a given lumbar sympathetic ganglion varies directly as the number of pilo-motor fibres given off by the ganglion.

I have said that with a weak current of certain strength the effect decreases from below upwards. The strength of current required to give minimal or maximal effects varies of course in the individual cases. The following gives the results in a particular case (Exp. 10). It is noticeable that a maximum effect is obtained with moderately strong shocks: increase of the strength of the current beyond a certain point having no further effect.

Large cat. Chloroform and A.C.E. The sympathetic was tied and cut just above the 7th lumbar ganglion, which was about 2 cm. below the 6th lumbar ganglion. The cut end of the sympathetic below the 6th ganglion was stimulated.

Position of index of secondary coil	Sensation when electrodes placed on tip of tongue	Effect in grey ramus areas		
		5th lumbar	4th lumbar	3rd lumbar
25 cm.	Not felt	Moderate	Slight and partial	
20 cm.	Not felt. (First felt at about 17 cm.)	Good	Moderate	
15 cm.		Good	Moderate to good	Very weak and partial
10 cm.	Sharp but not strong	,,	,,	Slight to moderate movement in a strip near the mid-line, and very feeble a little laterally of this
7 cm.	Very strong	,,	,,	,,
5 cm.	Unbearable	,,	,,	,,

Usually when a weak effect is produced in an area, it is in a strip near the mid-line, and when the effect becomes greater and greater, with increase in the strength of the currents, it spreads laterally, involving more and more completely and promptly the lateral regions. A similar effect is also commonly seen on stimulating the spinal nerves in the vertebral canal. The fact is I think chiefly due to a greater erectile power of the hair-muscles near the mid-line.

I have not determined the extent of the reflex by means of mechanical or chemical stimulation of the sympathetic; since I have not found that repeated pinching the nerve trunk of the sympathetic, or applying a saturated solution of sodium chloride to it, has a sufficiently exciting effect on pilo-motor nerves. I may mention that either method of stimulation when applied to a ganglion causes erection of hairs in the region supplied by the ganglion, leaving other areas unaffected or nearly so.

In a few of the experiments I extended the observations to the upper lumbar and to the sacral regions. The results are given in Table 2. In both regions the ganglia are less accessible and more irregular in position than in the lower lumbar region, and I have not persisted with the observations. But they indicate that as a rule two ganglia above the point stimulated are affected.

TABLE 2. *Extent of sympathetic reflex in the upper lumbar and in the sacral regions.*

Place of stimulation of sympathetic trunk	Grey ramus areas affected: Exp. 1	Exp. 2	Exp. 3 & 7
Below XIIth thoracic gang.	12 . 11 . 10		
,, XIIIth ,, ,,			
,, Ist lumbar gang.	1	1 . 13	
,, IInd ,, ,,	2 . 1	1 . 13	2

Place of stimulation of sympathetic trunk	Areas affected Exp. 9
Below 1st sac. gang.	1 . 7
,, 2nd ,, ,,	2 . 1
,, 3rd ,, ,,	3

EXP. 1. The spinal ganglion of the 12th thoracic nerve was cut away. The 13th thoracic nerve was cut peripherally of the dorsal skin branch, so that no effect was obtained in the area of the 13th grey ramus. Cp. Table 1.

EXP. 2. The spinal ganglia of the 1st lumbar and of the 13th thoracic nerves were cut away.

Dog. I have made one experiment in the dog in order to be certain that the reflex is not peculiar to the cat. The results were as follows:—

Pilo-motor reflex from the lumbar sympathetic of the dog.

Short-haired white terrier. Morphia, chloroform and A.C.E. mixture. Left lumbar sympathetic stimulated, white rami uncut.

Place of stimulation	Grey ramus areas affected: Lumbar	Thoracic
Below 7th lumbar ganglion	(7) . (6) . (5) . **4** . **3**	
Lower end[1] of 6th lumbar ganglion	(6) . (5) . **4** . **3** . 2 . 1^2 .	13^2
Below 5th lumbar ganglion	(5) . **4** . **3** . **2** . 1^3 .	13^3
,, 4th ,, ,,	**4** . **3** . **2** . 1^3 .	13^3
,, 3rd ,, ,,	**3** . **2** . **1** .	**13** . *12*
,, 2nd ,, ,,	**2** . **1** .	**13** . 12

[1] The 6th and 7th ganglia were close together, so that stimulation below the 6th could not be properly carried out.

[2] The hairs moved in a part only of these areas, viz. in a narrow strip near the mid-line.

[3] The movement was slow in the lateral regions of these areas; and apparently rather better on stimulating below the 4th ganglion than on stimulating below the 5th.

In all cases in the lower lumbar region, the first stimulation produced a weaker and less extensive hair-movement than the later stimulations, which are given in the Table.

The 7th lumbar ganglion sent pilo-motor fibres to the 1st sacral nerve, whether the 6th ganglion did so could not be determined. The 5th ganglion sent some pilo-motor fibres to the 4th lumbar nerve by way of its white ramus.

In the protocol the numbers indicating areas of the 5th, 6th, and 7th lumbar ganglia are put in brackets, since stimulation of the grey rami running to the 5th, 6th, and 7th lumbar nerves produced no hair-movement. The area of the 1st sacral grey ramus followed directly upon that of the 4th lumbar.

The experiment shows that the pilo-motor reflex occurs in the dog as well as in the cat, and it affords good evidence that the reflex is more extensive in the dog than in the cat, involving at least three ganglia above the point stimulated.

In the experiments upon the cat there was only one grey ramus in the lumbar region (the 6th) which did not contain pilo-motor fibres, in the experiment given above on the dog there were three, so that if the rule deduced on p. 370 with regard to the relation between the extent of the reflex on stimulating above and below a ganglion and the number of pilo-motor fibres given off by the ganglion, holds for the dog, there should not be any great difference in the extent of the reflex whatever point of the lumbar sympathetic below the 4th ganglion is stimulated. Taking the matter broadly, it will be seen that this was the case. On stimulating below the 4th, the 5th, and the 6th lumbar ganglia the same areas responded. It is true that on stimulating below the 7th lumbar, a less extensive reflex was produced than on stimulating above it, but it happened that the 7th lumbar ganglion though sending no pilo-motor fibres to its own grey ramus sent a considerable number to that of the 1st sacral, so that divergence from the rule was here only apparent.

EXTENT OF PILO-MOTOR REFLEXES IN THE THORACIC REGION OF THE SYMPATHETIC[1].

In the upper cervical sympathetic the direction of the spinal pilo-motor fibres is the opposite of that in the lumbar region. The fibres run upwards instead of downwards. Consequently on stimulating the sympathetic in the thoracic region, we can only obtain evidence of a reflex action from the ganglia below the point stimulated, and not, as in the lumbar region, only from the ganglia above the point stimulated.

Method of experiment. Much of what has been said above (p. 366) with regard to the method of experimenting on the lumbar sympathetic applies also to the thoracic sympathetic, and I need only mention some points of operative procedure.

When it is only desired to stimulate the sympathetic below the ganglion stellatum the simplest method is the following:—The anæsthetized animal is placed on (say) its right side, the left fore-leg is drawn backwards, an oblique cut is made through the skin in front of the lower or mid-portion of the scapula, the muscles from the scapula to the lower part of the neck severed; the head of the first rib can then be easily felt, the muscles of the first interspace close to the head of the rib are torn through and the ganglion stellatum exposed. The upper branches of the ganglion can then be tied, cut on the side away from the ganglion, the 1st and 2nd rami and the ventral limb of the annulus cut, and the sympathetic stimulated below the ganglion. But it is more convenient to tear through the muscles of the 2nd interspace, tie and cut away a piece of the 2nd rib, and to tie the sympathetic immediately below the ganglion. By this method the pleura is not punctured.

When it is desired to stimulate the lower portions of the thoracic sympathetic, it is better to proceed from the ventral surface, double tying the first 5 or more ribs on one side and resecting the part between the ligatures. The string ligatures used for the dorsal part of the ribs are tied to form loops; hooks are passed into the loops and over a horizontal stand above the animal. It is then easy to arrange that the nerve on one side and the hairs over the thoracic vertebræ on the other are properly seen.

In Table 3 are shown the results of stimulation above the several ganglia of the upper thoracic sympathetic, upon the grey ramus areas of the ganglia below. The numbers given in the columns under the

[1] A preliminary account of many of the experiments with regard to the pilo-motor reflex which is obtained on stimulating immediately below the ganglion stellatum I have given elsewhere. *Ricerche di Fisiologia e Scienze affini dedicate al Prof. Luigi Luciani*, 1900, p. 23.

TABLE 3. *Extent of sympathetic reflex in the upper thoracic region.*

Place of stimulation	Lowest grey ramus area affected							
	Exps. 1, 2, 3, 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exps. 10, 11	Exp. 12
Just below ganglion stellatum	6	6	7	7 . *8*[1]	7 . *8*[1]	7 . *8*[1]	8	9[4]
Above 4th thoracic gang.		6	8		7 . 8[2]	7 . *8*[1]		
,, 5th ,, ,,		6	8		7 . 8	8		
,, 6th ,, ,,		7	8		7 . 8	8 . ?9		
,, 7th ,, ,,		8	9		8	9 . *10*[3]		
,, 8th ,, ,,		9 . ?*10*	9		9	10		
,, 9th ,, ,,			10 . ?*11*		10	11		
		White rami cut	Spinal cord cut at 1st thoracic					White rami cut. Spinal cord cut at 2nd cervical

Exps. 1, 2, 3, and 4 were made incidentally to other observations, and are only quoted as showing that the area of the 6th grey ramus is constantly involved. It is probable that under more favourable conditions the reflex would have been more extensive.

[1] The movement of hairs was here very slight; in Exp. 7 and 8 it only occurred near the median line, in Exp. 9 it was only seen occasionally.

[2] The movement only occurred in the median portion of the area.

[3] The movement in this area was not always seen.

[4] The movement in the 9th area may have been due to fibres from the 8th ganglion, since the grey ramus area of the 8th ganglion appeared to include that of the 9th.

heading of Exp. indicate the lowest areas in which a movement of hairs was observed with the given stimulation. The intermediate areas from the point of stimulation are omitted, since in no case is any intermediate area passed over without erection of hairs. Thus in Exps. 10, 11 the number 8 opposite to 'Below ganglion stellatum' indicates that the sympathetic was stimulated immediately below the ganglion stellatum and that a hair-movement was observed in the areas of the grey rami of the 3rd, 4th, 5th, 6th, 7th, and 8th thoracic ganglia. The effect is not equal in all these areas; of that I shall say something later.

The experiments show that on stimulating below the ganglion stellatum the hairs in the region of the 3rd, 4th, 5th, and 6th thoracic grey rami are always erected; that they usually are in the area of the 7th, sometimes slightly in that of the 8th; and possibly occasionally in the area of the 9th grey ramus.

The effect in nearly all cases decreases from the 4th or 5th area downwards, it is fairly strong in the 6th area, but below this it is when it occurs but weak; in the 8th area the effect is commonly confined to the median portion.

The hair-movement in one or two of these areas is of course due to post-ganglionic fibres proceeding from the ganglion stellatum. This ganglion always sends some pilo-motor fibres to the 3rd thoracic nerve, and usually some to the 4th[1]; it may possibly in rare cases send a few fibres to the 5th thoracic nerve; but I have not found any certain instance of this. Allowing for the post-ganglionic fibres, it will be seen that the reflex obtained by stimulating just below the ganglion stellatum involves a greater number of areas than that obtained by stimulating any part of the lumbar sympathetic.

As progressively lower regions of the thoracic sympathetic are stimulated, no new area appears as a rule to be affected until the 6th thoracic ganglion is reached, that is to say, stimulation of any part of the thoracic sympathetic from the ganglion stellatum to below the 5th thoracic ganglion excites the hair-movement in the same areas, the strength of the movement however in the lower areas generally increases as the electrodes reach the 4th and the 5th ganglia.

When the stimulus is applied at any point from about the 6th to the 9th ganglia, two or three areas only are affected, so that the extent of the reflex is much the same as in the lumbar region.

[1] This *Journal*, xv. p. 199. 1893.

The 8th thoracic white ramus usually sends some pilo-motor fibres downwards as well as upwards so that on stimulating the thoracic sympathetic, at or below the accession of the 8th white ramus, any reflex effect there may be, will be commingled with the direct effect of stimulating pre-ganglionic fibres. Further the 7th white ramus may occasionally give off descending pilo-motor fibres (cp. p. 383).

EXPERIMENTS TO DETERMINE THE MECHANISM BY WHICH THE PILO-MOTOR REFLEXES ARE PRODUCED.

1. *Removal of the spinal cord, and of the spinal ganglia.*

Anderson and myself observed that removal of three or four segments of the lumbar spinal cord had no effect upon the lumbar sympathetic reflex, and we concluded that the spinal cord was not concerned in it. As the sympathetic trunk was not cut in this experiment, it is conceivable that the reflex might be produced by impulses travelling to and from the cord above the part removed, although it is extremely unlikely that they should then be produced in undiminished strength. In order to make the matter certain I have removed the spinal cord from the 12th thoracic segment downwards (see Table 1, Exp. 3). The results given in the Table were unaltered by cutting the sympathetic trunk between the 1st and 2nd lumbar ganglia; *i.e.* the complete separation of the sympathetic from the spinal cord did not affect the reflex.

Similarly, removal of the thoracic spinal cord does not affect the extent of the reflex obtained by stimulating the sympathetic just below the ganglion stellatum. In Exp. 12, Table 3, all the white rami down to, and inclusive of the 9th thoracic were cut, the 5th and 6th grey rami ran with the white rami, and were cut with them. The sympathetic trunk was cut below the 9th ganglion, thus the sympathetic was only connected with other structures by the grey rami of the 4th, 7th, 8th, and 9th ganglia; stimulation below the ganglion stellatum caused erection of the hairs in the areas of these grey rami, and of these only.

It is relevant here to state that I have not been able to obtain any reflex action on the hairs from the central nervous system in an anæsthetized animal, on which alone I have experimented. Stimulation of crura cerebri, pyramids or lateral columns of the spinal cord will cause movement of hairs in all parts of the back and in the tail; but

I have not found any effect on stimulating the central end of a cutaneous nerve or of an intercostal nerve. The stimulation of a white ramus also produces no effect beyond the local one due to its containing post-ganglionic fibres from the adjoining sympathetic ganglion, an effect which is unaltered by section of the nerve-roots from which the white ramus arises. So also if the sympathetic be cut above and below a ganglion, and the ganglion stimulated, the hair-movement only takes place in the small strip of skin to which it sends post-ganglionic fibres.

In Exps. 1 and 2 (Table 1, Table 2), two successive spinal ganglia were cut out without affecting the reflex. When removing a spinal ganglion it is to be borne in mind that the dorsal cutaneous branch of the nerve by which the pilo-motor fibres of the grey ramus run to the skin leaves the trunk close to the spinal ganglion; so that unless care be taken in removing the ganglion, the grey ramus may be cut, and in that case the reflex will of course be abolished. (Cp. Table 2, Exp. 1, 13th thoracic.)

These observations show that neither the spinal cord nor the spinal ganglia take part in the pilo-motor reflex.

2. *The effect of nicotine.*

As mentioned above, Anderson and myself found that the injection of nicotine abolished for a time the lumbar pilo-motor reflex.

The effect is perhaps more striking when 0·5 to 1 p.c. nicotine is applied locally to a single ganglion. The reflex is then abolished in the exclusive area of the ganglion to which the nicotine is applied. Thus suppose the sympathetic is stimulated below the 6th lumbar ganglion and an effect obtained in the areas of the 5th and 4th ganglia, if then dilute nicotine is brushed on the 5th ganglion, stimulation below the 6th will cause an effect in the area of the 4th ganglion, but not in that of the 5th; if instead of this dilute nicotine is brushed on the 4th ganglion, stimulation below the 6th ganglion will cause an effect in the area of the 5th ganglion but not in that of the 4th.

The local effect of the nicotine can be strikingly shown by applying a 0·5 p.c. solution to the 4th, 5th, 6th, 7th lumbar and 1st sacral ganglia. On stimulating the uncut sympathetic between the 4th and 5th ganglia, a small patch of hairs on the back will stand on end (3rd lumbar area), and the hairs on the tail except at the root (lower sacral and coccygeal areas), the intervening region being unaffected.

Similarly in the thoracic region, the application of nicotine to any one ganglion cuts out the effect of all the fibres proceeding from this ganglion.

These results show that the impulses set up at the point of stimulation do not affect any given ganglion by stimulating in the first instance another ganglion, but run direct to each ganglion the nerve-cells of which are affected.

3. *The effect of degeneration brought about by section of the sympathetic trunk.*

The preceding observations have shown that the mechanism by which the reflex is produced lies in the sympathetic itself. It is conceivable that the reflex should be produced either (*a*) by commissural fibres proceeding from the cells of one ganglion to the cells of several others, in which case it could no longer be called a reflex: or (*b*) by an action in the ganglia similar to a reflex action from the spinal cord. Both possibilities can be tested by cutting the sympathetic, allowing time for the peripheral ends of the cut fibres to lose their irritability, and then observing whether the reflexes persist or not. The facts which bear on the two views may conveniently be taken separately.

(*a*) If the cells of one ganglion send nerve-fibres to the cells of another, the fibres will degenerate after section of the strand between the two, provided sufficient time is allowed. The arrangement might be represented diagrammatically as in Fig. 1. And the reflex which is normally obtained on stimulating a given point of the sympathetic trunk should no longer be obtained if the sympathetic has been cut some days previously at this point.

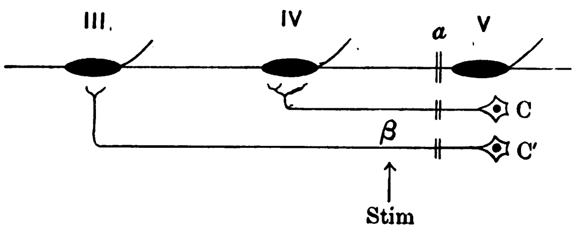

Fig. 1.

I have made five experiments upon the lumbar sympathetic of the cat on these lines. The following gives a summary of them.

	Operation	Time allowed for degeneration
Exp. 1.	Sympathetic cut just above 5th lumbar ganglion (and white ramus of 4th nerve cut)	5 days
Exp. 2.	Sympathetic cut just above 5th lumbar ganglion	7 days
Exp. 3.	Excision of 6th lumbar ganglion	6 days
Exp. 4.	Sympathetic cut above 6th lumbar ganglion	8 days
Exp. 5.	,, ,, ,, ,,	20 days

The upper cut end of the sympathetic was stimulated.

	Place of stimulation	Grey ramus areas affected
Exp. 1.	Below 4th lumbar ganglion	4 . ?3
Exp. 2.	,, 4th ,, ,,	4 . *3*
Exp. 3.	,, 5th ,, ,,	– . [1]4 . 3
Exp. 4.	,, 5th ,, ,,	– . [1]4 . 3
Exp. 5.	,, 5th ,, ,,	5 . 4 . 3

[1] The 5th lumbar ganglion sent no pilo-motor fibres to its grey ramus.

In all cases then a reflex was obtained by stimulating the cut nerve, although it could not have contained any nerve-fibres arising from the ganglia below.

Little attention was paid to the effects of stimulating above the cut end, since although on the theory of ascending ganglionic fibres, the effects might be expected to be weaker for about two segments, the results would be inconclusive. The results were:

	Areas affected		
Place of stimulation	Exp. 1	Exp. 4	Exp. 5
Below 3rd lumbar ganglion	3		3 . 2
Below 4th ,, ,,		4 . 3 . 2	4 . 3 . 2

The weak point of experiments of this kind in the lumbar region is that the distance between the point of stimulation and the ganglion above is not very great. It was 2 cm. in Exps. 2 and 3, and 1·5 cm. in the other experiments. I do not however think that the ganglion above was stimulated directly; and against the possibility is to be set (1) the fact that normally after nicotine has been applied to a ganglion stimulation similar to that used in these experiments, a very short distance below the ganglion, has no effect in the area supplied by the ganglion, although it still has an effect on the area supplied by the ganglion next above, and (2) the effects of stimulating below the place of section, to be related presently (p. 382).

The experimental conditions are much more favourable in the upper thoracic region. We have seen that stimulation just below the ganglion stellatum causes a reflex through the lower ganglia as far as the 6th to the 8th thoracic, and that stimulation at some little distance from the ganglion does not very greatly increase the reflex. Consequently, on stimulating below the ganglion stellatum we may be certain, if ordinary precautions are taken, that no important effect is produced by an escape of current to lower ganglia. I have made two experiments on the thoracic sympathetic.

Exp. 1. Cat. Six days after section of the sympathetic just below the ganglion stellatum, the animal was again anæsthetized, the thoracic sympathetic exposed and stimulated.

Place of stimulation	Grey ramus areas affected
Just below ganglion stellatum	3.4.5.6.7.8
Above 5th thoracic ganglion	5.6.7.8
„ 6th „ „	6.7.8.9.10
„ 7th „ „	7.8.9.10.11
„ 8th „ „	8.9.10.11.12

The rami of the 3rd to the 7th thoracic nerves inclusive were cut. Stimulation just below the ganglion stellatum still gave movement of hairs in the 8th thoracic area.

The second experiment, in which 34 days were allowed for degeneration, gave a similar result.

Thus an operation—which would cause degeneration of all the fibres proceeding downwards from the ganglion stellatum—had no effect upon the reflex; the reflex in fact was rather better in Exp. 1 than in most of the normal cases.

We can then conclude that the reflex is not due to nerve fibres proceeding from the cells of one ganglion to the cells of another ganglion.

(*b*) If the reflex were produced by afferent fibres connected with cells in the ganglion in which the reflex action takes place, the arrangement must be essentially like that of the diagram in Fig. 2, although the actual arrangement in order to obtain the difference in strength of response in the several areas would be much more complicated.

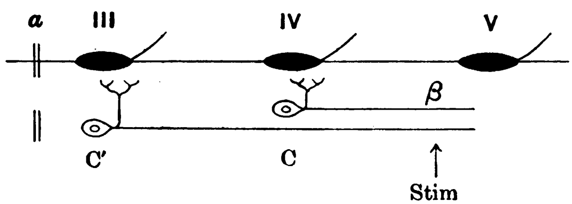

Fig. 2.

It is obvious that with such a mechanism, the degeneration caused by section of the sympathetic in the lumbar region would not abolish the reflex in the region below; thus degeneration of the fibres cut at a, could not abolish the reflex obtained by stimulating at β.

In the experiments already mentioned on p. 380 the sympathetic was stimulated below as well as above the place of section. But three only of them gave results directly bearing on the point we are now concerned with. The results were as follows:

Place of stimulation	Grey ramus areas affected		
	Exp. 1	Exp. 2	Exp. 5
Below 5th lumbar ganglion	0	0	–
Below 6th " "	0	0	0
On 5th " "	5	5	–
On 6th " "	5	5	5
On 7th " "	7	7.1	7

There were then in the three experiments five points of stimulation which normally would have produced a reflex, and no reflex was produced in any one of them; stimulation of the ganglia in all cases caused erection of hairs.

In each of these experiments the 6th lumbar ganglion sent some pilo-motor fibres to the 5th nerve. In Exp. 2 these fibres caused a moderate movement of hairs in the whole area of the 5th grey ramus, though of course much less strong than that caused by the 5th grey ramus itself; in the other two cases the movement was slight.

In Exp. 2 the fibres from the 6th lumbar ganglion to the 5th lumbar nerve ran by the white ramus of the 5th nerve which was intact. The ramus produced its usual spinal reflex and peripheral effects; this ramus never has pre-ganglionic pilo-motor fibres, and it will be noticed that it did not prevent the disappearance of the pilo-motor reflex. In the other two cases the possibly existing white ramus from the 5th nerve was not investigated.

The result I think shows that the pilo-motor reflex cannot be due to stimulation of afferent fibres proceeding to nerve-cells in the sympathetic ganglia.

4. *Effect of degeneration of efferent spinal fibres.*

We have seen in the preceding section that the reflex is dependent upon the integrity of the nerve-fibres which run to the sympathetic by the white rami. In the white rami there are afferent fibres having their origin in the spinal ganglia, and efferent fibres having their origin in the spinal cord. Since stimulation of the peripheral end of the cut posterior roots does not cause erection of hairs, the afferent fibres might fairly be put out of account and we might conclude by a process of exclusion that the efferent fibres are essential to the reflex. But a more satisfactory way of obtaining proof as to the part played by the efferent pre-ganglionic fibres, is to determine whether the reflex occurs when these fibres, and these only, have degenerated in the sympathetic.

The efferent fibres which pass to a given series of ganglia will degenerate on cutting the nerve-roots of the spinal nerves which send fibres to the series, the afferent fibres in the sympathetic will remain intact after such section since they will still be in connection with the spinal ganglia.

In these experiments a difficulty at once presents itself. We do not know with certainty the maximum ganglionic connection of all the spinal nerves, and it is hardly feasible to ascertain the connections in an experiment in which the extent of the reflex has to be determined.

The greatest extent of connection which I have so far observed in the cat for each nerve is given in the following Table.

TABLE 4. *Connection, as observed so far, of the pilo-motor fibres of the spinal nerves with the ganglia of the sympathetic chain (cat).*

		Sympathetic Ganglia	
Spinal Nerve		Highest connection	Lowest connection
Vth	thoracic	Ganglion stellatum[1]	Ganglion stellatum
VIth	,,	,, ,,	Ganglion stellatum usually, in two cases, 5th and possibly 6th thoracic ganglion[2]
VIIth	,,	,, ,,	11th thoracic
VIIIth	,,	,, ,,	12th ,,
IXth	,,	,, ,,	12th ,,
Xth	,,	5th thoracic	3rd lumbar
XIth	,,	11th thoracic, possibly 10th	4th lumbar, possibly 5th
XIIth[3]	,,	13th ,,	5th lumbar
XIIIth[3]	,,	1st lumbar	3rd sacral
Ist[3]	,,	2nd ,,	Upper coccygeal
IInd[3]	,,	3rd ,,	Last coccygeal
IIIrd[3]	,,	4th ,,	Last ,,
IVth[3]	,,	5th ,,	Last ,,

[1] The cervical ganglia are here left out of account.

[2] I have not made many accurate observations with this nerve.

[3] On stimulating any of these spinal nerves, an effect may be obtained in the area of the corresponding grey ramus, but it is probably produced by way of the ganglion of the segment below.

It must be borne in mind that the connections here given have not been observed in any one animal, but represent the combined results obtained in a considerable number of experiments[1].

These results show that it might be necessary to cut the nerve-roots of the 10th thoracic to the 4th lumbar in order to cause degeneration in all the efferent fibres running to the lumbar ganglia.

This was done in Exp. 1; the results of which are given below.

In Exp. 1 and in the other experiments given in this section, the animal being etherized, the arches of the vertebra were cut through on one side only, the vertebral spines not being removed. In Exp. 4 the animal was young, but nearly fully grown; Exps. 1, 2 and 5, it was about half-grown; in Exp. 3 less than half-grown The nerve-roots were cut centrally of the spinal ganglion, but outside the dura mater.

Exp. 1. Young cat. Left 10th thoracic to 4th lumbar nerve-roots inclusive cut 5 days previously. Chloroform and A.C.E. The sympathetic was stimulated from below upwards, and the effect on the hairs, if any, noted.

Place of stimulation	Grey ramus areas affected above the point of stimulation	
	Operated side (left)	Normal side (right)
Below 6th lumbar ganglion	None[1]	5.4
„ 5th „ „	None	5.4
„ 4th „ „	None	4.3
„ 3rd „ „	—[2]	3.2.*1*
„ 2nd „ „	None	2.1

Stimulation of each ganglion caused strong erection of hairs in the appropriate area.

[1] On stimulating just above the 7th ganglion, no effect was obtained (except in the area of the 7th grey ramus): on moving the electrodes nearer the 6th ganglion, there was movement of a few hairs in a spot 2 to 3 mm. in diameter in the 5th grey ramus area; this ceased on cutting the white ramus running from the 5th nerve to the 6th ganglion; it was probably due to stimulation of post-ganglionic fibres arising from aberrant cells of the 6th ganglion.

[2] The 3rd and 4th ganglion were too close together on the left side to allow of isolated stimulation of the nerve between them.

In this case the results were clear and precise. The integrity of the spinal ganglia, of the fibres proceeding from them, and of the sympathetic ganglia did not avail for the preservation of the reflex. The degeneration of the efferent fibres passing from the spinal cord to the ganglia—the

[1] I have given earlier the details of some of these experiments. This *Journal*, xv. p. 219. 1893.

pre-ganglionic fibres—was accompanied by the disappearance of the reflex.

It might perhaps be said that the degeneration of so many fibres in the sympathetic would cause considerable functional disturbance in the ganglia. The experimental evidence is against this possibility, for stimulation of the ganglia direct produced the normal result. And further evidence against it is afforded by Exp. 2. in which the 10th thoracic to the 2nd lumbar nerves were cut, and a large number of fibres degenerated in the lower half of the lumbar region without any alteration in the reflex.

Exp. 2. Kitten. Left 10th thoracic to 2nd lumbar nerves inclusive cut 9 days. Chloroform and A.C.E. The 3rd lumbar nerve sent pilo-motor fibres to the 4th and to all the lower ganglia; the 4th lumbar nerve had no pre-ganglionic pilo-motor fibres.

Place of stimulation	Grey ramus areas affected	
	Left side	Right side
Below 6th lumbar ganglion	5.4	5.4.3
„ 5th „ „	5.4	5.4.3
„ 4th „ „	4	4.3.2
„ 3rd „ „	None	3.2

1 p.c. nicotine placed on the 3rd lumbar ganglion caused strong erection of hairs in its grey ramus area.

In this experiment a large number of fibres were degenerated throughout the lumbar sympathetic. Only one white ramus running to it was intact; this ramus, the third lumbar, sent pilo-motor fibres to the 4th lumbar ganglion and the lower lumbar ganglia, and we see that the reflex from these ganglia was normal, notwithstanding the degeneration in the other fibres. No reflex was obtained from the 3rd lumbar ganglion, the pre-ganglionic efferent fibres of which had all degenerated.

Three experiments were made upon the thoracic region of the sympathetic. From the distribution of the efferent fibres given on p. 383 it appears that the reflex in the upper part of the sympathetic would probably disappear on cutting the 7th to the 10th thoracic roots, but that it might be necessary to cut the 6th also. The 7th to the 10th roots on the left side were cut in Exp. 3, six days being allowed for degeneration. On stimulating the sympathetic just below the ganglion stellatum, there was no movement of hairs in the 6th or in any lower area, so that the reflex normally obtained from the 6th and lower ganglia was abolished.

There was a slow but distinct movement in the 4th and 5th thoracic areas; this may have been due to post-ganglionic fibres from the ganglion stellatum, or, more probably, to an axon-reflex by means of the intact fibres of the 6th thoracic nerve.

Stimulation of the sympathetic from the 6th to the 10th ganglia gave less clear results. The animal was small—the distance from the 6th to the 10th ganglion being only 2·6 cm.—so that there was great risk of escape of current to the adjoining ganglia on stimulating between any two of them. The result of stimulating between the ganglia was inconstant, sometimes there was no effect, sometimes there was a very slight and sluggish movement in scattered hairs in one or more areas below the point stimulated.

In the other two experiments (Exp. 4, Exp. 5) the section of the efferent fibres was less complete, and no difference was observed in the reflex. The result of Exp. 5 emphasizes the necessity of cutting a long series of nerves in order to abolish the reflex.

Exp. 4. Left 6th and 7th thoracic nerve roots cut 10 days.

Exp. 5. Left 5th, 6th, 7th, and part of 8th thoracic roots cut 5 days.

Place of stimulation	Grey ramus areas affected	
	Exp. 4	Exp. 5
Just below ganglion stellatum	4 . 5 . 6 . *7* . *8*	4 . 5 . 6 . 7 . *8*
Above 4th thoracic ganglion		4 . 5 . 6 . 7 . *8*
" 5th " "	5 . 6 . *7* . *8*	
" 6th " "	6 . 7 . 8 . ?*9*	

In Exp. 5 after the sympathetic had been cut upon the 9th rib, *i.e.* between the 8th and 9th ganglia, stimulation of the cut end below the 8th ganglion caused hair-movement in all the areas above, thus probably pre-ganglionic fibres from the 9th white ramus ran to the 8th ganglion and to all the ganglia above.

5. *Question of escape of current.*

The possibility of the reflex described being apparent only, and in fact due to the stimulating electric currents spreading along the sympathetic some distance from the point to which the electrodes were applied, I have passed over till now, because the various phenomena of the reflex afford the best proof that this possibility has no basis. I do not think it necessary to argue the matter at length: the following are the chief points on which I should lay stress.

The reflex is produced by quite weak shocks, sometimes not perceptible to the tip of the tongue, and although the reflex is stronger and may be more extensive with stronger shocks, a limit is soon reached, and then a very great increase in the strength of the shock has no additional effect. And it will be remembered that in some cases, as on stimulating the lower lumbar sympathetic in the dog, there is a long stretch of nerve between the point stimulated and the uppermost ganglion affected.

Reversing the direction of the exciting induced currents—a method suggested to me by Prof. Gotch—has no effect upon the extent of the reflex.

We have seen that stimulating the sympathetic below the 3rd, 4th, or 5th lumbar ganglion excites ganglia at about the same distance in each case from the point stimulated, but that stimulating the sympathetic below the 6th ganglion affects ganglia appreciably more remote from the point stimulated. If the electrical currents when applied just below the 5th ganglion can only extend in exciting strength as far as the 4th ganglion they should be unable to excite the 4th ganglion when passed away from it as far as the upper limit of the 7th ganglion; in fact the effect on the 4th ganglion is barely altered.

The action of nicotine shows that no escape of current occurs of sufficient strength to stimulate the post-ganglionic fibres of a ganglion, for a trifling quantity of nicotine applied to a ganglion prevents it responding to a stimulus applied to the sympathetic trunk, and it will be remembered that if the sympathetic be stimulated below a lumbar ganglion to which nicotine has been applied, although no effect is obtained from the nerve-fibres of this ganglion an effect will still be obtained from the nerve-fibres of the ganglion above it.

If cocaine hydrochlorate (1 or 2 p.c.) be applied to a short stretch of nerve centrally of the point stimulated, the reflex is abolished. The very limited extent to which the exciting currents spread along the nerve—proper precautions being taken—is also shown by the absence of effect, even in the area of the ganglion immediately above or below the point stimulated, when the efferent fibres from the spinal cord have degenerated. And lastly the absence of escape current is shown in the normal state, by the absence of pilo-motor effect when the splanchnic nerve or other similar strand[1] is stimulated close to the sympathetic trunk.

[1] For experiments on the effect of stimulating the central end of the annulus of Vieussens see *Cinquantenaire de la Société de Biologie* (Volume Jubilaire), 1899, p. 220.

THE MECHANISM OF THE REFLEX DEDUCED FROM THE EXPERIMENTS GIVEN ABOVE.

The experiments given above show that the reflex involves the pre-ganglionic efferent fibres. The only way in which these fibres can in the circumstances be involved in bringing about a reflex is that already suggested by Anderson and myself, viz. by the single nerve-fibres sending branches to more than one ganglion. On stimulating the central end of any one branch, the nervous impulse spreads to the more central branches, and thus to nerve-cells in the ganglia to which these branches run.

This view explains all the results obtained. Thus the degeneration which follows section of the sympathetic just below the ganglion stellatum, does not diminish the reflex in the upper thoracic sympathetic region, because the efferent fibres which ascend in the upper part of the thoracic sympathetic remain intact. And the degeneration which follows section of the lumbar sympathetic below the last white ramus containing spinal pilo-motor fibres, does abolish the reflex below the point of section because efferent spinal pilo-motor fibres are in this case included in the fibres which degenerate.

Actions of the kind here spoken of, I have called "pseudo-reflex" or "axon-reflex[1]" actions. The latter term is I think the better, as it is both descriptive and accurate.

We may, then, state the general conclusion at which we have arrived thus: The pilo-motor reflexes obtainable from the sympathetic chain are pre-ganglionic axon-reflexes.

THE CONNECTIONS OF SINGLE PRE-GANGLIONIC NERVE-FIBRES IN THE SYMPATHETIC.

The axon-reflex helps us to a more accurate knowledge of the highly complex connection which exists between the spinal cord and the sympathetic ganglia. Stimulation of the several spinal nerves in the vertebral canal gives a means of determining to which ganglia each spinal nerve sends nerve-fibres, but it does not allow a conclusion to be drawn as to whether each single fibre runs to one ganglion only or to

[1] *British Assoc. Adv. Sci. Reports*, 1899, *Presidential Address in Physiology*; *Cinquantenaire de la Société de Biologie*, 1899; *Ricerche di Fisiologia e Scienze affini dedicate al Prof. Luciani*, 1900.

several, or to all the ganglia supplied by the spinal nerve. The axon-reflexes afford a first approximation towards a knowledge of the connection of the nerve-fibres.

The extent of the axon-reflexes in a given part of the sympathetic shows the maximum number of ganglia with which any fibre in that part is connected. It is no doubt true that if one or two fibres only were stimulated, no visible effect might be produced. On the other hand, it is to be remembered that in a given area, a few hairs only may be moved by a given stimulation, all the rest being quiescent; this may be taken as meaning that each pilo-motor cell of a ganglion supplies chiefly at any rate a small group of hairs or even a single hair; and as the hairs can move separately, the stimulation of even a single pre-ganglionic fibre may produce visible results. And it is I think certain that if any efferent fibres on stimulation produce no visible effect, their number can only be small; and to neglect them will not seriously affect our conclusions as to the general plan of arrangement.

In considering the Tables given above (pp. 369, 375) as to the extent of the reflex, it must not be forgotten that on stimulating below a ganglion in the lumbar region, or above a ganglion in the upper thoracic region, the efferent fibres which produce the axon-reflex will be connected with one more ganglion than is indicated by the grey ramus areas affected in the reflex. Thus if stimulation below the 4th lumbar ganglion causes a movement of hairs in the areas of the 4th and 3rd lumbar ganglia, and the movement in the area of the 3rd lumbar ganglion fails on stimulating below the 5th ganglion, then obviously, the fibres which cause a movement by way of the 3rd lumbar ganglion must end in the 5th ganglion, and the pre-ganglionic fibres must run to the 5th as well as to the 4th, and 3rd ganglion.

It is, I think, clear from the results which have been given above that the pre-ganglionic pilo-motor fibres which run downwards in the sympathetic end as a rule in three consecutive sympathetic ganglia.

The arrangement may be represented diagrammatically as in Fig. 3.

If this arrangement were rigidly adhered to, we should on stimulating below any given ganglion (as IV), stimulate twice as many branches passing to the ganglion immediately above (IV), as branches passing to the ganglion next but one above (III). And we have seen in fact, that the hair-movement in the area immediately above the point stimulated is greater than in the area of the ganglion next but one above. The arrangement however, is in all probability, not so regular as in the diagram, for more nerve-fibres may run to a given set of three ganglia than to the adjoining sets.

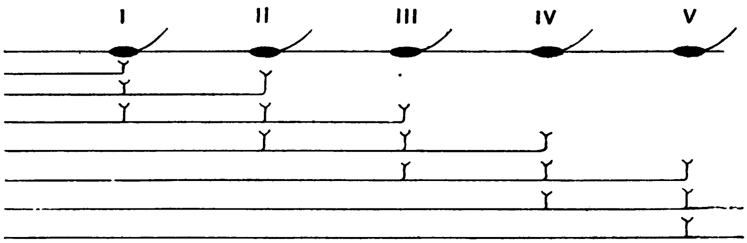

Fig. 3.

I have called attention above (p. 370) to the curious state of things which exists in the lowermost lumbar region. Normally, stimulation below the 6th ganglion gives nearly as good a reflex effect from the 4th ganglion as stimulating below the 5th ganglion, and the effect from the 4th ganglion is not obtained by stimulating below the 7th ganglion. This must mean that a considerable number of fibres send branches to the 4th, 5th and 7th ganglia, so that here the symmetry of the arrangement existing in a large part of the sympathetic above this is lost.

With regard to the 6th ganglion, certain possibilities present themselves. The nerve-fibres might pass by the 6th ganglion without sending fibres to it; or they might send branches to it which end free; or they might send branches to it which end in connection with nerve-cells, not pilo-motor nerve-cells.

We have seen that the difference of the reflex effect in the 4th ganglion, obtained from the sympathetic above and below the 6th ganglion, is broadly speaking less the fewer pilo-motor fibres given off by the ganglion. We may assume that the number of pilo-motor fibres given off by the ganglion represents the number of pilo-motor cells in the ganglion, for if the cells were unfunctional they would probably atrophy. We may conclude then, that the more pilo-motor nerve cells the 6th ganglion contains, the more fibres there are which give branches to the 5th and 6th ganglia without passing on to the 7th, and that the fewer pilo-motor cells the 6th ganglion contains, the more fibres there are giving branches to the 4th, 5th and 7th.

And we may I think fairly conclude from this that most of the fibres which pass on to the 7th ganglion do not send branches to nerve-cells in the 6th ganglion. There is some direct evidence on this point. On stimulating below the 6th ganglion, the reflex is usually much stronger from the 4th ganglion than from the 6th, so that some fibres which are connected with the 4th and 7th ganglia are not connected with the 6th. These fibres would then conform to the usual type of the fibres in the lumbar sympathetic, and end in three ganglia only. The ganglia in this case are not consecutive. The arrangement is represented in the diagram, Fig. 4. With such an arrangement, stimulation below the 6th ganglion would obviously give the same reflex effect as stimulating below the 5th ganglion.

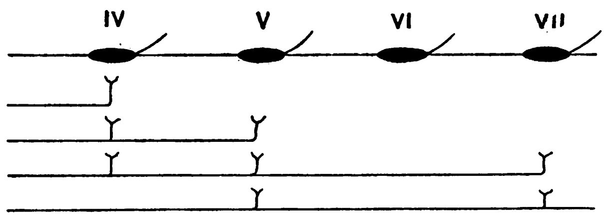

Fig. 4.

The general rule for the arrangement of fibres in the lumbar sympathetic is then as follows:—

Each nerve-fibre sends branches to three ganglia, the ganglia are consecutive if there are a sufficient number of nerve-fibres of the same class in each ganglion; if there are not a sufficient number of such nerve-cells in any one ganglion, fibres roughly proportional in number to the deficit pass on to the next ganglion which has such nerve-cells.

But this rule cannot I think be regarded as absolute. We have seen that there is evidence that in some cases a reflex may be obtained from three ganglia above the point stimulated, although all the ganglia have a considerable number of pilo-motor nerve-cells, and this I have taken as indicating that a few fibres may send branches to four consecutive ganglia.

I do not propose to discuss these complications now, but I may point out that the axon-reflexes afford the only means we have of obtaining any knowledge with regard to them.

It is possible there is another factor in the matter, really an extension of that already mentioned. The ganglia supply areas of different size, and have a varying number of pilo-motor nerve-cells. The primary nerve-branch to a ganglion no doubt divides into many secondary and tertiary branches. If the number of pilo-motor nerves in a ganglion has an influence on a nerve-branch as to whether it ends in a ganglion or passes on, it may influence the branching of the nerve in another way. When the number of nerve-cells is small compared with the number of branches, fewer secondary branches may be formed, and the terminal branch of the nerve may form more branches, and some of these—in a manner analogous to the fibres passing by the 6th ganglion—may grow out to an additional ganglion. Thus whether the nerve supplies 1, 2, 3 or more ganglia might be to a certain extent dependent on the number of nerve-cells in the ganglia to which it passes.

The ascending fibres of the thoracic region end, as a rule, in a greater number of ganglia than do the descending ones of the lower thoracic and of the lumbar region; some of the fibres about the level of the 8th thoracic ganglion have the maximum connection, sending branches to all the ganglia above inclusive of the ganglion stellatum, that is they send branches to five and in some cases to six ganglia, in addition to the compound ganglion stellatum.

The axon-reflexes throw some light upon the distribution in the sympathetic ganglia of the nerve-fibres of each nerve-root. Thus—to select a simple case—it was found in a particular experiment that stimulation of the 1st lumbar nerve in the vertebral canal produced movement of hairs in the areas of the first five lumbar ganglia, the effect being greatest in the areas of the 3rd and 4th ganglia, less in the areas of the 2nd and 5th ganglia, and least in the area of the 1st lumbar ganglion. The relative proportions of the fibres running to the several ganglia might then be represented as in the diagram, Fig. 5.

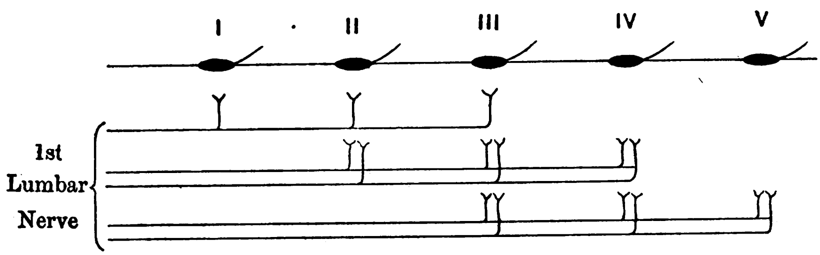

Fig. 5. Diagram of probable distribution of the pilo-motor fibres of the 1st lumbar nerve.

A question which naturally presents itself here is:—Are the fibres which issue from the spinal cord to run to any one nerve arranged in order, so that the uppermost fibres run to the uppermost three sympathetic ganglia, the next to the next three, and so on. In one or two trial experiments with the 2nd lumbar nerve-roots, I found that on weak stimulation the uppermost roots gave hair-movement in the region of the uppermost ganglia, and the lowermost nerve-roots gave hair-movement in the region of the lowermost ganglia, but that as the strength of the stimulus was increased, the movement was less and less localized. The short length of the nerve-roots in the cat makes it difficult if not impossible to map out the distribution of the several small bundles. More accurate results may perhaps be obtained in the dog.

If, as we should expect, the fibres of the nerve-roots pass in series from above downwards to a more posterior series of ganglia, we have to face the remarkable fact that the lowest nerve-root of any one lower thoracic or lumbar segment passes to a more posterior series of sympathetic ganglia than the highest nerve-root of the segment next below. Thus for example the lowest nerve-root of the 1st lumbar nerve might pass to the three sacral ganglia whilst the highest nerve-root of the 2nd lumbar nerve might pass to the 3rd, 4th, and 5th lumbar ganglia.

Further if this is the case, what happens in the different arrangements of the nerves which we speak of as anterior, median and posterior? The customary view of these arrangements is, taking the median arrangement as a starting point, that the uppermost roots of the segment pass out in the nerve of segment above in the anterior

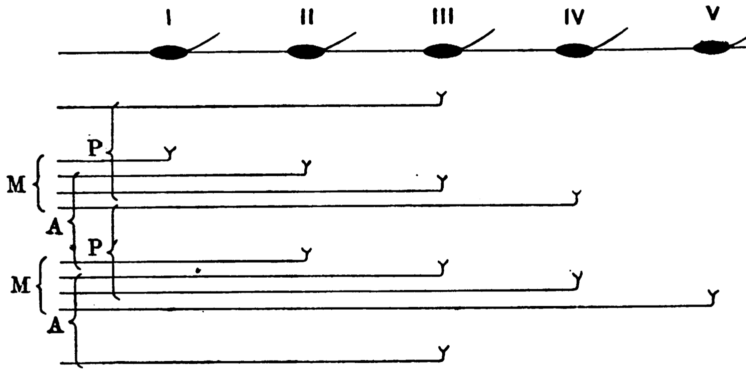

Fig. 6. For the sake of simplicity the nerve is supposed to be made up of four successive rootlets running in the median arrangement (M) to successive ganglia (I, II etc.). In the anterior arrangement (A) the highest nerve root in M passes in the nerve above. In the posterior arrangement (P) the lowest root in M passes into the root below. In either case the root transferred is asymmetrical with the rest.

arrangement, and the lowermost roots of the segment pass out in the nerve of the segment below in the posterior arrangement.

Adopting this view we see that with an anterior shift of nerves the lowest root of a given nerve, being really the highest root of the segment below, should run to a higher series of ganglia than the roots immediately in front of it; and that with a posterior shift of the nerves, the highest root of the segment would run to a lower series of ganglia than the roots immediately following it. The difficulty may be made clearer by reference to the diagram, in which the connections are reduced to a simple form.

Experiment upon the nerve-roots of the dog may be expected to settle the question, whether any asymmetry occurs in the distribution of the nerve-roots. If such asymmetry occurs, it will give a basis for determining which arrangement of nerves corresponds to the true spinal segments. If it does not occur, we can only suppose that the nerve-fibres have a very extended ganglionic connection in the embryonic condition, and that the limitation in the connection of the several fibres is the result of a physiological differentiation occurring in the course of development.

NOTES ON SOME OTHER AXON-REFLEXES, OTHER THAN PILO-MOTOR.

The ganglia of the sympathetic trunk supply not only the unstriated muscles of the hairs, but also the blood vessels of the skin. I have shown that the distribution of the vaso-motor fibres of a given spinal nerve differs only from that of the pilo-motor fibres in being as a rule a little more extensive. We might then expect that on stimulating any part of the sympathetic trunk an axon-reflex would be obtained on the blood vessels of the skin, just as it is obtained on the hairs. That in fact is the case. If the skin be turned back, and the sympathetic stimulated, the small arteries disappear from view, and the skin becomes quite pale in the regions in which the pilo-motor reflex is obtained. The presence of arterial anastomoses often makes the contraction more marked, for there may be complete contraction up to a particular point of the anastomosing vessel—coinciding with the hair-movement on the outer surface of the skin—and the vessel may be little, or not at all, affected past this point. As a rule the vascular constriction has appeared to me somewhat more extensive than the erection of hairs; thus on stimulating below the 6th lumbar nerve, the hair-muscles and the arteries in the skin region of the 5th and 4th will be affected, but there may be perceptible pallor on the area of the 3rd nerve without movement of hairs. But my observations on this point are too few to enable me to say definitely more than that a vaso-motor axon-reflex is obtained in the regions in which there is a pilo-motor axon-reflex. It may be noted however that the vaso-motor reflex is obtained in the lateral skin regions in which no erection of hairs takes place.

From the lower sacral region of the cord axon-reflexes can be obtained on the external generative organs, but as I have said above, the variations which occur in the ganglia and grey rami in this region do not make it a satisfactory field of observation.

Some time ago[1], I mentioned an experiment on the accessory cervical ganglion, which I now think showed the existence of a pilo-motor axon-reflex. At the time this explanation did not occur to me. In this experiment stimulation of the cervical sympathetic both above and below the accessory cervical ganglion caused erection of hairs in the upper cervical region. On applying nicotine to the ganglion, no effect was obtained on stimulating either above or below. After an interval both regions were again effective. As the evidence is against the existence of efferent fibres passing from the cranial nerves to the cervical sympathetic, I conclude that some of the pilo-motor fibres on their way to the cervical sympathetic sent branches to the accessory cervical ganglion. I have tried to make further experiments on the accessory cervical ganglion, but in all the cases—more than a dozen—in which I have looked for it with a view to experiment, it has been absent.

SUMMARY AND GENERAL CONCLUSIONS.

Summary. Cat. On stimulating any point of the lumbar sympathetic from the 1st to the 6th ganglion, an erection of hairs occurs constantly in the dorsal skin areas of the two ganglia immediately above the point stimulated. The ganglia usually send some pilo-motor fibres to the spinal nerve of the segment immediately above its own, by way of the white ramus of the nerve, so that if the white rami are intact, a movement of hairs will commonly occur in the areas of three grey rami even though the nerve-cells of two ganglia only are involved. In the upper lumbar region, two ganglia may fuse together, and the

[1] This *Journal*, xv. p. 199. 1893.

white rami of two spinal nerves above may join the sympathetic close to the compound ganglion; in such case each white ramus may receive some pilo-motor fibres from the ganglion, and the reflex erection of hairs may occur in the areas of four grey rami. The movement of hairs which occurs by means of fibres taking the course of the white rami is never strong, and it is usually confined to a narrow strip bordering the middle line.

Occasionally when the white rami are cut, the reflex is obtained in the areas of three rami, though it is but slight and partial in the uppermost of the three; this indicates that occasionally the reflex may involve three ganglia above the point stimulated.

The 6th lumbar ganglion hardly ever sends any pilo-motor fibres by its grey ramus, but it commonly sends a few—varying in number in different cases—to the skin area of the 5th grey ramus; these usually at any rate pass to the 5th nerve by the white ramus of this nerve. The reflex effect of stimulation of the sympathetic below the 6th ganglion is nearly the same as that produced by stimulating it below the 5th ganglion, and broadly speaking, the result is more nearly the same the fewer the pilo-motor fibres given off by the 6th ganglion. Thus on stimulating below the 6th lumbar ganglion, the hairs may move in two grey ramus areas only (4th and 5th), although the nerve-cells in three ganglia are excited (4th, 5th, 6th).

A similar reflex occurs in the sacral and in the lower thoracic regions of the sympathetic and the extent of the reflex—so far as the experiments go—is ordinarily the same, as in the lumbar region.

On stimulating the thoracic sympathetic just below the ganglion stellatum an erection of hairs occurs in the dorsal skin areas of the ganglia below about as far as the 8th thoracic. The effect is slight in the 7th and 8th areas, and stronger in the 4th and 5th than in the 6th.

On passing the electrodes down the thoracic sympathetic, the effect becomes stronger in the 7th and 8th areas, but as a rule no additional area is introduced until the 6th thoracic ganglion is stimulated; in the mid-thoracic region the reflex involves two or three ganglia only, *i.e.* it is of much the same extent as in the lumbar region.

The reflex effect can be obtained with interrupted shocks which are not or are barely felt on the tip of the tongue.

Nicotine—0·5 to 1 p.c.—when applied to a ganglion abolishes the reflex effect from that ganglion.

The reflex effect does not involve the spinal cord or the spinal ganglia, for it is unaffected by severing all connection of these with the sympathetic ganglia. It is not produced by commisural fibres between the sympathetic ganglia; for an operation which would cause such fibres—if they exist—to degenerate, does not affect the reflex.

An operation which causes degeneration of all the pilo-motor fibres, or of the efferent fibres only, proceeding from the spinal cord to a series of sympathetic ganglia, abolishes the reflex so far as those ganglia are concerned. Thus the reflex is brought about by impulses passing centripetally along pre-ganglionic efferent fibres, which, on their part, excite nerve-cells in one or more sympathetic ganglia. Such an effect may be spoken of as an axon-reflex from pre-ganglionic nerve-fibres or shortly as a pre-ganglionic axon-reflex.

Pre-ganglionic axon-reflexes may also be obtained in the unstriated muscles and blood vessels of the external generative organs, and on the blood vessels of the skin, and probably in all the tissues supplied with nerve fibres by the ganglia of the trunk of the sympathetic.

Dog. In the lumbar region of the dog the pilo-motor reflex is more extensive than in the cat. The 5th, 6th and 7th lumbar ganglia may send no pilo-motor fibres to their respective grey rami; when this is the case, the reflex effect obtained as the stimulating electrodes are passed upwards from a point below the 7th ganglion to a point below the 5th ganglion does not very greatly increase. When a ganglion sends pilo-motor fibres to its grey ramus, there is a considerable difference in the reflex effect obtained by stimulating above and below the ganglion.

General conclusions. Each efferent nerve-fibre (pre-ganglionic nerve-fibre) passing from the spinal cord to the sympathetic divides into branches, and supplies several, probably many, nerve-cells.

The nerve-fibres which run to compound ganglia, as the superior cervical ganglion, the ganglion stellatum, the coccygeal ganglion, may send all their branches to one ganglion. The fibres which run to single segmental ganglia, send their branches to more than one ganglion. In the lower thoracic, the lumbar, and the sacral regions of the sympathetic in the cat, the great majority of the fibres send branches to three ganglia, a few send branches to four. In the corresponding regions in the dog, the single nerve-fibres appear commonly to send fibres to four ganglia and occasionally to more. In the upper cervical region, many of the pre-ganglionic fibres run to five or six ganglia in addition to the compound ganglion stellatum.

The ganglia to which a single nerve-fibre gives branches are ordinarily consecutive. But if a ganglion contains no nerve-cells of a given class, the fibres of this class will ordinarily pass over the ganglion without making connection with it, and send their branches to the next ganglion peripherally which does contain nerve-cells of the given class.

Stimulation of a pre-ganglionic fibre at any part of its course sets up a nervous impulse which travels to all the branches of the fibre and stimulates the nerve-cells with which the branches are connected. Thus stimulation of a fibre peripherally of one or more branches will excite nerve-cells in one or more ganglia centrally of the point stimulated, and will produce a pre-ganglionic axon-reflex. The results I think support the view I have previously put forward, viz. that no reflexes save axon-reflexes occur from the ganglia of the sympathetic system; this question however I shall return to in a later paper.