ON THE QUESTION OF COMMISSURAL FIBRES BETWEEN NERVE-CELLS HAVING THE SAME FUNCTION AND SITUATED IN THE SAME SYMPATHETIC GANGLION, AND ON THE FUNCTION OF POST-GANGLIONIC NERVE PLEXUSES. BY J. N. LANGLEY, *Professor of Physiology in the University of Cambridge.* (Two Figures in the Text.)

(*From the Physiological Laboratory, Cambridge.*)

THE experiments I have already published show I think that commissural fibres do not exist[1] between (1) the nerve-cells of different ganglia, (2) all the nerve-cells of any one ganglion, (3) the nerve-cells in one ganglion which have the same function but which run to areas separated from one another.

There is a final question, viz. whether commissural fibres exist between the nerve-cells in one ganglion which have the same function and which innervate different parts of (what may be regarded as) the same area. On this point the direct experimental evidence I have given is slight, and the conclusion I came to was based largely on the absence of commissural fibres in the other cases.

Recently Hofmann[2] in the course of an interesting account of the neurogenic and myogenic theories of the beat of the heart has taken up this question. He recalls the known facts that stimulation of either the first or the second thoracic nerve causes general dilatation of the pupil, whilst stimulation of each of the ciliary nerves causes local dilatation[3].

[1] Cp. *Text-Book of Physiology*, edited by Schäfer, II. p. 682. 1900; and *Ergebnisse der Physiologie*, II. Jahrg., 2te Abth., S. 854. 1903.

[2] Hofmann. *Schmidt's Jahrb. d. ges. Medicin*, 281, p. 113. 1904.

[3] Budge and Waller obtained unsymmetrical dilatation of the pupil by stimulating the edge of the cornea. Hensen and Völkers obtained local contraction by stimulating a single short ciliary nerve. Jegorow found local dilatation from a single long ciliary nerve. Anderson and myself confirmed Jegorow's observation but sometimes obtained a general effect, possibly owing to escape of current. We found that dilatation of the pupil and contraction of the sphincter were more localized by stimulating the edge of the sclerotic than by stimulating the separate ciliary nerves, since usually in such case a branch and not the whole of a single long and short ciliary nerve was affected. Braunstein also confirmed Jegorow's result. No experiments appear to have been made on the degree of overlapping (if any) of the areas supplied by the several ciliary nerves.

In other words, the pre-ganglionic fibres of each of these thoracic nerves supply the whole of the iris, whilst the post-ganglionic fibres contained in each of the long ciliary nerves supply a part only. He argues from this that the nerve-cells which give off the post-ganglionic fibres must be united by commissural fibres to form a coordinating centre. And apparently he considers that a minimal impulse passing to this centre by however few pre-ganglionic fibres would lead to a discharge from the whole centre and to general dilatation of the pupil.

The class of facts to which Hofmann calls attention undoubtedly requires more explanation than has been given it. For in the first place the spreading out of impulses passing along the pupillo-dilator pre-ganglionic fibres is in fact considerably greater than in the cases mentioned by Hofmann. Both the 1st and the 2nd thoracic nerves caused maximal dilatation of the pupil, and there is little difficulty in believing that each contains sufficient fibres to supply nerve-cells governing all parts of the iris. But the 3rd thoracic nerve has often but a slight action on the pupil, nevertheless its action is general, and not local. Further, when the cervical sympathetic has been cut and has regenerated, each of the thoracic nerves which acquires or reacquires an action on the iris affects it, as a rule, all round. In the second place, it is well known that a considerable number of spinal nerves cause contraction of the spleen, contraction of the arteries of the kidney, contraction of the arteries of the small intestine, inhibition or contraction of the walls of the intestine, and that so far no local effect of any one of these nerves has been described[1].

It is undeniable that this wide range of influence of single nerve roots fits readily with the theory that the peripheral nerve-cells of like function are connected together and discharge as a whole when an impulse reaches any part. Nevertheless the facts to be mentioned presently show, I think, that this is not the method by which the spreading out of pre-ganglionic impulses is brought about.

PUPILLO-DILATOR NERVE-CELLS.

An incidental observation which I made some time ago shows that nerve-cells of like function in the superior cervical ganglion may be excited unequally by pre-ganglionic nerve fibres.

[1] In the intestine I should expect to find that the maximal effect of successive nerves is on successive portions.

In a cat in which the cervical sympathetic had been cut on both sides and had regenerated[1], stimulation of the left 1st thoracic nerve, though causing great dilatation of the pupil, had a greater effect on the temporal than on the nasal side ; this was best shown by the after-effect, the iris on the temporal side relaxing much more slowly than on the nasal side (Fig. 1 b).

On the right side, both 1st and 2nd thoracic nerves had a marked after-action of such sort that the long diameter of the pupil was at an angle of about 30° from the vertical. This was probably due to a rotation of the globe of the eye caused by unequal contraction of the unstriated muscles of the orbit; but the matter is not quite clear, since after *section* of the cervical sympathetic a slight rotation of the globe of the eye is occasionally present, the upper part being turned nasally.

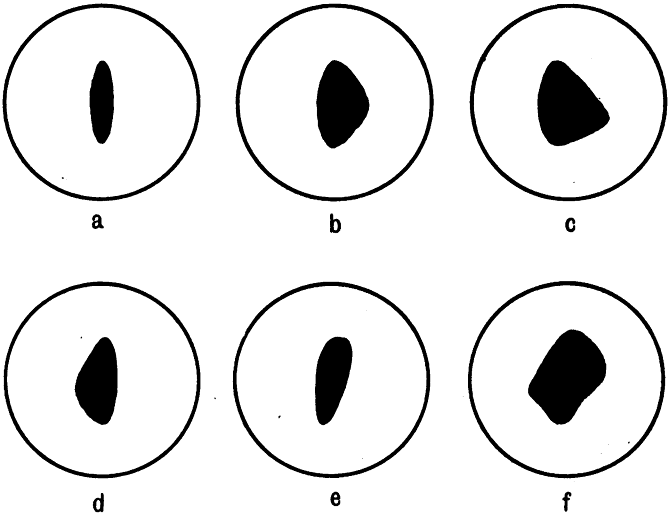

Fig. 1. a. Size and shape of the pupil in the resting state.
b. After-effect of stimulation of the 1st thoracic nerve in a cat in which the cervical sympathetic had been cut and had regenerated.
c. Effect of direct stimulation of the superior cervical ganglion in a case in which the cervical sympathetic had been cut and had regenerated.
d. e. f. Effect of stimulation of three different rootlets of the 3rd thoracic nerve.

In my experiments upon the action of nicotine on the superior cervical ganglion, I noticed in one case[2], in which the cervical sympathetic had been cut and had degenerated, that direct stimulation of a point of the ganglion 2 to 3 mm. from its anterior end caused marked local dilatation of the pupil (Fig. 2 c). The local dilatation may have been due to excitation of a few post-ganglionic nerve fibres, or—and this seemed to me more likely—to excitation of a small group of nerve-cells.

[1] Cp. This *Journal*, XXII. p. 216. 1897. Cat D.
[2] This *Journal*, XXV. p. 469. 1900. Exp. 3.

Hence it seemed to me probable that if a sufficiently small number of pre-ganglionic fibres could be stimulated by themselves, the action on the iris would be local and not general. In order to obtain a few fibres only, I have had recourse to the rootlets of the upper thoracic nerves in the cat.

In the dog, the rootlets are longer and more easily obtained for separate stimulation, but in a trial experiment I did not succeed in isolating more than four rootlets in the 2nd thoracic nerve; each of these gave on stimulation general dilatation of the pupil, though two of them had a greater effect on one side than on the other.

I also cut and teased out on glass the cervical sympathetic in a cat. Most of the strands obtained gave no effect on stimulation, they had no doubt been injured by teasing; three of the strands gave general dilatation of the pupil, and one of these gave a greater effect in a part (about $\frac{1}{4}$) of the iris than elsewhere.

In the cat, the best method of experiment is perhaps the following: The posterior roots outside the dura mater are cut, the dura mater is cut open, the anterior roots are carefully drawn away from the cord, and cut at their entrance into the cord, and the piece of cord is removed; the roots isolated from one another on the dura mater are then held up with fine pointed forceps, and separately stimulated with weak tetanizing currents. By this method there is less escape of current than when the cord is raised, and the electrodes put on the uncut rootlets. Mechanical stimulation (pinching) of the rootlets was tried, but without result.

In the cat a dozen or more rootlets of the 1st, 2nd and 3rd thoracic nerves can, with a little care, be separated from one another. The lower ones of each root are however too short for separate stimulation. Even with the longer upper rootlets there is considerable risk of escape of current to the other rootlets; but since such escape would cause general and not local dilatation of the pupil, the escape in these experiments is mainly of consequence in that it makes it difficult to obtain a local effect, though that alone may be produced by the rootlet itself.

I have made five experiments, stimulating in each case the rootlets of two of the first three thoracic nerves on both sides. There was considerable variation in the results obtained from the several rootlets. (i.) In each experiment one or more of the long upper rootlets caused marked local dilatation, which with weak and moderate currents was confined to a portion of the pupil. (ii.) Other rootlets caused unsymmetrical dilatation of the pupil, but all parts of the iris were affected; after cessation of the stimulus, a local area remained affected for a short time after the remainder had become normal. (iii.) In two cases a rootlet caused slight general dilatation of the pupil. (iv.) In some cases a single rootlet, and in all cases a bundle of rootlets gave good general dilatation.

In the different experiments local dilatation at all parts of the pupil was obtained, but in no case was the local contraction of the dilator structure so great, nor so local, as that which can be obtained by stimulating a small part of the sclerotic.

In Fig. 1, d, e, f, I give the different shapes of the pupil obtained in one experiment by stimulating three different rootlets of the third thoracic nerve. It will be noticed that one rootlet gave a locally greater effect at two points of the iris.

For my immediate purpose, the essential part of the foregoing results is, that stimulation of a single rootlet of any one of the first three thoracic nerves may cause contraction of a portion only of the dilator structure of the iris. This means that the several pupillo-dilator nerve-cells may be excited separately, and the fact disproves the theory that the pupillo-dilator nerve-cells are connected together to work as a whole. The theory might, however, be modified. It might be supposed that a certain strength of stimulus is requisite in order that the excitation may spread from the cells immediately affected to the rest. With regard to this it may be remarked that the local dilatation which is given by a rootlet, though far from maximal, is yet considerable, and that it is improbable that excitation of a group of nerve-cells sufficient to produce this should not pass on to other nerve-cells if they are all physiologically connected. And it is to be remembered that although the effect on the iris is not maximal, the excitation of the nerve-cells concerned may be. Further, although this modified theory might account for a rootlet giving a slight dilatation confined to one part of the pupil, it cannot at the same time account for another rootlet giving a less but general dilatation. If the excitation in the former case is too weak to pass from the stimulated nerve-cells to the other nerve-cells, it must be too weak in the latter case, *i.e.* the weak general dilatation is produced without the passage of nervous impulses from nerve-cell to nerve-cell. If a rootlet can do this, *à fortiori*, a root can also, and it becomes entirely gratuitous to postulate the presence of connections between the nerve-cells in order to account for the fact that each of the first three thoracic nerves causes general dilatation of the pupil.

I conclude then that the theory of the coordination of the peripheral pupillo-dilator nerve-cells is untenable, and I pass to consider what other explanation can be given of the facts, on the view that the pre-ganglionic fibres stimulate only those nerve-cells with which they are directly connected. In the experiments mentioned above, the majority of the rootlets caused dilatation of all parts of the pupil, although the dilatation was often unsymmetrical. This may in part have been due to escape of current to other rootlets, but I do not think it can be doubted that a small proportion of the pupillo-dilator fibres are sufficient to cause considerable general and symmetrical dilatation.

It is conceivable that the wide spreading out of impulses might be brought about by the several fibres of each rootlet intermingling in the cervical sympathetic, and by numerous small bundles of the sympathetic spreading out widely in the ganglion and becoming connected with nerve-cells dotted over the whole area. This possibility is not however satisfactorily supported by the histological appearances. Although no doubt there is in the cervical sympathetic considerable intermingling of the fibres of the rootlets, the fibres in the sympathetic itself change their relative position very little, and general dilatation of the pupil may be obtained from a small bundle of the sympathetic. In the ganglion the sympathetic divides into bundles, and each bundle appears to end in the main in connection with neighbouring nerve-cells. Although then some spreading out of impulses may occur in consequence of the mode of distribution of the pre-ganglionic fibres, I do not think the facts can be accounted for in this way.

A second possibility is that a distribution of pre-ganglionic impulses is brought about by the spreading out of the post-ganglionic fibres. The bundles of nerve fibres which leave the ganglion soon form a plexus, and a portion of this is continued along the internal carotid artery until the fibres run to the 5th cranial nerve. It is hardly possible to explain the existence of the plexus except as due to an intermingling of the fibres which compose the bundles leaving the ganglion. Now the histological appearances in the ganglion show that in the main each bundle arises from adjoining nerve-cells. It is then in the highest degree probable that the fibres from adjoining nerve-cells in the ganglion run to different long ciliary nerves, so that any small group of nerve-cells in the pupillo-dilator region of the ganglion would cause dilatation in a more or less extended area of the pupil. The extent of the area affected would depend primarily upon the degree of separation of the post-ganglionic fibres, and secondarily upon the number of fibres, *i.e.* of nerve-cells involved. This question I have tested experimentally.

The number and arrangement of the rami given off from the anterior end of the superior cervical ganglion vary in different cases, but four rami or bundles of rami may be distinguished for purposes of experiment.

In a cat in the dorsal position, the œsophagus and trachea being tied and turned forward and the superior cervical ganglion viewed from the median side (Fig. 2), two rather large strands can be seen issuing from the anterior pole of the ganglion, the one on the median side (medio-polar strand) is usually the larger and it may more or less cover the lateral one (latero-polar strand). A millimetre or two from the pole a strand of moderate size arises from the medio-dorsal part of the ganglion (medio-dorsal strand), in some cases it consists of two rami. At about the same distance from the pole on the latero-dorsal edge another strand (latero-dorsal strand) arises, this usually consists of two or more small rami. Fibres from these four strands intermix soon after they leave the ganglion and form what may be called a pre-terminal plexus. The plexus has great variations in different animals. In Fig. 2 I give a sketch of the arrangement in a particular case.

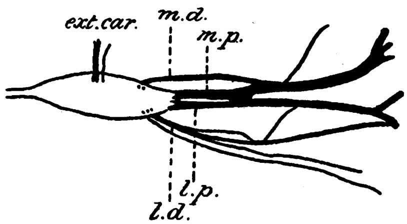

Fig. 2. Example of arrangement of the rami proceeding from the anterior end of the sup. cerv. ganglion in the cat. *m.d.* = medio-dorsal strand; *m.p.* = medio-polar strand; *l.p.* = latero-polar strand; *l.d.* = latero-dorsal strand; *ext. car.* = rami to external carotid artery.

These bundles I have tied separately, isolated for a short distance and stimulated. Very weak tetanizing shocks (1 Daniell, du Bois Reymond inductorium, sec. coil at 20 cm.) caused general dilatation of the pupil in all cases except one in which the latero-dorsal strand gave local dilatation. Since there is considerable chance of escape of current, I lay no great stress on these results.

Instead of tying and stimulating the separate bundles, the bundles may be cut in succession, the cervical sympathetic stimulated after each section, and the effect on the pupil noted. It is easy to pass a fine needle through the larger of the polar strands and to tie or cut a portion of the fibres. From experiments made in this way I find that if any one of the three larger strands is intact, or $\frac{1}{3}$ to $\frac{1}{2}$ of the polar ones, stimulation of the cervical sympathetic causes general and not local dilatation of the pupil. When the latero-dorsal strand only is intact the results vary, there is sometimes general but weak dilatation and sometimes local dilatation affecting $\frac{1}{3}$ to $\frac{1}{2}$ of the iris.

Thus the effect of stimulating a portion of the post-ganglionic fibres as they leave the ganglion is fundamentally the same as that of stimulating a portion of the pre-ganglionic fibres before they enter it. A small proportion of the total number of fibres is sufficient to cause maximal general dilatation. When the number of fibres is very greatly reduced either slight general dilatation or local dilatation is produced.

Occasionally in the cat, the presence of pupillo-dilator nerve-cells on the course of the cervical sympathetic, proximal to the superior cervical ganglion, affords an opportunity of readily observing that either a few pre-ganglionic or a few post-ganglionic fibres may cause slight all-round dilatation of the pupil. In a favourable case stimulation of the cervical sympathetic low in the neck, after the superior cervical ganglion has been paralysed by moistening it with nicotine, causes a slight symmetrical dilatation of the pupil, and no increase in the strength of the stimulus makes it otherwise than slight; here pre-ganglionic fibres running to the nerve-cells on the course of the sympathetic are stimulated. After brushing nicotine over the nerve itself, stimulation of the sympathetic low in the neck has no effect, but stimulation distally of the nerve-cells in it causes the slight symmetrical dilatation seen at first; in this case the post-ganglionic fibres of the nerve-cells are stimulated.

Hence the cause of the spreading out of the pre-ganglionic impulses is not the co-ordination of the nerve-cells of the ganglion; it may be in a very minor degree caused by the intermingling of the pre-ganglionic fibres, but in the main it is caused by the intermingling of the post-ganglionic fibres which occurs in the pre-terminal plexus on the way to the tissue.

Other nerve-cells of the superior cervical ganglion.

On the other nerve-cells in the ganglion I have chiefly incidental observations to record, but they afford evidence that the general conclusions drawn above with regard to pupillo-dilator nerve fibres and nerve-cells hold for the other kinds of nerve fibres and nerve-cells in the superior cervical ganglion. In the experiments on post-ganglionic fibres mentioned above, the movements of the eyelids and the nictitating membrane were observed. The results were that each of the four strands (cp. Fig. 2) leaving the ganglion contained fibres for these structures, the rapidity of the movement, and in the case of the eyelids, the extent of it, varying directly with the number of fibres. Either of the two polar strands was apparently able to give a maximal effect.

In two of the experiments mentioned above, the arteries of the ear were observed, and I have made a few additional experiments in which they were specially noted. The matter here is complicated by the fact that the proximal end of the ganglion sends vaso-motor fibres to the ear by the rami it gives to the 2nd and 3rd cervical nerves. The general results were—that contraction of the vessels of the ear can be obtained from each of the four distal strands as well as from the proximal strands; that the rapidity and to some extent the degree of contraction varies with the number of fibres set in action; that the region of maximum effect is not the same with all the strands, and that in some cases the smaller strands give considerable local contraction with little or no contraction elsewhere.

With regard to the pre-ganglionic fibres, I have not made direct experiments to determine how far a local action on the arteries of the ear can be obtained by stimulating the several rootlets of the 2nd to 5th thoracic nerves, but I have mentioned earlier a case in a cat in which after regeneration of the cervical sympathetic, the 1st thoracic nerve had a local action on the central artery. In this case[1] 24 days had been allowed for regeneration. Stimulation of the 1st thoracic nerve caused complete and ready contraction in half a centimetre in the middle of the central artery, the proximal part was not at all affected and the distal part very slightly; some of the branches of the artery were also entirely unaffected.

PILO-MOTOR NERVE-CELLS OF THE SYMPATHETIC CHAIN.

Primâ facie the case for the co-ordination of pilo-motor nerve-cells in the several ganglia of the sympathetic chain is strong, for most of the ganglia receive fibres from four spinal nerves[2], and some from more, and erection of hairs in the whole area of the grey ramus of the ganglion can usually be obtained from each of the spinal nerves, though the effect is not equal in the several areas.

The criteria as to whether the nerve-cells form a co-ordinated centre which have been applied above to the pupillo-dilator nerve-cells of the superior cervical ganglion may also be applied to the pilo-motor nerve-cells of the ganglia of the sympathetic chain. If they are connected

[1] This *Journal*, XXII. p. 228. 1897.

[2] Cf. Langley. *Ergebnisse der Physiologie*, Jahrg. II. Abt. 2te. p. 847. 1903.

together to work as a whole, stimulation of a few pre-ganglionic pilo-motor fibres cannot in some cases cause feeble movement of hairs in the whole of the area governed by the nerve-cells and in other cases cause fairly strong movement in patches of the area with little or none in the intervening regions.

We have then to consider what happens when a few nerve fibres running to a single ganglion are stimulated. I have made experiments in three ways:—

A. *Stimulation of nerve roots.* On stimulating in the vertebral canal one of the spinal nerves which contain pilo-motor fibres, erection of hairs is obtained in the dorsal skin areas supplied by a series of ganglia. The rapidity and strength of the movement is, as I have said, not the same in the different areas, and it often happens that the movement in the uppermost or lowermost area is only slight. Section of a spinal nerve and observation of the number of degenerated fibres running to each ganglion show that the effect in the several areas is roughly proportional to the number of nerve fibres running to each ganglion: and there is reason to believe that the effect on the movement of hairs is strictly proportional to the number of pilo-motor fibres. Hence the slight movement observed in certain areas may be taken as the movement produced by a few pre-ganglionic fibres. The skin area supplied by a given ganglion usually receives some post-ganglionic fibres from the ganglion above or below, such fibres may be put out of action by the application of nicotine to the ganglia above and below. When, then, stimulation of a spinal nerve gives only a slight movement of hairs in an area, and nicotine is applied to the ganglion above and to that below the ganglion mainly supplying the area, subsequent stimulation of the spinal nerves gives in this area the effect of stimulating a few pre-ganglionic fibres running to this ganglion. In experiments conducted in this way the effect varies; it is either (1) a slight movement of hairs in the whole area, but greatest in the median portion, or (2) a slight movement in the median portion of the area only, or (3) a movement in patches of the median portion of the area. The greater tendency to movement of hairs in the median portion of area is no doubt due to a greater development of the arrectores pilorum in this region[1], for if the whole of the pre-ganglionic fibres running to a

[1] Cf. this *Journal*, xxv. p. 371. 1900. Similarly, the arrectores pilorum are probably unequally developed in different areas; for the minimal stimulus required to produce erection of hairs over the greater part of the tail is less than that required to produce erection of hairs in the lower lumbar region.

ganglion are stimulated with minimal currents, the erection of hairs is confined to the median half to two-thirds of an area, dying away gradually though rapidly at the junction. Since there is a difference in ease of response in the median and the lateral portion of a pilo-motor skin area, I only take into account the movement of hairs in the median region. The results which are pertinent are that maximal stimulation of a few pre-ganglionic fibres in a spinal nerve may cause either (1) slight movement in all the hairs in the median part of a skin area or (2) movement in patches of the median part of the area, with little or no movement of the intervening hairs. The latter was in my experiments the less common case.

B. *Axon reflexes.* In a previous paper I have described the pilo-motor axon reflexes which are observable in the sympathetic chain. In the lumbar region in the cat, the reflex is usually obtained from the two ganglia above, occasionally from three[1]. The movement of hairs brought about by the axon reflex is usually in the whole area of the two ganglia above the point stimulated, being greatest in the area of the ganglion nearest the stimulated point. But when the reflex occurs in the area of the third ganglion above the stimulated point, the movement of hairs is usually in patches in the median part of the area; and the movement may be fairly strong in some patches and absent or very slight in the intervening regions. The axon reflex is due to the stimulation of pre-ganglionic fibres which send branches to ganglia centrally of the point stimulated; when there are many such branches to a ganglion the hair movement is strong in the whole region, when they are fewer the hair movement is weak in the whole region but greater dorsally than laterally, when they are still fewer the hair movement may be unequal in the dorsal part of the region or confined to patches in it.

Since the axon reflex is not always obtainable from the third ganglion above the point stimulated in the lumbar region, it may be necessary to make several experiments to obtain a result. The method of experimenting is as follows. In an anæsthetised cat, the hairs are cut short over the lower lumbar vertebra, the lumbar sympathetic is tied and cut on the left side just below the 2nd lumbar ganglion and just above the 6th lumbar ganglion, and the white rami in the intervening region are severed; warm 1 p.c. nicotine is brushed on the sympathetic from a point a little above the 4th lumbar ganglion down to and including the 5th lumbar ganglion; thus all the nerve-cells except those of the 3rd lumbar ganglion are put out of action. The sympathetic is stimulated above the 3rd lumbar ganglion, and the patch of hairs governed by this ganglion is noted; the sympathetic is then stimulated below the 5th ganglion, in successful cases small patches of hairs become erect in the median part of the region governed by the third ganglion. It may be noted that the maximal effect is usually only obtained after several stimulations.

[1] This *Journal*, xxv. p. 368. 1897.

The results then of stimulating the pre-ganglionic fibres either in the nerve roots or after they have given branches to a ganglion are fundamentally the same, the only difference being that in the experiments which have so far been made the local action has been more frequently observed in the latter than in the former case[1].

C. *Stimulation during regeneration.* Lastly it is to be noted that a local effect of stimulating the spinal nerves may be seen after section and partial regeneration of the lumbar sympathetic. This occurred in Exps. 2 and 3 given in this *Journal*, XXV. p. 420. 1900. In the former, the 3rd lumbar nerve caused erection of the hairs in patches in the lower lumbar and sacral region. In the latter, the effective lumbar nerves, and the lower lumbar sympathetic itself, caused erection of patches of hairs and of isolated hairs on the tail. Normally a slight general movement of the hairs in a given region of the tail is nearly always obtained by stimulating one of the upper lumbar nerves.

Thus by all three methods of observation, results are obtained which are inconsistent with the hypothesis that the pilo-motor nerve-cells in a given ganglion of the sympathetic chain are connected by commissural fibres to form a co-ordinated centre. And we have seen above that the pupillo-dilator and the vaso-motor nerve-cells of the superior cervical ganglion do not form co-ordinated centres.

Since these nerve-cells of varying function are not connected with one another by nerve fibres it is, I think, a fair conclusion that none of the nerve-cells of the sympathetic system, and none of the similar nerve-cells on the course of the cranial and sacral nerves are so connected.

Passing to the arrangement of the post-ganglionic fibres, the facts are as follows. Usually two strands run from a ganglion and form a plexus on the vertebral artery before they join the spinal nerve. Each of these branches usually causes strong movement of hairs over the whole area. Weaker movement of hairs on the whole area may be obtained by stimulating the post-ganglionic fibres which come from the ganglion above or below either by way of the white ramus or by way of the sympathetic chain, but these strands not infrequently only cause movement in part of the area[2].

Here again then the effect of stimulating a portion of the post-

[1] The difference may be due either to the small number of experiments, or to fewer fibres being stimulated in the axon reflex method.

[2] Cf. Langley. This *Journal*, xv. p. 201. 1893.

ganglionic fibres is fundamentally the same as stimulating a portion of the pre-ganglionic fibres, and it is unnecessary to assume any co-ordination of impulses in the nerve-cells interposed between the two sets of fibres.

Remarks on the distribution of the post-ganglionic fibres in the tissues.

We have seen above that a given small region of the iris, or of the blood vessels of the ear, or of the skin with erectile hairs, is affected by post-ganglionic fibres which run in several different strands; and that in the case of the skin with erectile hairs the strands may arise from three separate ganglia. Further we have seen that when a few post-ganglionic fibres are stimulated the effect produced is weak, that as more fibres are stimulated the effect increases till it becomes maximal, and that on stimulating still more fibres the maximal effect is more quickly obtained. In all probability the same sequence holds for all tissues supplied by post-ganglionic fibres.

In order to explain these facts we must first explain how it is that maximal stimulation of a few nerve fibres can cause a minimal effect on the tissue. The explanation I take it is that each post-ganglionic fibre ends in connection with a few contractile cells only, and these probably not immediately adjoining one another; so that although maximal stimulation of the fibre produces maximal contraction of the cells in which it ends, the contraction of the tissue as a whole is slight. This is especially indicated in the iris, the dilatation of the pupil produced by stimulating a few fibres follows quickly on the stimulation, but the dilatation itself is slight[1].

As the number of nerve fibres stimulated is increased, more contractile cells will be involved until there are sufficient to produce a maximal effect. When still more fibres are stimulated more cells are brought into play, and the maximal effect is more quickly produced.

The diminution in the time required to produce a maximal effect may in part be due to the contractile cells receiving nerve endings from

[1] When the whole of the pre-ganglionic pupillo-dilator nerve fibres are stimulated, a slow, slight dilatation of the pupil is sometimes obtained, but at times the dilatation starts fairly quickly but remains slight although the stimulus is continued. In the conditions of my experiment the minimal stimulus varied rapidly, and it is possible that in the cases in which the pupil dilated fairly quickly without continuing to dilate, the actual stimulus to the iris was becoming weaker.

more than one post-ganglionic fibre, but I do not think there are any facts which make this view necessary.

I have so far left unmentioned the peripheral plexus of nerve fibres which occurs in unstriated muscle, in the iris and in glands. The plexus is described by a good many observers as forming a network, and recently Bethe has supported this view, so far at any rate as regards the nerve fibres present in the blood vessels.

In the iris and in the skin it is certain that nervous impulses entering at any one point affect a limited and local area. If electrodes are placed on the sclerotic, radial contraction occurs in a small part only of the iris, a slight shifting of the electrodes causes contraction of another part. Similarly if a small piece of the dorsal sub-cutaneous tissue is picked up in fine forceps, erection of a few hairs immediately opposite the point stimulated is obtained. There is similarly local, though less local, contraction of the arteries. The plexus (or network) which occurs in these regions is connected with the plexus of the adjoining regions but nervous impulses do not spread out into them. Consequently there cannot be either in the skin or in the iris any considerable spreading out of impulses by means of a nervous network. If any such spreading out of impulses occurs it can only occur in the small area to which direct fibres run, and in which it is superfluous to assume it. The experimental evidence is, I think, in favour of isolated conduction in the post-ganglionic branches, and the terminal plexus probably serves chiefly for the distribution of the branches of post-ganglionic fibres, just as the pre-terminal plexus serves for the distribution of the fibres themselves.

SUMMARY AND CONCLUSIONS.

It has been argued that the pupillo-dilator nerve-cells of the superior cervical ganglion must be connected together to form a co-ordinated centre, since dilatation of all parts of the pupil is given both by the 1st and the 2nd thoracic nerve, *i.e.* by a portion of the pre-ganglionic nerve fibres.

I have pointed out that symmetrical dilatation of the pupil may be given by a number of pre-ganglionic fibres much fewer than those contained in either of these nerves. Notwithstanding this, I hold that the wide spreading out of post-ganglionic impulses is not due to the pupillo-dilator nerve-cells being connected together because—

(*a*) Stimulation of a small number of post-ganglionic fibres as they leave the ganglion may also cause symmetrical general dilatation of the pupil. Since a spreading out of the nervous impulses occurs peripherally of the ganglion, it is unnecessary to assume that the spreading out of pre-ganglionic nerve impulses is due to a co-ordinating centre in the ganglion itself.

(*b*) Stimulation of a rootlet of one of the first three thoracic nerves, *i.e.* of a few pre-ganglionic fibres, although it may cause symmetrical dilatation of the pupil, may also cause asymmetrical dilatation, or local dilatation. It seems to me that on no theory of the cells being connected to form a co-ordinating centre can one small bundle of pre-ganglionic fibres cause weak dilatation of all parts of the pupil, and another cause rather stronger dilatation of one part only of it.

Any one of four bundles of post-ganglionic fibres leaving the anterior end of the ganglion may cause general dilatation of the pupil, and the same may be produced by a portion of the larger bundles. This spreading out of nervous impulses I take to be due to the nerve bundles forming a plexus (the pre-terminal plexus) which begins soon after leaving the ganglion.

Within the limits of observation the effect on the pupil is proportional to the number of nerve fibres stimulated, whether they are pre-ganglionic or post-ganglionic. When the number of fibres is very small either local dilatation or weak general dilatation is obtained (probably a minimal number of fibres would always give a local effect). As the number of nerve fibres stimulated becomes greater, general dilatation is always obtained but it may be unsymmetrical. With further increase in the number of fibres, symmetrical maximal dilatation is obtained. With still further increase, the maximal dilatation is more quickly attained.

It is known that the post-ganglionic fibres when they have entered a long ciliary nerve cause local dilatation of the pupil. More limited local dilatation may be obtained by stimulating a branch of a long ciliary nerve on the sclerotic. It follows that the spreading out of impulses in the tissue itself is at most slight.

As has been said above, when a few nerve fibres are stimulated, the dilatation is slight; the explanation of this I take to be that each nerve fibre ends in connection with a certain number only of the radial contractile cells of the iris, and does not influence the rest. It is probable that the contractile cells supplied by the branches of a single post-ganglionic fibre, although near one another, are not immediately adjoining cells, so that the minute areas supplied by the single fibres more or less overlap. The plexus in the iris (terminal plexus) is, I think, in the main due to the interlacing of the branches of the post-ganglionic fibres on their way to their overlapping areas. This plexus is considered by some observers to be a network; if a network exists it is difficult to see how it can have any physiological importance.

All the general statements made above for pupillo-dilator nerve fibres hold also for the pilo-motor nerve fibres of the sympathetic chain. They hold also, so far as they have been worked out, for the vaso-motor nerve-cells of the superior cervical ganglion. Further, the facts known about the pre-vertebral ganglia are in harmony with these statements. The general statements may then, I think, be held to apply to all the sympathetic ganglia and to the similar ganglia of the cranial and sacral nerves.

The observations given in this paper support the general view of the connection of the peripheral ganglia with the central nervous system and with the tissues, which I have earlier put forward. They give further evidence that the nerve-cells in the ganglia are not connected with one another[1], and they show that the function of the pre-terminal plexus is to distribute over a wide area the impulses coming to the ganglion by a portion of its pre-ganglionic fibres.

[1] There is not sufficient evidence to show that a nerve-cell may not receive branches from more than one pre-ganglionic fibre, just as there is not sufficient evidence to show that a contractile cell may not receive branches from more than one post-ganglionic fibre; all that can be said with certainty is that the number of such connections in any one cell, if they exist, must be much less than the number of branches of a single fibre.