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RE-INNERVATION OF GANGLIA TRANSPLANTED TO THE NECK FROM DIFFERENT LEVELS OF THE GUINEA-PIG SYMPATHETIC CHAIN

BY DALE PURVES, WESLEY THOMPSON* AND JOSEPH W. YIP†

From the Department of Physiology and Biophysics, Washington University School of Medicine, 660 S. Euclid Avenue, St. Louis, Mo. 63110, U.S.A.

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SUMMARY

Thoracic and lumbar sympathetic ganglia from donor guinea-pigs were transplanted to the bed of an excised superior cervical ganglion in host animals. Homotopic transplants of superior cervical ganglia served as controls. In this way the same set of preganglionic axons (the cervical sympathetic trunk) was confronted with ganglia from different levels of the sympathetic chain. Re-innervation of the transplants was studied after 3–5 months.

1. Neurones in ganglia transplanted from different levels of the sympathetic chain were re-innervated to about the same over-all degree by the preganglionic axons of the host's cervical sympathetic trunk. Thus, the mean amplitude of post-synaptic potentials, the estimated number of innervating axons, and the number of spinal segments providing innervation to each neurone were similar in transplanted thoracic, lumbar and superior cervical ganglion cells.

2. Neurones in transplanted mid-thoracic ganglia, however, were re-innervated more frequently, and more strongly, by axons arising from more caudal thoracic segments than neurones in transplanted superior cervical ganglia. Stimulation of axons arising from the fourth thoracic spinal segment (T4), for example, elicited post-synaptic potentials that on average were twice as large in transplanted fifth thoracic ganglion cells as in transplanted superior cervical ganglion cells; conversely, axons arising from T1 re-innervated neurones in the superior cervical ganglion about 2–3 times more effectively than fifth thoracic ganglion cells. This difference in the re-innervation of the fifth thoracic and the superior cervical ganglion is in the same direction as (although less pronounced than) the normal difference in the segmental innervation of these ganglia.

3. Transplanted lumbar ganglia were also re-innervated more effectively by relatively caudal segments compared to re-innervated cervical ganglia, but this difference was no greater than that observed for transplanted thoracic ganglia.

4. We conclude that preganglionic axons can distinguish (or be distinguished by) ganglia derived from different levels of the sympathetic chain. Our findings are consistent with the view that ganglion cells have some permanent property that biases the innervation they receive.

* Present address: Department of Zoology, University of Texas, Austin, TX 78712, U.S.A.
† Present address: Department of Physiology, School of Medicine, University of Pittsburgh, Pittsburgh, PA 15261, U.S.A.

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INTRODUCTION

The highly specific patterns of neural connexions that characterize the nervous system must arise from a number of different mechanisms, including neuronal differentiation and proliferation, the migration of neurones to a final position, and the guidance of their axons to an appropriate target. A further mechanism of specific connectivity is presumably the ability of axon terminals to form synapses in a selective manner with target cells, contacting those cells which are in some sense correct, while eschewing neighbouring cells within the target that are inappropriate. Although relatively little is known about any of these mechanisms, selective synapse formation has been particularly difficult to study because of the formidable technical problems associated with exploring synapse formation in embryos.

A part of the nervous system in which selective synapse formation has been explored in some detail is the sympathetic chain of adult mammals (see Purves & Lichtman, 1978, for a review). Langley (1892) was the first to observe that stimulation of each ventral root supplying the superior cervical ganglion elicits different end-organ effects, and that these orderly responses to segmental stimulation are re-established upon regeneration of preganglionic fibres (Langley, 1895). Based on these findings, he proposed that preganglionic axons arising from different levels of the spinal cord make preferential connexions with different classes of ganglion cells. The basis of these specific end-organ responses is that each superior cervical neurone is normally innervated by a number of different axons which arise from a contiguous subset of the spinal cord segments that contribute innervation to the ganglion as a whole (Njå & Purves, 1977*a*; see also Lichtman, Purves & Yip, 1979); when denervated ganglion cells are contacted by regenerating axons, this pattern of innervation is again established (Njå & Purves, 1977*b*, 1978).

Since there is no obvious way to separate for further investigation the different classes of cells that apparently make up the superior cervical ganglion, it would be of considerable interest if the anatomically separate ganglia of the sympathetic chain also differed from one another with respect to the selective formation of synapses. There is, in fact, some evidence to suggest that the innervation of each ganglion in the sympathetic clain is related to the selective bias observed amongst neurones *within* the superior cervical ganglion. Not only is each ganglion innervated by axons arising from an appreciably different set of spinal segments, but some ganglia are innervated by a relatively restricted subset of the segments whose axons appear to be available to them (Lichtman, Purves & Yip, 1980). In the present work we have explored the selective properties of several different ganglia relative to one another by transplanting cervical, thoracic, and lumbar ganglia to the neck where they become re-innervated by axons of the cervical sympathetic trunk.

Our results show that cervical preganglionic axons can distinguish (or be distinguished by) ganglia transplanted from different levels of the sympathic chain.

METHODS

Transplantation

Mature, inbred guinea-pigs weighing 300–500 g (strain 'Magnum', Biological Systems, Toms River, N.J.) were anaesthesized with pentobarbitone (35 mg/kg, I.P.). In an initial series of

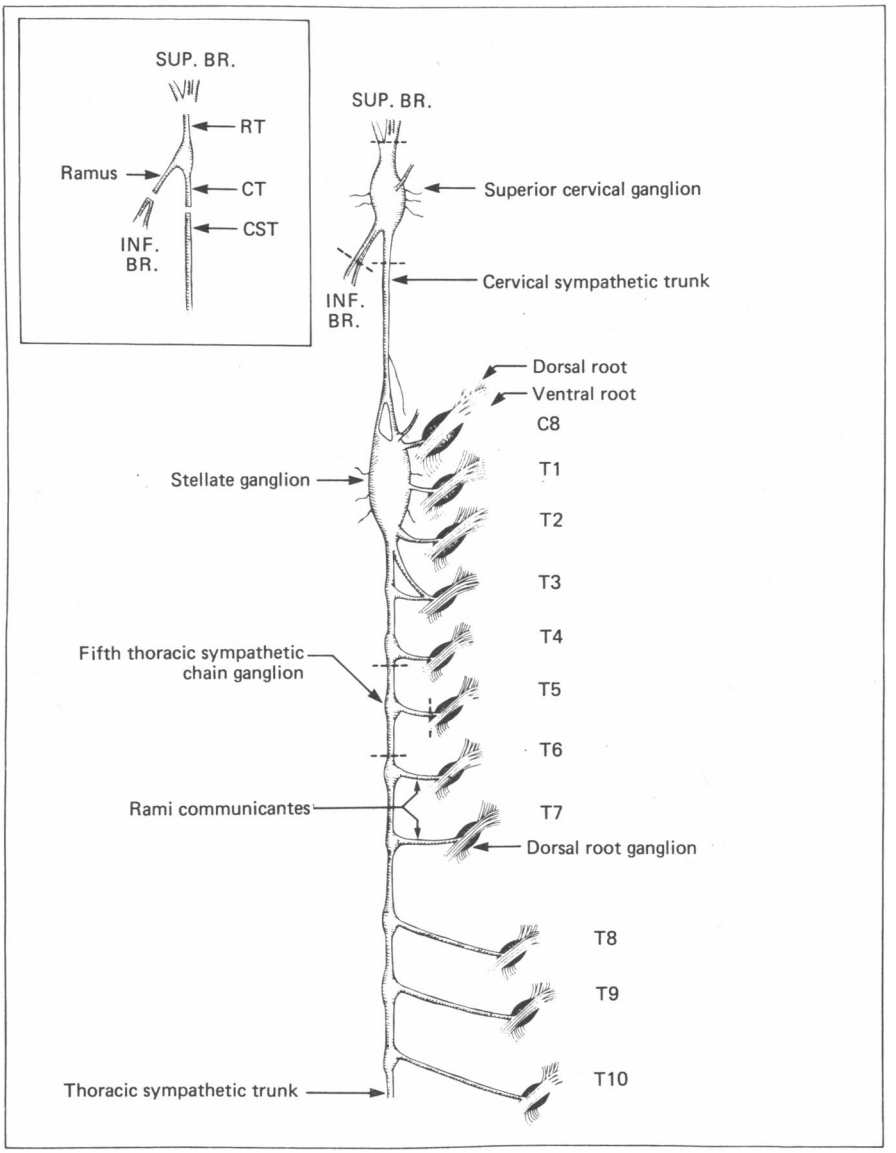

Fig. 1. Diagram of part of the guinea-pig thoracic and cervical sympathetic system used in these experiments (right side shown in ventral view). The ganglia to be transplanted were excised from a donor animal as indicated by the dashed lines. The anastomotic arrangement of implanted fifth thoracic ganglia is shown in the inset. Transplanted superior cervical ganglia were placed in their normal orientation; transplanted lumbar ganglia (not shown) were oriented in the same way as transplanted fifth thoracic ganglia. SUP. BR. = superior post-ganglionic branch; INF. BR. = inferior post-ganglionic branch; RT = rostral sympathetic trunk; CT = caudal sympathetic trunk; CST = pre-ganglionic cervical sympathetic trunk; C8 = eighth cervical segment; T1...T10 = thoracic segments 1–10.

experiments, superior cervical ganglia were removed under sterile conditions from donor animals and transplanted to the position of the excised, right superior cervical ganglion in a host animal of the same sex (in the orientation shown in Fig. 1). In a second series, fifth thoracic ganglia were transplanted from donor animals to the bed of the excised right superior cervical ganglion in a host. In occasional animals the fifth thoracic ganglion was very small; in these instances the fourth or sixth thoracic ganglion was transplanted instead. In a final series of experiments, first lumbar ganglia were transplanted in the same manner. As in transplants from the mid-thoracic level, the L2 or L3 ganglion was sometimes used if L1 was small. In this way, the same set of preganglionic axons was confronted with ganglia transplanted from different rostro-caudal levels of the sympathetic chain.

Electrophysiological examination of transplanted ganglia

After 3–5 months the transplanted ganglia were removed in continuity with the host's cervical sympathetic trunk, thoracic chain, communicating rami, and vertral roots (see Fig. 1); isolated preparations were maintained at room temperature in a bath perfused with oxygenated Ringer fluid (Njå & Purves, 1977*a*). The ventral roots of the spinal segments that normally contribute axons to the cervical sympathetic trunk (C8–T7) were stimulated with suction electrodes, and the re-innervation of neurones in the transplanted ganglia tested by means of intracellular recording, as in previous experiments (Purves, 1975; Njå & Purves, 1977*a*, *b*, 1978). In every neurone impaled we measured the maximum amplitude of the excitatory post-synaptic potential (e.p.s.p.) evoked by individually stimulating the ventral roots C8–T7 and estimated the total number of axons innervating each cell (Purves, 1975; Njå & Purves, 1977*a*).

Re-innervation of superior cervical ganglia *in situ* is complete in about 3 months (Njå & Purves, 1977*a*, 1978), even when the post-ganglionic nerves are also cut (Purves & Thompson, 1979). Thus a 3–5 month inverval between transplantation and the assessment of re-innvervation is probably sufficient to allow establishment of a final pattern. Since in the guinea-pig and other mammals the preganglionic axons in a particular ventral root arise from the corresponding level of the spinal cord (Rubin & Purves, 1980), stimulation of a ventral root activates only those preganglionic axons arising from that spinal segment.

Histological examination of transplanted ganglia

After completion of electrophysiological studies, the transplanted ganglia were treated with Karnovsky's fixative, dehydrated, and embedded in Araldite (Purves, 1975). Semithin sections (1–2 μm) stained with toluidine blue were compared to sections of homologous normal ganglia taken from animals of about the same size. Average cell size was determined with an automated planimeter (Zeiss MOP-3) from outlines of nucleated neuronal profiles drawn with the aid of a camera lucida.

Retrograde labelling with horseradish perioxidase (HRP)

To assess whether peripheral targets had been re-innervated by transplanted ganglion cells, the right eye of three anaesthetized animals was injected with 0·15 ml. HRP solution (10% w/v in saline, Sigma type VI). After a survival time of 48 hr the transplanted ganglia were removed and fixed; 60 μm frozen sections were treated with tetramethylbenzidine (DeOlmos, Hardy & Heimer, 1978; see also Rubin & Purves, 1980) and counterstained.

RESULTS

Gross and microscopical appearance of transplanted ganglia

Most ganglia looked surprisingly normal 3–5 months after transplantation, and had retained the approximate orientation given them at the time of surgery (Fig. 1). The transplants were, however, only about half as large as their normal homologues. Histological examination showed this shrinkage to result from the death of cells in the interior of transplanted ganglia; thus the surviving neurones formed a rind around a neurone-free central region (Pl. 1; see also Zalewski, 1974). The cells originally in the centre of transplanted ganglia died presumably because of inadequate nutrition

prior to revascularization. The size of surviving neuronal somata in the transplants was similar to that of normal ganglion cells (see Pl. 1).

Since mature ganglion cells chronically deprived of target contact lose most of their innervation and degenerate within 3 months (Purves, 1975), it seemed likely that the surviving neurones in transplanted ganglia had sent axons to the periphery. To

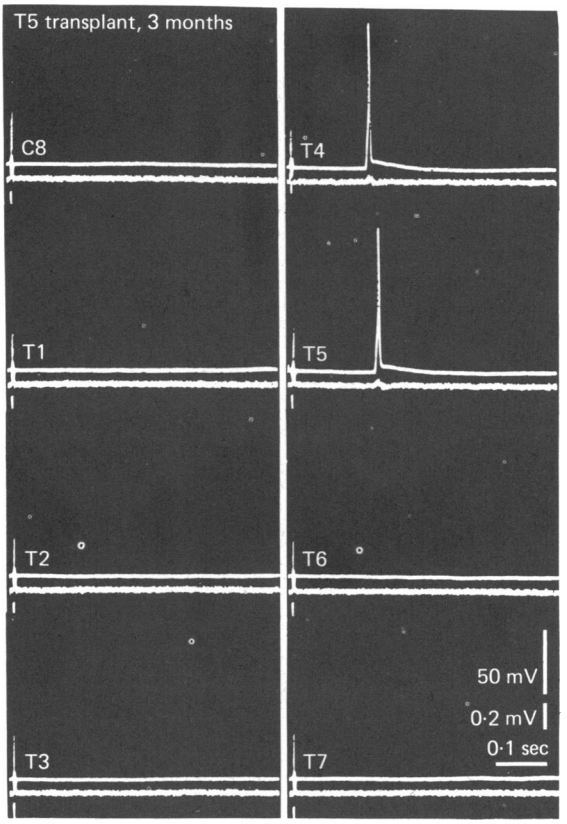

Fig. 2. Example of intracellular recording (upper trace of each pair) from a neurone in a fifth thoracic ganglion transplanted 92 days earlier. Each pair of traces shows response to supramaximal stimulation of the ventral root indicated at the left. A suprathreshold response is elicited by activation of T4 and T5. Lower trace is the compound action potential recorded from the superior post-ganglionic nerve (see Fig. 1). Absence of an appreciable compound action potential to stimulation of ventral roots other than T4 and T5 indicates that the innervation of this transplant was derived primarily from these two segments. Resting potential = −67 mV.

confirm this, HRP was injected into the right eye of three guinea-pigs 5–12 months after transplantation of the fifth thoracic ganglion. Labelled neurones were detected in two of the three ganglia; thus at least some transplanted T5 ganglion cells are able to innervate peripheral targets in locations entirely different from their original targets (see also Purves & Thompson, 1979).

Over-all re-innervation of transplanted ganglia

Neurones in the transplanted ganglia were impaled without difficulty, and showed resting potentials and action potential amplitudes within the normal range (Fig. 2; cf. Purves, 1975). The degree of re-innervation of the transplants was gauged by the percentage of neurones responding to stimulation of one or more ventral roots, the average number of segments contributing innervation to each cell, the number of

TABLE 1. Comparison of the over-all re-innervation of superior cervical, fifth thoracic, and lumbar ganglion cells 3–5 months after transplantation. (means are given ± S.E.)

	Superior cervical ganglion transplants	Fifth thoracic ganglion transplants	Lumbar ganglion transplants
No. of ganglia	36	36	28
No. of neurones impaled	499	491	486
No. of neurones re-innervated	373	354	331
Neurones re-innervated (%)	74·7	72·1	68·1
Mean no. of segments contributing innervation to each neurone	1·4 ± 0·1	1·3 ± 0·1	1·4 ± 0·1
Mean no. of preganglionic axons innervating each neurone	1·9 ± 0·1	1·6 ± 0·1	2·1 ± 0·1
Total mean e.p.s.p. amplitude recorded in each neurone (sum of the segmental responses in mV)	14·2 ± 0·6	15·0 ± 0·7	14·2 ± 0·7

axons innervating each ganglion cell, and the sum of the average e.p.s.p. amplitudes elicited by stimulation of the ventral roots C8–T7. There was no difference in the re-innervation of the ganglia transplanted from different rostro-caudal levels by any of these criteria (Table 1).

Transplanted ganglion cells were, however, contacted by only about a third as many preganglionic axons as superior cervical ganglia re-innervated *in situ* (Njå & Purves, 1977*b*, 1978), or re-innervated *in situ* after post-ganglionic axotomy (Purves & Thompson, 1979), and by only about one-fifth as many preganglionic axons as normal neurones (Njå & Purves, 1977*a*). The reasons for the generally weak re-innervation of transplanted ganglion cells are uncertain, but probably include failure of many preganglionic axons to reach the transplant and the lack of attraction between preganglionic axons and ganglion cells during the time that post-ganglionic axons are actually regenerating (Purves & Thompson, 1979). A further difference from normal ganglia was that post-synaptic potentials recorded in the neurones of particular transplanted ganglia were often elicited at about the same threshold and with the same latency, suggesting that a single regenerated axon had made synaptic contact with many of the cells in the transplant. Normally only a small percentage of the total number of ganglion cells is innervated by a particular axon (D. J. Wigston and D. Purves, unpublished). This difference is presumably due to the smaller number of neurones and innervating axons in the transplants.

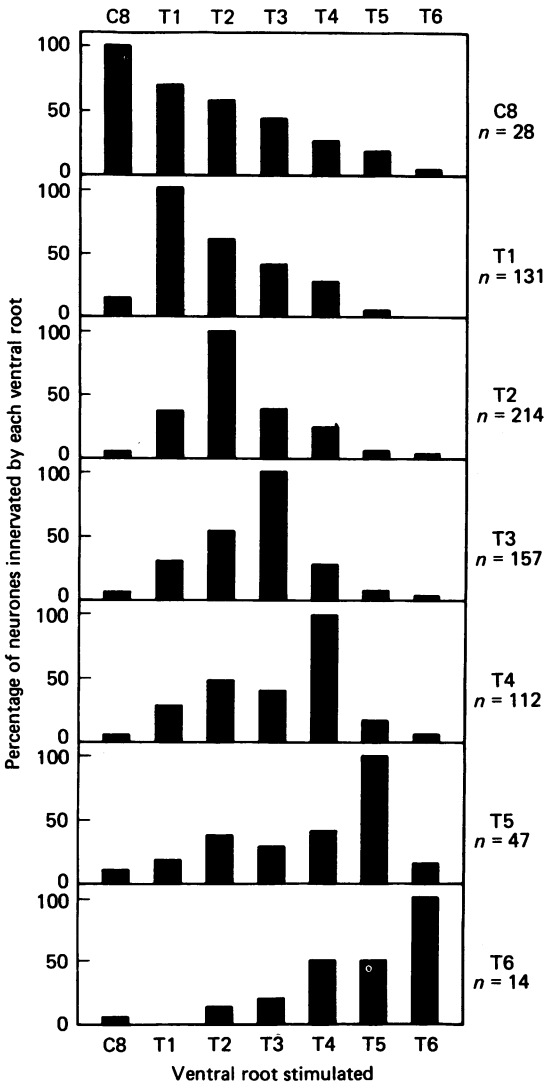

Fig. 3. Likelihood of other segments innervating neurones receiving synapses from particular spinal levels. Each histogram is based on all the neurones in transplanted superior cervical ganglia innervated by a particular ventral root (indicated to right). Selective re-innervation (see text) is apparent, even though this must be impeded by the failure of appropriate axons to reach the transplant in many instances, and by the generally less effective re-innervation by preganglionic axons arising from the more caudal segments represented in the cervical trunk (Njå & Purves, 1977*b*). Only one cell of 499 was re-innervated by preganglionic axons arising from T7.

Selective re-innervation of transplanted superior cervical ganglion cells

An important question is whether the re-innervation of transplanted ganglia continues to reflect the selective mechanisms that operate during re-innervation *in situ*. It might be, for example, that the period of poor nutrition that precedes

revascularization abolishes selectivity, or that selectivity cannot be expressed in the face of the generally weak re-innervation that characterizes transplants. In fact, the overall weakness of innervation to the transplants made it difficult to use contiguity of segmental origin as a measure of selectivity during re-innervation (see Njå & Purves, 1977*a*, *b*, 1978). We could, however, ask if neurones innervated by axons from a relatively rostral segment (C8, for example) were appreciably different in their

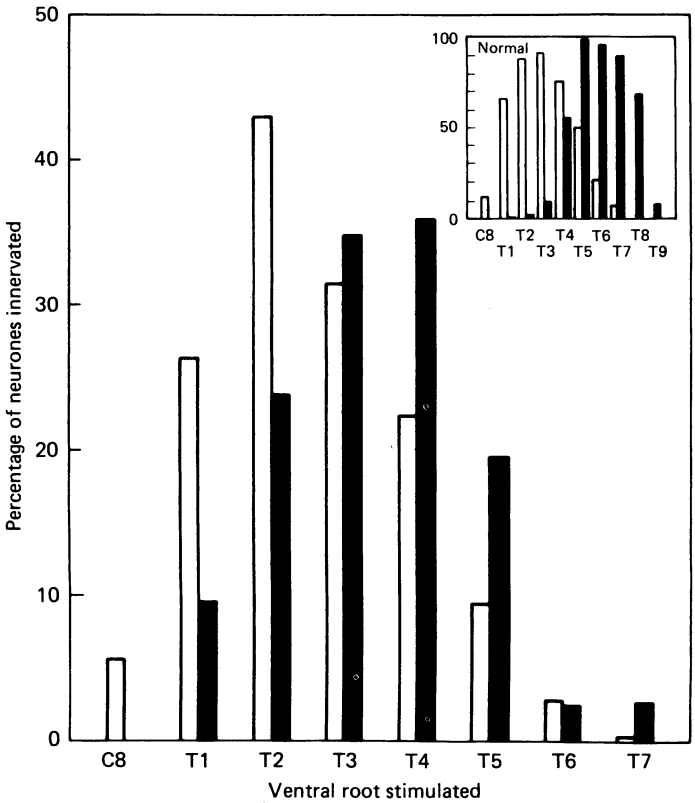

Fig. 4. Percentage of neurones in transplanted superior cervical ganglia (open bars; $n = 499$) and transplanted fifth thoracic ganglia (filled bars; $n = 491$) re-innervated by preganglionic axons arising from the different spinal segments. Inset (redrawn from Lichtman *et al.* 1980) shows the segmental innervation of these two ganglia in normal animals.

predilection for innervation from other segments compared to neurones innervated by axons arising from a relatively caudal segment (T6, for example). As in normal (Njå & Purves, 1977*a*) and re-innervated superior cervical ganglia (Njå & Purves, 1977*b*), transplanted superior cervical neurones innervated by axons arising from rostral segments showed a higher probability of being co-innervated by axons from adjacent rostral segments; conversely, neurones innervated by axons arising from relatively caudal segments showed a higher probability of being co-innervated by axons arising from adjacent caudal segments (Fig. 3). Thus, selective mechanisms are still able to influence the re-innervation of transplanted ganglion cells.

Re-innervation of transplanted ganglia by preganglionic axons arising from different levels of the thoracic spinal cord

(*a*) *Comparison of the segmental re-innervation of superior cervical and fifth thoracic ganglia.*

Although the over-all degree of re-innervation of ganglion cells transplanted from different rostro-caudal levels was similar, there was a difference in the segmental

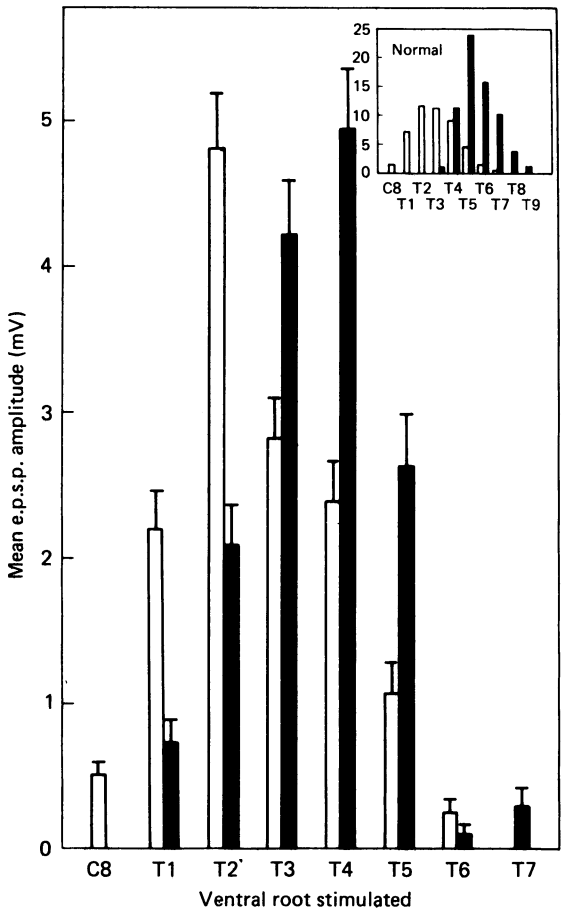

Fig. 5. Mean amplitude (±S.E.) of synaptic responses elicited by stimulation of each ventral root in transplanted superior cervical (open bars; $n = 499$) and fifth thoracic ganglion cells (filled bars; $n = 491$) after 3–5 months. A similar result was obtained if the estimated number of innervating axons from each segment was used as the index of re-innervation. Inset shows amplitude distribution in normal ganglia (from unpublished observations of J. W. Lichtman, D. Purves and J. W. Yip).

origin of the axons that best re-innervated homo- and heterotopic transplants. Thus, fifth thoracic ganglion cells tended to be re-innervated more strongly by axons arising from relatively caudal thoracic segments; conversely, control superior cervical transplants were better re-innervated by relatively rostral segments. This difference

was apparent whether the criterion of re-innervation was simply the number of neurones contacted by axons arising from each ventral root (Fig. 4), the average e.p.s.p. amplitude elicited by stimulation of each ventral root (Fig. 5), or the distribution of those ventral roots supplying the strongest (dominant) innervation to each ganglion cell (Fig. 6).

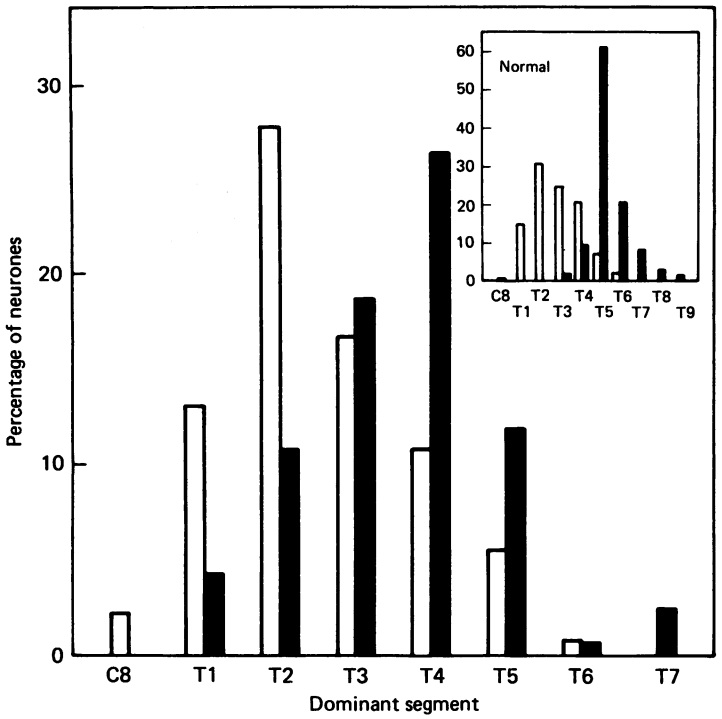

Fig. 6. Fraction of neurones in transplanted cervical and thoracic ganglia dominated by innervation arising from different ventral roots using e.p.s.p. amplitude as the criterion of segmental dominance. Open bars = transplanted superior cervical ganglion cells ($n = 499$); filled bars = transplanted fifth thoracic neurones ($n = 491$). Inset (redrawn from Njå & Purves, 1977*a*, and Lichtman *et al.* 1980) shows distribution of dominant segments in these two ganglia in normal animals.

The caudally shifted re-innervation of transplanted fifth thoracic ganglia might reflect the influence of selective synapse formation observed *within* transplanted superior cervical ganglia. Alternatively, the caudally shifted segmental pattern might be due to a relative failure of rostral axon regeneration. When we compared the strength of T1 and T4 innervation to those cells in the fifth thoracic transplants that received contacts from *both* these segments it was apparent that the fifth thoracic ganglion cells preferred T4 innervation even when T1 innervation was available (Table 2). This suggests that the tendency of transplanted fifth thoracic ganglion cells to be re-innervated by the more caudally derived axons in the sympathetic trunk is due to some quality of the transplanted ganglion cells rather than to a systematic failure of rostral axons to reach the heterotopic transplants.

TABLE 2. Comparison of innervation from T1 and T4 preganglionic axons to those neurones in transplanted thoracic and lumbar ganglia receiving contacts from *both* these segments. Means are given ± S.E.)

Fifth thoracic ganglion cells receiving innervation from both T1 and T4 ($n = 15$)

	T1	T4
Mean e.p.s.p. amplitude (mV)	3·0 ± 0·7	13·3 ± 2·8
Mean no. of axons	1·1 ± 0·1	1·7 ± 0·2
Mean depolarization/axon (mV)	2·8 ± 0·6	8·0 ± 1·2

Lumbar ganglion cells receiving innervation from both T1 and T4 ($n = 27$)

	T1	T4
Mean e.p.s.p. amplitude (mV)	8·5 ± 1·5	7·3 ± 1·6
Mean no. of axons	1·4 ± 0·1	1·4 ± 0·1
Mean depolarization/axon (mV)	6·0 ± 1·2	5·4 ± 1·3

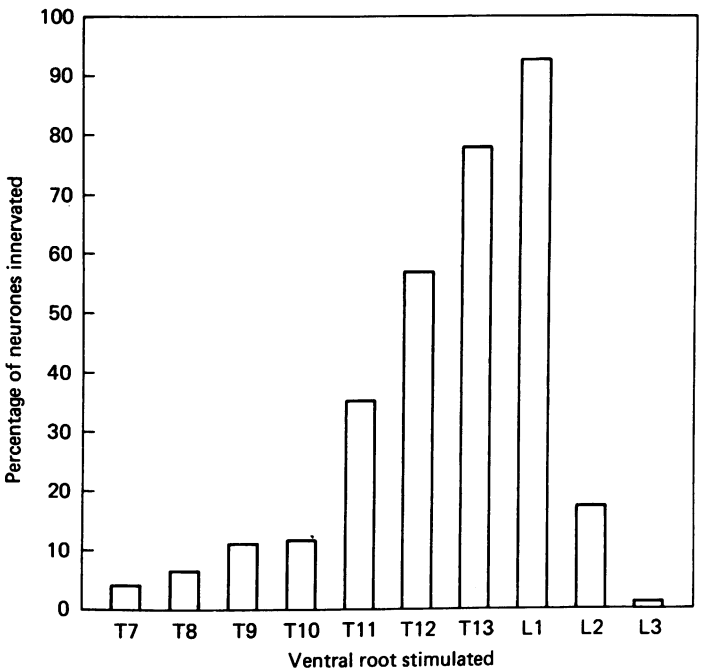

Fig. 7. Percentage of neurones ($n = 199$) in normal first lumbar ganglia innervated by preganglionic axons arising from different spinal segments.

(*b*) *Segmental re-innervation of transplanted lumbar ganglia*

These results with mid-thoracic transplants raise the question of whether a ganglion transplanted from a still more caudal level of the sympathetic chain might cause an even greater bias during re-innervation. We thus undertook another series of experiments in which a lumbar ganglion was transplanted to the neck.

Impalements of 199 neurones in the first lumbar ganglion from thirteen unoperated

animals showed that this ganglion *normally* receives innervation from axons arising from T7–L2, the largest contribution arising from the corresponding spinal cord segment, L1 (Fig. 7). Thus the first lumbar ganglion normally shares little or no preganglionic innervation with the superior cervical ganglion. A somewhat smaller number of segments ($3{\cdot}1 \pm 0{\cdot}1$) and axons ($8{\cdot}0 \pm 0{\cdot}3$) innervated normal L1 neurones compared with normal fifth thoracic ganglion cells (Lichtman *et al.* 1980), or superior cervical ganglion cells (Njå & Purves, 1977*a*).

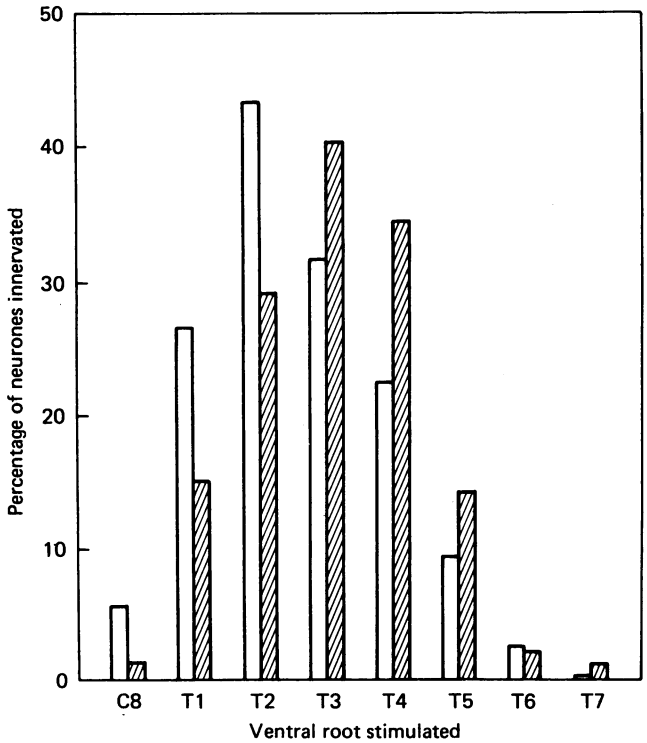

Fig. 8. Percentage of neurones in transplanted lumbar ganglia (crosshatched bars, $n = 486$) re-innervated by preganglionic axons from different spinal levels compared with the re-innervation of transplanted superior cervical ganglia (open bars; redrawn from Fig. 4). The segmental origin of the innervation to transplanted lumbar ganglia is shifted caudally compared to the innervation of transplanted superior cervical ganglia, but no more so than the innervation of transplanted mid-thoracic ganglia (cf. Fig. 4).

The segmental distribution of innervation to *transplanted* lumbar ganglia was also shifted caudally compared with transplanted superior cervical ganglia (Fig. 8), but no more so than the segmental origin of innervation to transplanted fifth thoracic ganglia (cf. Fig. 4). Thus this more caudal ganglion did not lead to re-innervation by more caudally derived axons than a mid-thoracic ganglion. In spite of this, transplanted lumbar ganglia did not appear to be entirely equivalent to mid-thoracic ganglia. For example, those lumbar ganglion cells innervated by *both* T1 and T4 axons, unlike fifth thoracic neurones, did not show a clear preference for T4 axons (Table 2). This somewhat paradoxical finding suggests that while most transplanted

lumbar ganglion cells prefer relatively caudal axons, *some* also attract T1 axons; a possible explanation of this result is considered in the Discussion.

DISCUSSION

The major finding of these experiments is that a given set of regenerating axons, the preganglionic fibres in the cervical sympathetic trunk, is able to distinguish (or be distinguished by) ganglia transplanted from different levels of the sympathetic chain. Although the neurones in the various transplanted ganglia were re-innervated to about the same over-all degree, cervical trunk axons arising from upper thoracic segments were more effective in re-innervating the superior cervical ganglion than thoracic or lumbar ganglia. Conversely, axons arising from the more caudal thoracic levels represented in the cervical trunk were more effective in re-innervating thoracic and lumbar ganglia.

Nearly a century ago, Langley (1895) proposed that the innervation of ganglion cells might be influenced by a 'chemiotactic' affinity between particular ganglion cells and preganglionic axons arising from different levels of the spinal cord. This idea, expressed in a more general form by Sperry (1963), has come to be called the chemoaffinity hypothesis of specific neuronal connectivity. Because the discrimination made by cervical trunk axons is in the same direction as the normal segmental difference in the innervation of the superior cervical and more caudal ganglia, average chemical differences between these anatomically distinct neuronal populations may explain our results. Several other factors, however, must be considered.

First, the segmental origin of the innervation of the heterotopic ganglion transplants is abnormal, presumably because the pool of axons available to them is quite different from the pool that would be available at their normal level in the sympathetic chain. For example, some fifth thoracic ganglion cells are normally contacted by axons arising from T8–T10, which do not run as far rostral as the cervical trunk (Lichtman *et al.* 1980). Moreover, there are fewer axons from T5–T7 (which normally provide most of the innervation to the fifth thoracic ganglion) in the cervical sympathetic trunk than in the mid-thoracic preganglionic nerves (see, for example, Rubin & Purves, 1980). The cervical sympathetic trunk is therefore incapable of fully restoring the normal segmental innervation of the fifth thoracic ganglion. This may explain the fact that the normal difference in the average innervation of the superior cervical ganglion and fifth thoracic ganglion is about two to three segments, while after transplantation the average difference is only about 1½–2 segments (see Figs. 4–6). The same argument of course applies to transplanted lumbar ganglia. In sum, the final pattern of innervation established in the transplants is probably a compromise between selective criteria and the compatibility of those axons which are available (see also Lichtman *et al.* 1980).

Secondly, one might expect the innervation of a particular ganglion (or ganglion cell) to reflect not only preference for axons arising from a particular segmental level, a phenomenon which appears to be based on the *positional* attributes of the pre- and post-synaptic cells (Lichtman *et al.* 1980), but on functional modality as well. The three ganglia we have examined are presumably made up of neurones that are substantially different in this regard. While functions like piloerection are almost

certainly represented in each ganglion, other functions such as pupillary dilatation, cardioacceleration, and the control of various viscera must be distributed unevenly along the sympathetic chain. Thus, it is quite possible that preganglionic innervation arising from a particular level might be unattractive to a transplanted ganglion cell on positional grounds, but be attractive according to some functional criterion. A conflict of this sort might explain why those transplanted lumbar cells innervated by both T1 and T4 showed a roughly equal preference for these axons (Table 2), while the ganglion as a whole preferred caudal to rostral preganglionic innervation (Fig. 8).

Finally, it is possible that something other than (or in addition to) selective synapse formation contributes to the bias we have observed. Since each transplanted ganglion was accompanied by a short stump of preganglionic nerve (see Fig. 1), regenerating axons could conceivably have responded to guidance cues provided by degenerating preganglionic axons or axon terminals (or non-neural cells), rather than to synaptogenic cues provided by the ganglion cells themselves. Differences in the size of the transplanted ganglia (see Fig. 1 and Lichtman *et al.* 1980) might also have influenced re-innervation in some systematic way.

The simplest explanation of the results of ganglion transplantation, however, and the one most consistent with our previous findings (Njå & Purves, 1977*a*, *b*, 1978; Purves & Thompson, 1979; Lichtman *et al.* 1980), is that each ganglion cell has some permanent quality that selectively influences the innervation it receives. The finding that this quality is, on average, different in at least some of the ganglia that make up the sympathetic chain may allow a further analysis of the basis of selective synapse formation.

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REFERENCES

DeOlmos, J., Hardy, H. & Heimer, L. (1978). The afferent connections of the main and accessory olfactory bulb formations in the rat: an experimental HRP study. *J. comp. Neurol* **181**, 213–244.

Langley, J. N. (1892). On the origin from the spinal cord of the cervical and upper thoracic sympathetic fibres, with some observations on white and grey rami communicantes. *Phil. Trans. R. Soc.* **183**, 85–124.

Langley, J. N. (1895). Note on regeneration of pre-ganglionic fibres of the sympathetic. *J. Physiol.* **18**, 280–284.

Lichtman, J. W., Purves, D. & Yip, J. W. (1979). On the purpose of selective innervation of guinea-pig superior cervical ganglion cells. *J. Physiol.* **292**, 69–84.

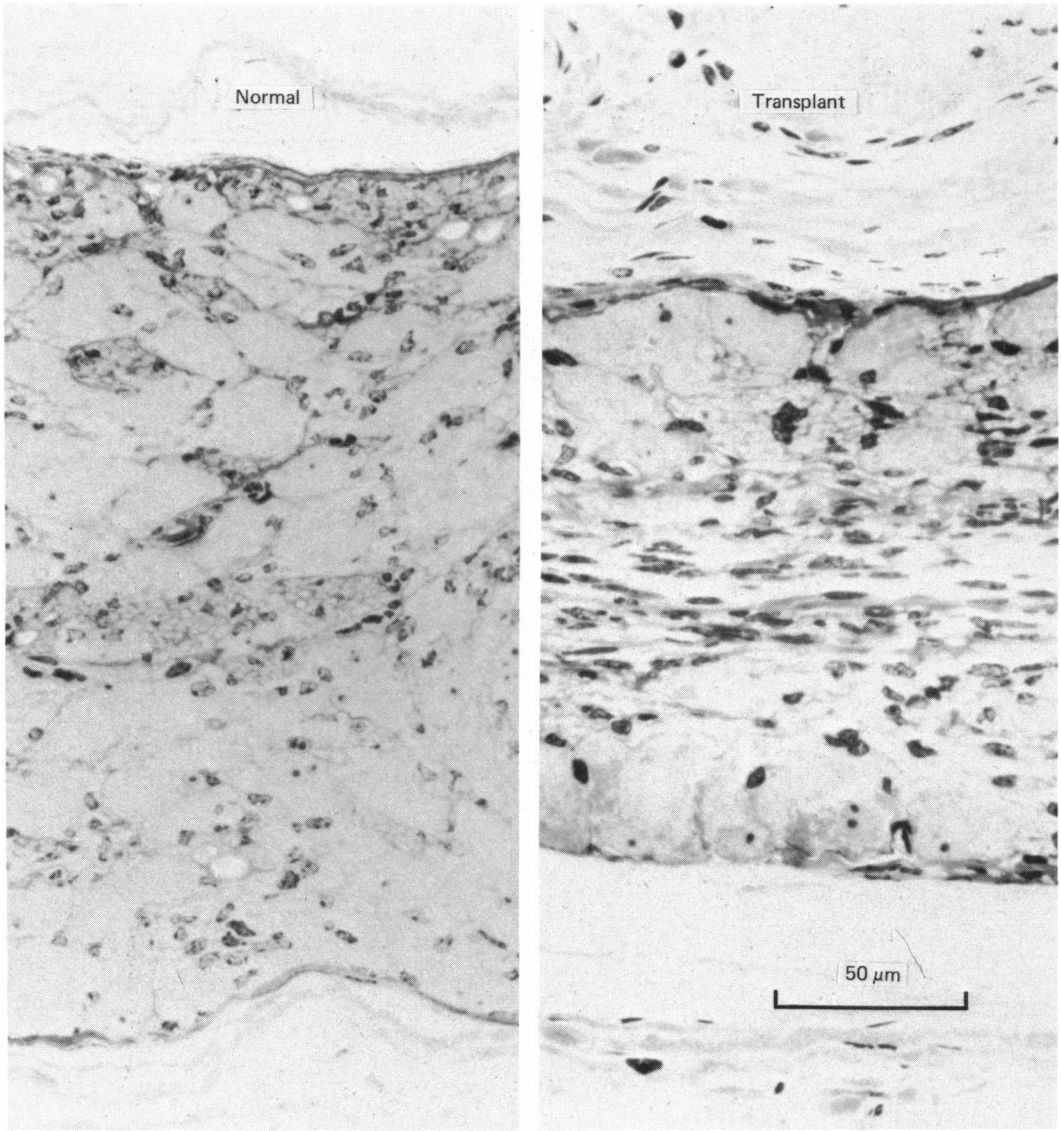
Lichtman, J. W., Purves, D. & Yip, J. W. (1980). Innervation of sympathetic neurones in the guinea-pig thoracic chain. *J. Physiol.* **298**, 285–299.

Njå, A. & Purves, D. (1977*a*). Specific innervation of guinea-pig superior cervical ganglion cells by preganglionic fibres arising from different levels of the spinal cord. *J. Physiol.* **264**, 565–583.

Njå, A. & Purves, D. (1977*b*). Re-innervation of guinea-pig superior cervical ganglion cells by preganglionic fibres arising from different levels of the spinal cord. *J. Physiol.* **272**, 633–651.

Njå, A. & Purves, D. (1978). Specificity of initial synaptic contacts on guinea-pig superior cervical ganglion cells during regeneration of the cervical sympathetic trunk. *J. Physiol.* **281**, 45–62.

Purves, D. (1975). Functional and structural changes in mammalian sympathetic neurones following interruption of their axons. *J. Physiol.* **252**, 429–463.


Normal
Transplant
50 μm

PURVES, D. & LICHTMAN, J. W. (1978). Formation and maintenance of synaptic connections in autonomic ganglia. *Physiol. Rev.* **58**, 821–861.

PURVES, D. & THOMPSON, W. (1979). The effects of postganglionic axotomy on selective synaptic connexions in the superior cervical ganglion of the guinea-pig. *J. Physiol.* **297**, 95–110.

RUBIN, E. & PURVES, D. (1980). Segmental organization of sympathetic preganglionic neurons in the mammalian spinal cord. *J. comp. Neurol.* **192**, 163–174.

SPERRY, R W. (1963). Chemoaffinity in the orderly growth of nerve fiber patterns and connections. *Proc. natn. Acad. Sci. U.S.A.* **50**, 703–709.

ZALEWSKI, A. A. (1974). Trophic functions of neurons in transplanted neonatal ganglia. *Expl Neurol* **45**, 189–193.

EXPLANATION OF PLATE

Typical histological appearance of a normal fifth thoracic ganglion (left), and a fifth thoracic ganglion 3–5 months after transplantation (right). Normal neurones are evenly distributed throughout the thickness of the ganglion; after transplantation, neurones are present near the ganglion surface, but are absent in its centre. Sections are from the mid-region of each ganglion: the dorsal surface is uppermost.