TWO TYPES OF SYNAPTIC SELECTIVITY AND THEIR INTERRELATION DURING SPROUTING IN THE GUINEA-PIG SUPERIOR CERVICAL GANGLION

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SUMMARY

1. The synaptic connexions of the guinea-pig superior cervical ganglion were examined after collateral sprouting provoked by cutting the preganglionic nerve supply from spinal segments T3–T7. The selective properties of the connexions made by the remaining segments C8, T1 and T2 were explored both with respect to the segmental origin of the preganglionic axons (Njå & Purves, 1977a) and with respect to their conduction velocity (Wigston, 1983).

2. After sprouting, the ventral root T1 elicited strong sympathetic effects on *both* the eye and the ear, while the normal response is largely confined to the region of the eye. This effect on the expressed selectivity was confirmed by intracellular recording *in vitro*, which showed that virtually all the ganglion cells were now innervated by T1.

3. However, neurones that received dominant innervation from T1 were more frequently innervated by sprouted axons from C8 than were neurones whose dominant innervation derived from T2. This indicates that basic mechanisms promoting segmental selectivity were still functioning.

4. The selective innervation of ganglion cells with respect to the conduction velocity of the preganglionic axons was well maintained after sprouting.

5. These results show that during sprouting from a restricted set of preganglionic axons the synaptic partners are still matched according to both types of selectivity. This suggests that the recognition mechanisms which guide neural development are preserved in adult life, but that the differences in the available sets of preganglionic axons lead to different competitive interactions and different resulting patterns of innervation.

INTRODUCTION

Neurones in mammalian sympathetic ganglia are selectively innervated by particular sets of ganglionic axons. First, the synaptic input to each ganglion cell is selective with respect to the spinal level of origin of the preganglionic axons. In the guinea-pig each neurone in the superior cervical ganglion receives about twelve preganglionic axons, which arise mainly from a few neighbouring spinal cord segments out of the eight segments (C8–T7) which innervate this ganglion as a whole

(Njå & Purves, 1977a; Lichtman, Purves & Yip, 1979, 1980). Secondly, the preganglionic axons that innervate a particular neurone tend to have similar conduction velocities (Wigston, 1983). This means that each ganglion cell can further distinguish, or be distinguished by, a subset of the preganglionic axons that arise from the preferred segments of the spinal cord.

In general, a neurone will be matched to potential presynaptic axons with respect to multiple criteria. For example, in a sensory pathway each different axon signals not only the location of the stimulus but also its modality or some further subdivision of this modality, all of which are important for the arrangement of synaptic connexions made with higher-order sensory neurones. In a similar way, the two types of synaptic selectivity described in the peripheral sympathetic nervous system are thought to form maps of positional values (Lichtman *et al.* 1979) and of functional characteristics (Wigston, 1983), respectively, in a motor pathway. The aim of the present work was to examine the interrelation and possible similarities between the mechanisms underlying these two types of selectivity in the superior cervical ganglion.

The basis for the segmentally selective pattern of innervation of sympathetic ganglion cells has been examined in some detail. It is known that a largely normal pattern can be re-established after section and regeneration of the preganglionic nerve fibres (Langley, 1897; Guth & Bernstein, 1961: Njå & Purves, 1977b; see also Purves, Thompson & Yip, 1981), and by sprouting of the remaining preganglionic axons after a partial denervation which spares some axons from each of the segments normally innervating the ganglion (Henningsen, Liestøl, Mæhlen & Njå, 1985). On the other hand, the normal pattern of selective end-organ responses to ventral root stimulation is lost after sprouting if all the preganglionic axons arising from the upper thoracic segments (T1–T3) are cut while those from the lower segments (T4–T7) are left intact (Murray & Thompson, 1957). Some degree of selectivity returns, however, upon regeneration of the interrupted axons (Guth & Bernstein, 1961). These and other results suggest that segmental selectivity in this system depends on a graded affinity between pre- and post-synaptic neurones which influences the competition among the preganglionic axons for synaptic connexions with ganglion cells (see Liestøl, Mæhlen & Njå, 1986 for a review). The tendency for ganglion cells to be innervated by preganglionic axons having generally similar conduction velocities (Wigston, 1983) has not yet been examined after nerve lesions in mammalian sympathetic ganglia (see, however, Landmesser & Pilar, 1970; Feldman, 1979, 1980; and Marshall, 1985, for studies on other vertebrates).

In the present experiments, the guinea-pig superior cervical ganglion was partially denervated by interrupting all the preganglionic axons except those emerging from spinal segments C8, T1 and T2. This procedure markedly restricted the range of spinal cord segments contributing innervation to the ganglion, without significantly changing the range of preganglionic conduction velocities. After sprouting was complete (3–6 weeks after the operation) individual ganglion cells were impaled with a micro-electrode in order to examine their pattern of innervation with respect to both the spinal level of origin and the conduction velocity of the preganglionic axons.

Some of these experiments have been reported in abstract from (Mæhlen & Njå, 1983).
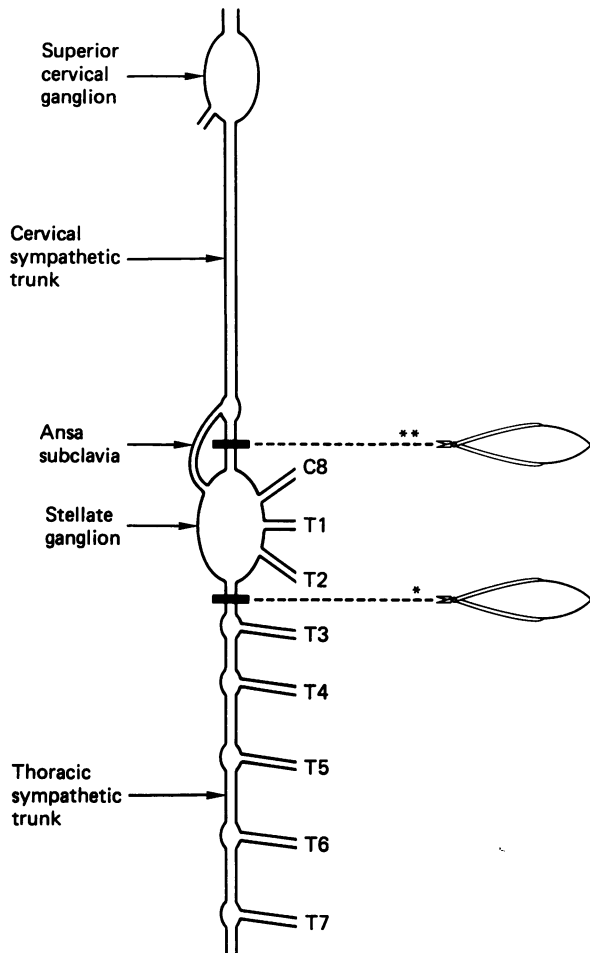
Fig. 1. Diagram of the peripheral sympathetic nervous system in the neck and upper thorax of the guinea-pig (right side, ventral view). Different types of partial denervations may be obtained by sectioning the sympathetic chain at different levels. Interruption below the level of T2 (*) eliminates all the innervation to the superior cervical ganglion arising from ventral roots T3–T7, while the preganglionic axons arising from C8–T2 are left intact. A partial denervation that spares some axons from each ventral root C8–T7 (**) was used in the earlier investigations (Mæhlen & Njå, 1981; Henningsen *et al.* 1985) which are referred to below for comparison with the present results.

METHODS

Partial denervation

Young adult guinea-pigs (200–400 g) of either sex were anaesthetized with sodium pentobarbitone (30–40 mg/kg I.P.) and the right thoracic sympathetic trunk was exposed and cut between the stellate and the third thoracic ganglion (Fig. 1) via a dorsal approach. This procedure interrupts the preganglionic nerve supply to the superior cervical ganglion arising from spinal segments T3–T7, whereas the preganglionic axons emerging in the ventral roots of C8, T1 and T2 remain intact. Immediately after the partial denervation the degree of vasoconstriction of the ear (controlled mainly by preganglionic axons arising from T2–T6) was markedly reduced on the operated side. By contrast, the pupil and the palpebral fissure (controlled mainly by T1–T3) appeared normal.

Stimulation of the ventral roots in anaesthetized animals

The pattern of peripheral sympathetic effects elicited by stimulation of each of the ventral roots C8, T1, T2 and T3 was examined 3–6 weeks after the operation, when sprouting is expected to be completed (Mæhlen & Njå, 1981). Five animals were anaesthetized with sodium pentobarbitone and maintained on a positive pressure respirator with supplements of the anaesthetic as needed. Laminectomies were performed over the segments C8–T3 and the spinal cord removed after cutting the ventral roots C8–T3 intradurally. The cut roots were stimulated one at a time with a suction electrode (20 Hz, 10–100 V, 0·5 ms) while the dilatation of the pupil, widening of the palpebral fissure, piloerection of the hairs of the face and snout, and vasoconstriction of the pinna were graded subjectively on a scale from 0 to + + + +. No end-organ responses were elicited by stimulation of the ventral root T3 on the operated side, showing that the partial denervation had been successful and that regeneration of the injured axons had not occurred.

Intracellular recording from ganglion cells in vitro

3–6 weeks after the operation a further series of animals were deeply anaesthetized and perfused through the heart with oxygenated (95 % O_2–5 % CO_2) mammalian Ringer solution containing (mM): NaCl, 137; KCl, 4; $MgCl_2$, 1; KH_2PO_4, 1; $NaHCO_3$, 12; $CaCl_2$, 2; glucose 11. The right superior cervical ganglion was removed in continuity with the cervical and part of the thoracic sympathetic chain, rami communicantes and ventral roots of spinal cord segments C8–T7, which were further exposed by dissection in a pool of oxygenated Ringer solution (Njå & Purves, 1977a). For comparison, we performed similar experiments on a series of normal animals. The preparation was maintained at room temperature in a flow of oxygenated Ringer solution, and principal cells were impaled with glass micro-electrodes filled with 5 M-potassium acetate (80–100 MΩ). In each neurone meeting the criterion of showing an action potential amplitude equal to or greater than 60 mV in response to a depolarizing current pulse, we recorded the synaptic response to stimulation of each ventral root C8–T3 in turn. The number of axons innervating a neurone from each ventral root was estimated by counting the number of increments in the synaptic response to graded nerve stimulation. The amplitude of the excitatory post-synaptic potential (e.p.s.p.) elicited by supra-maximal stimulation was measured in the refractory period of an action potential initiated by current injection through the recording micro-electrode (Njå & Purves, 1977a, 1978).

Preganglionic nerve sprouting was assessed by the number of preganglionic axons that innervate each ganglion cell after partial denervation. With little or no change in the estimated mean depolarization produced by each axon, the degree of multiple innervation of ganglion cells recovers gradually over a period of about 3 weeks, due to increased branching and synapse formation by the surviving preganglionic axons (Mæhlen & Njå, 1981; Fonnum, Mæhlen & Njå, 1984). Reinnervation of the superior cervical ganglion by the injured axons after partial denervation takes a considerably longer time (Mæhlen & Njå, 1984). In one experiment, stimulation of the ventral root T3 produced a synaptic response in some ganglion cells, suggesting that the partial denervation had been unsuccessful; this preparation was therefore discarded.

In most experiments we obtained a measure of the conduction velocity of the preganglionic axons by recording the latency from the stimulus artifact to the first component of the intracellularly recorded synaptic potential, elicited by supramaximal stimulation of each ventral root (Njå & Purves, 1977b). In two ganglia we also recorded the latency to each individual step in the synaptic response (Wigston, 1983). Since the ventral roots of interest (C8, T1 and T2) were located at similar distances from the superior cervical ganglion (their preganglionic axons enter the stellate ganglion before they ascend in the cervical sympathetic trunk), we present the measured latencies, rather than axonal conduction velocities. There was no correlation between the mean latency and the size of the animal (weight range after sprouting: 350–520 g). Presumably recently formed sprouts may have lower conduction velocities than those of the original intraganglionic branches. However, the total length of the preganglionic conduction path is in the order of 50 mm, whereas the ganglionic dimensions are only about 0·5 × 1 × 2 mm. Therefore, we assume that possible differences between the conduction times for the original and sprouted intraganglionic branches do not affect the analysis performed in the present study.

RESULTS

End-organ responses to ventral root stimulation after sprouting from C8–T2

The pattern of end-organ effects elicited by repetitive stimulation of the upper thoracic ventral roots (C8–T2) was examined 3–6 weeks after the partial denervation, when sprouting was complete (see Mæhlen & Njå, 1981). Stimulation of C8 caused only weak effects on sympathetic end-organs and was not useful for evaluation of response selectivity. However, stimulation of T1 elicited strong effects, and there were marked differences between the response patterns on the normal and operated side in each of the five animals examined (Table 1). On the operated right side stimulation of the ventral root T1 elicited an abnormally wide range of end-organ responses. For example, while T1 on the normal left side elicited no or only a slight vasoconstriction of the ear, the same ventral root on the operated side elicited a near-maximal vasoconstriction. For T2 the difference between the operated and

TABLE 1. End-organ responses to electrical stimulation of the ventral root T1 after sprouting caused by two different types of partial denervation. The sympathetic effects on the eye and the ear (at 20 Hz) are judged subjectively on a scale from 0 to $+++ +$. Top, results obtained in five animals 3–6 weeks after section of the thoracic sympathetic trunk below the level of T2. On the normal side stimulation of T1 caused strong dilatation of the pupil but little or no vasoconstriction of the ear, whereas on the operated side stimulation of T1 caused strong effects on both the eye and the ear. Bottom, results obtained when the partial denervation removed a comparable proportion of the preganglionic axons, but affected all ventral roots about equally (reproduced from Mæhlen & Njå, 1981). Strongly reduced responses were obtained immediately after the partial denervation, while a largely normal pattern was obtained 3–6 weeks after the operation. Thus, depending on the type of partial denervation, sprouting may restore a normal pattern of end-organ responses, or cause a clearly abnormal pattern

End-organ responses to stimulation of T1 after sprouting from C8–T2

Normal side		Operated side	
Dilatation of the pupil	Vasoconstriction of the ear	Dilatation of the pupil	Vasoconstriction of the ear
$+++$	$+$	$++++$	$+++$
$++++$	$+$	$+++$	$+++$
$+++$	0	$+++$	$+++$
$+++$	$+$	$+++$	$+++$
$++++$	$+$	$++++$	$+++$

End-organ responses to stimulation of T1 after sprouting from C8–T7

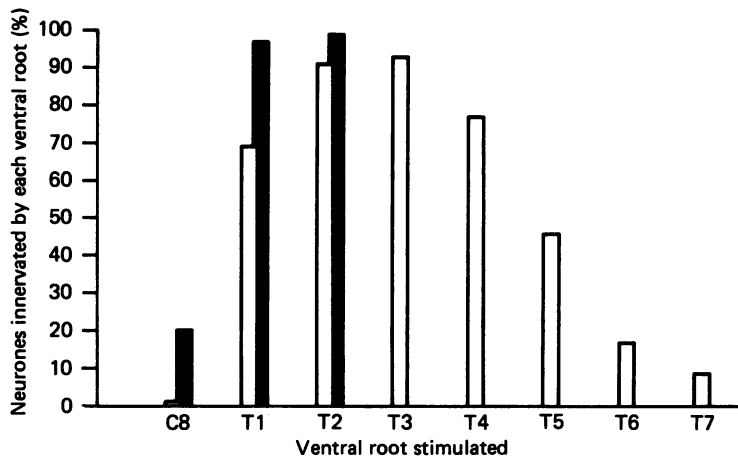| Before sprouting		After sprouting	
Dilatation of the pupil	Vasoconstriction of the ear	Dilatation of the pupil	Vasoconstriction of the ear
$+$	0	$+++$	$+$
$+$	0	$+++$	0
$+$	0	$+++$	0
$+$	0	$++$	0
$+$	0	$+++$	0

Fig. 2. The percentages of neurones innervated by each of the ventral roots C8–T7 in normal animals (open bars), and in animals examined 3–6 weeks after section of the thoracic sympathetic chain below the level of T2 (filled bars). The histogram is based on pooled data from 201 ganglion cells impaled in fifteen normal animals, and from 226 cells from twelve animals examined after sprouting. Note the large increase in the percentages of neurones innervated by C8, and that after sprouting nearly all neurones are innervated by both T1 and T2.

intact side was smaller because T2 normally elicits a fairly wide range of end-organ responses. These results are complementary to those of Murray & Thompson (1957), who originally demonstrated abnormal end-organ responses to stimulation of T4–T7 in cats a few weeks after section of the sympathetic rami T1–T3.

Innervation of individual ganglion cells after sprouting from C8–T2

Quantitative aspects of sprouting. In normal ganglia all neurones were innervated and the mean number of preganglionic axons innervating each neurone was 11·5 ($n = 201$). Of these axons 4·2, on average, were contributed by spinal segments C8–T2 (see also Njå & Purves, 1977*a,b*; Lichtman *et al.* 1980). About 9 % of the neurones (18 of 201) received all their innervation from T3–T7 (and would therefore have been completely denervated by section of the preganglionic axons from segments caudal to T2). By contrast, when examined 3–6 weeks after the operation all but one neurone was innervated by C8–T2 ($n = 226$) and the mean number of axons innervating each cell was increased to 7·8. This demonstrates extensive sprouting of the intact preganglionic axons.

After sprouting each ventral root C8, T1 and T2 innervated a larger percentage of ganglion cells than normal (Fig. 2). There was also an increase in the mean number of preganglionic axons innervating each ganglion cell (Fig. 3). In relative terms, this change was greatest for C8 and smallest for T2. An estimate of the mean depolarization per innervating axon is more difficult to obtain (see Njå & Purves, 1978; Fonnum *et al.* 1984), especially in the present experiments where most neurones received several innervating axons from both T1 and T2. However, the mean e.p.s.p. amplitude in neurones receiving a single preganglionic axon from the ventral root
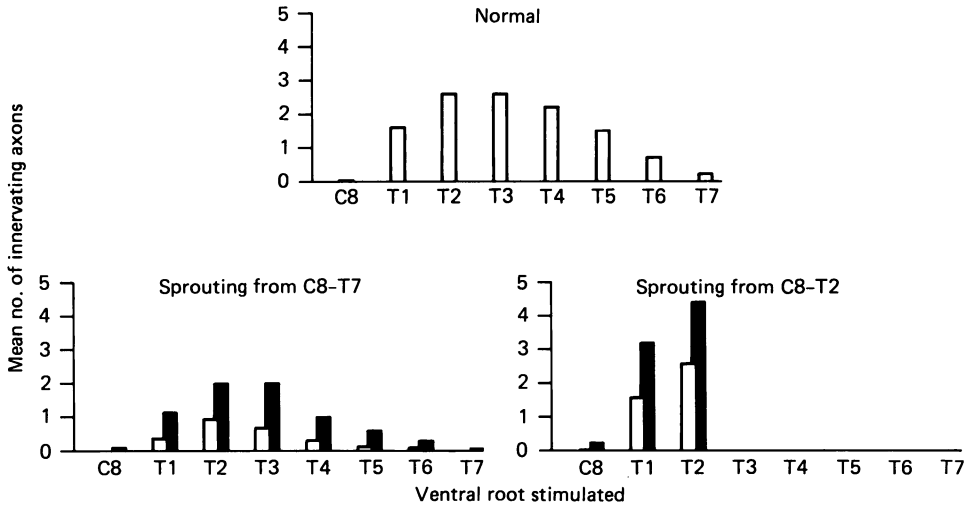
Fig. 3. Segmental innervations of ganglion cells in three different situations: normal animals, and before and after sprouting in animals subjected to two different kinds of partial denervation. In each experimental situation the mean number of innervating axons from each of the ventral roots C8–T7 to 201–226 ganglion cells is shown. Top, normal ganglion cells. Bottom left, before sprouting (open bars) and after sprouting (filled bars) when the partial denervation left intact some preganglionic axons arising from each ventral root C8–T7 (redrawn from Henningsen *et al.* 1985). Bottom right, input from C8, T1 and T2 to normal ganglion cells (open bars, redrawn from top histogram) and to neurones examined after sprouting when the thoracic sympathetic chain was cut below the level of T2 (filled bars).
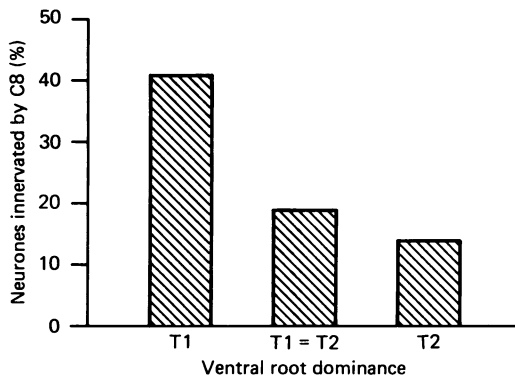

Fig. 4. Evidence for residual segmental selectivity after sprouting when the partial denervation removed all the preganglionic axons except those arising from spinal segments C8, T1 and T2. The ordinate shows the incidence of innervation by preganglionic axons arising from C8 to different subsets of neurones in the superior cervical ganglion: those receiving a larger number of axons from T1 than from T2 (left), an equal number from T1 and T2 (middle), and a larger number from T2 than from T1 (right). Input from C8 occurs much more frequently in neurones receiving dominant innervation from T1 than in neurones receiving dominant innervation from T2. Most synapses maintained by C8 in these ganglia were formed during sprouting (see Figs. 2 and 3). This means that some degree of segmental selectivity is expressed during sprouting, even after section of all the preganglionic axons arising from T3–T7. (The difference in the percentages of innervated cells is statistically significant ($P < 0.005$) in a multiple logistic regression which takes possible differences between animals into account.)
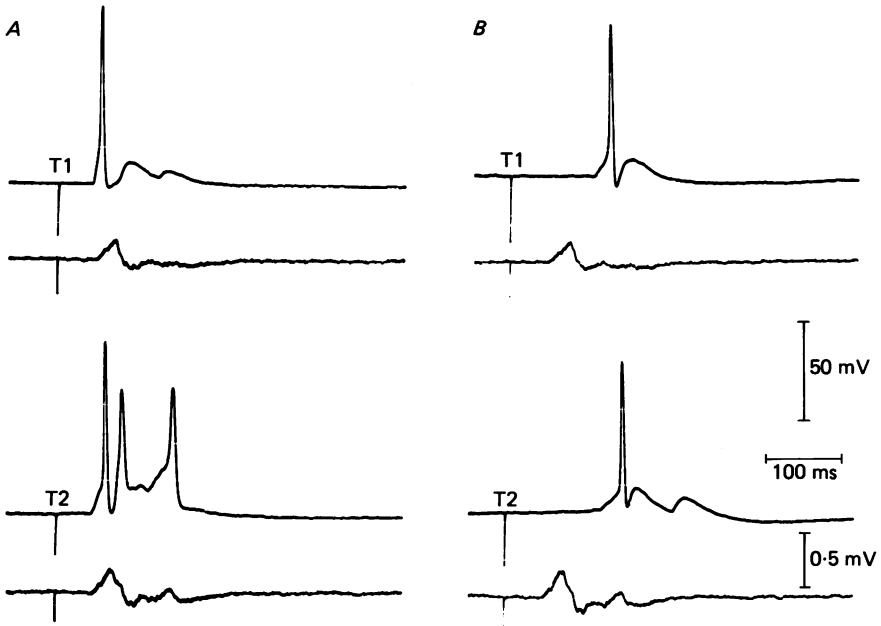
Fig. 5. Synaptic responses to supramaximal stimulation of individual ventral roots recorded from two neurones (*A* and *B*) impaled in the same ganglion 40 days after the sympathetic chain had been cut below the level of T2. The upper trace in each pair of records shows the intracellularly recorded membrane potential and the lower trace the compound action potential recorded extracellularly from the superior post-ganglionic nerve. The cell in *A* received predominantly short-latency inputs from both T1 and T2 (the minimum latency was about 40 ms for each ventral root), whereas that in *B* received only long-latency inputs (the minimum latency was about 110 ms for each ventral root). Neither of these two cells was innervated by C8.

examined was increased for C8 and largely unchanged for T1 and T2 (not shown). The differences between the relative extent of sprouting of the individual ventral roots are presumably related to the fact that our method of partial denervation of the superior cervical ganglion also partially denervates the stellate ganglion (see Discussion).

Selectivity with respect to spinal cord segments. The ventral root T1 innervated nearly all the ganglion cells after sprouting (95 %), compared to only 65 % in normal ganglia. This implies a substantial loss of segmental selectivity, which is consistent with the observation of non-selective end-organ responses to ventral root stimulation in anaesthetized animals (Table 1).

We have recently argued that sprouting does not change the way in which segmental selectivity operates but may modify the result to varying degrees, depending on the type of partial denervation (Henningsen *et al.* 1985). Therefore we examined the post-sprouting pattern of ganglion cell innervation for signs of residual selectivity. The majority of the synaptic connexions maintained by C8 in the superior cervical ganglion after sprouting were new (Figs. 2 and 3). The normal pattern of segmental selectivity implies that ganglion cells receiving a larger number of
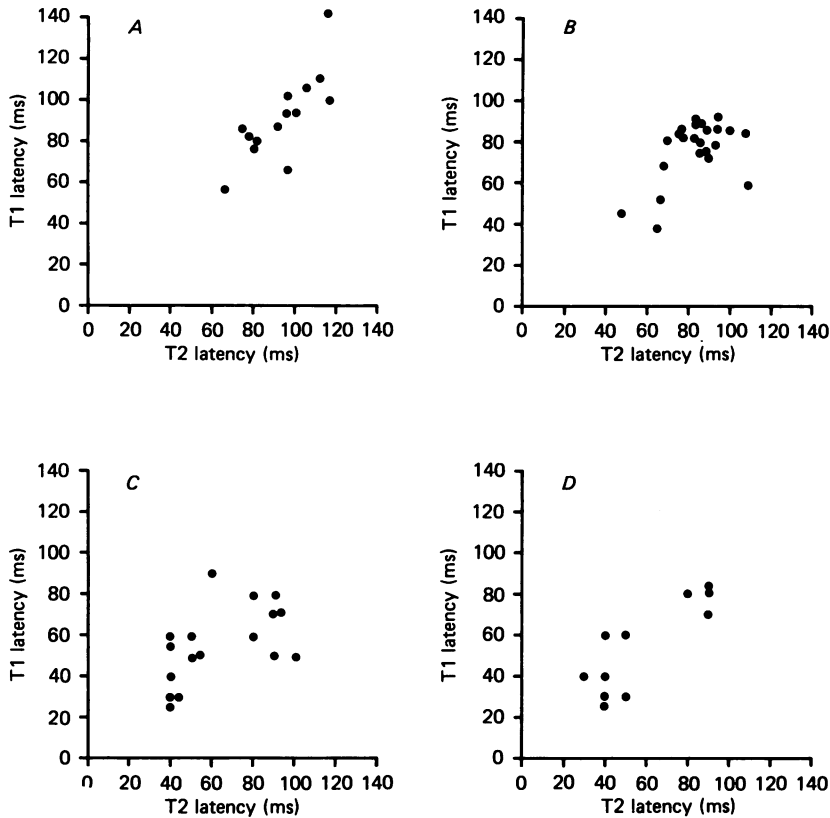
Fig. 6. Correlation between the latencies to the synaptic potentials elicited in single neurones by stimulation of the ventral roots T1 and T2 after sprouting. *A–D* show the results from four different animals examined 3–6 weeks after section of the thoracic chain below the level of T2. Each symbol represents one neurone (only cells that were innervated by at least two preganglionic axons from each of the ventral roots T1 and T2 were included). In *A* and *B* the geometric averages of all recorded latencies have been used to characterize the cells; in *C* and *D* the latencies to the first component of the synaptic potentials have been used. The correlation between latencies from T1 and T2 is highly significant both when calculated from average latencies and from latencies to the first component of the synaptic response.

innervating axons from T1 than from T2, should, in relative terms, have a higher incidence of innervation by C8. This was observed after sprouting (Fig. 4). The difference was highly significant ($P < 0.005$ in a logistic regression analysis where possible differences between animals were taken into account).

Selectivity with respect to preganglionic conduction velocity. Neurones in the normal superior cervical ganglion are selectively innervated with respect to the conduction velocities of the preganglionic axons (Wigston, 1983). This type of synaptic selectivity was also observed after sprouting in the present experiments (Figs. 5 and 6). The correlation coefficients between the latencies of synaptic potentials elicited in the same neurones by stimulation of T1 and T2 were positive in all ganglia examined.

The distributions of the latencies to the first component of the synaptic response
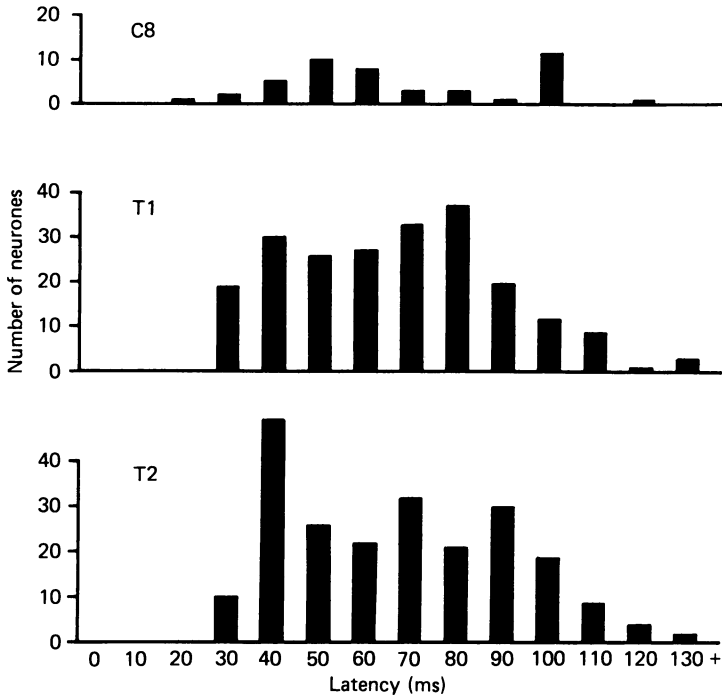
Fig. 7. Histograms showing the distributions of the latencies to the first component of the synaptic response to supramaximal stimulation of the ventral roots C8, T1 and T2, recorded in ganglion cells 3–6 weeks after section of the thoracic sympathetic trunk caudal to the level of T2. Note the wide distribution of latencies. Moreover, these distributions do not seem to have a unimodal form.

to supramaximal stimulation of each of the ventral roots C8, T1 and T2 were wide and did not appear to be unimodal (Fig. 7). These distributions were roughly similar to those obtained in normal ganglia, although the deviation from a simple unimodal form was less prominent in normal ganglia where the number of axons innervating each neurone from each ventral root was smaller (not shown; see Njå & Purves, 1977*b*).

DISCUSSION

Our results show that the preganglionic axons of the ventral root T1, which normally innervate only a subset of the neurones in the guinea-pig superior cervical ganglion (about 65%) have the potential to innervate most (possibly all) of the neurones in this ganglion (Fig. 2). This extensive synapse formation with ganglion cells that are not normally innervated by T1 provides a cellular basis for the non-selective pattern of end-organ responses to ventral root stimulation after sprouting (Table 1). A similar loss of selective end-organ responses to stimulation of the ramus communicans T4 has been reported in the cat after sprouting in response to section of the rami T1–T3 (Murray & Thompson, 1957).

However, the results of intracellular recording show that the synaptic connexions

formed by sprouting are not completely non-selective. Thus, the ventral root C8 preferentially formed synapses on those neurones that received strong innervation from T1 compared to T2 (Fig. 4). With non-selective sprouting, the opposite result would be expected. Synapse formation should then occur mainly on ganglion cells that had lost the majority of their normal input, i.e. neurones that originally received dominant innervation from the more caudal segments, and accordingly were more strongly innervated by T2 than by T1. Synaptic connexions therefore appear to be subject to selection even in a situation where many, possibly the majority, of the new connexions are established between classes of pre- and post-synaptic cells that are unconnected in normal ganglia.

The observed pattern of innervation conforms to what one would expect if each denervated ganglion cell can be innervated by preganglionic axons from any segment, but that inputs are ranked in a graded fashion on the basis of segmental origin. This ranking process presumably represents selective recognition between preganglionic axons and ganglion cells, since reinnervation of totally denervated superior cervical ganglia re-establishes the normal matching of preganglionic inputs and peripheral responses (Langley, 1897; Njå & Purves, 1977*b*). Although the precise connectivity formed during sprouting is unknown, our results suggest that the intact ventral roots distributed their synapses in such a way that T2 dominated the innervation of ganglion cells that were originally innervated by the more caudal segments while C8 preferentially formed synapses on cells that were originally innervated by rostral segments.

In systems of this kind, synapse formation may be described as a competitive process, where the presynaptic terminals are thought to compete for growth stimulating factors and where cell recognition may determine the competitive strength of the individual axons. The appropriateness of the connexions formed by such systems will depend on the composition of the available presynaptic axon pool. In the present experiments, the intact axons arise from a restricted set of ventral roots and segmental selectivity is strongly distorted (Table 1; see also Murray & Thompson, 1957). By contrast, if the partial denervation removes approximately the same percentage of the axons from each ventral root, near-normal selectivity is maintained during sprouting (Table 1; see also Henningsen *et al.* 1985).

Since the partial denervation eliminated the most caudal ventral roots that innervate the superior cervical ganglion, one might expect that the T2 fibres would have sprouted more vigorously than the C8 and T1 fibres. This was not the case (Fig. 3). Rather, there seemed to be more sprouting from C8 than from either T1 or T2, and this was observed both in the numbers of axons innervating each neurone and in the estimates of unitary e.p.s.p. amplitudes. The most likely explanation for this result is that some preganglionic axons innervating the superior cervical ganglion also form synapses with neurones in the stellate ganglion, which loses about 90 % of its innervation when the sympathetic trunk is interrupted caudally to the level of T2 (see Lichtman *et al.* 1980). While T2 innervates a large part of this ganglion, T1 only innervates cells in the rostral part and C8 makes no or very few contacts (Lichtman *et al.* 1980). In an earlier study (Mæhlen & Njå, 1984) it was shown that when preganglionic axons sprout in response to partial denervation of the superior cervical ganglion there is a marked decrease in the number of connexions maintained by the

same group of axons in the stellate ganglion. In the present experiments, sprouting of the T2 fibres in the stellate ganglion must similarly be expected to represent a stress on synaptic terminals maintained by these fibres in the superior cervical ganglion, and therefore reduce their ability to sprout there. It is also possible that C8 'redistributes' some of the synapses previously maintained with ganglion cells located cranial to the superior cervical ganglion (see Perri, Sacchi & Casella, 1970; Purves, 1975).

Our results also show that the pattern of connexions after sprouting is selective with respect to preganglionic conduction velocity. This type of selectivity has been described in sympathetic ganglia of normal animals (Wigston, 1983; see also Bishop & Heinbecker, 1932; Eccles, 1935). The observed selectivity in ganglia examined after sprouting might be only a residue from the normal innervation pattern. This, however, appears unlikely from numerical considerations. There has been a marked sprouting of both fast and slow fibres from T1 and T2 (not shown). If such contacts were formed at random, they would rapidly destroy patterns like the ones shown in Figs. 5 and 6. Actually, the pattern appears more prominent after sprouting. This is partially due to the greater than normal number of innervating axons from each ventral root after sprouting. One may, however, also speculate as to whether the small difference in segmental origin of the presynaptic fibres remaining after partial denervation allows an enhanced expression of the selectivity related to conduction velocity.

The selectivity with respect to conduction velocity might reflect the mapping of subgroups of the presynaptic axon pool onto ganglion cells that project to functionally different types of end-organs. One observation on the distribution of the latencies is interesting in this respect. It concerns the latency to the first component of the synaptic response, in which there is a tendency towards a clustering of cells into two groups, one which receives rapidly conducting fibres from both T1 and T2, and another which receives no such fibres (Fig. 6C and D). Moreover, the distributions of the shortest latencies from each ventral root appear multimodal. These observations would be expected if the presynaptic fibres were divided roughly into two groups ('fast conducting' and 'slow conducting', each of which may possibly consist of subgroups) that selectively innervate subpopulations of ganglion cells.

Proper functioning of the peripheral sympathetic nervous system requires selective patterns of activation of different end-organs as parts of physiological control systems. Presumably the selective innervation of sympathetic neurones serves this purpose by mapping the central nervous system onto the periphery in a manner which reflects both anatomical and physiological features. The present experiments show how the expression of different types of synaptic selectivity can be differentially affected by preganglionic nerve sprouting. An attractive explanation for these results would be the existence of two separate recognition systems. Given the available set of preganglionic axons, the observed pattern of connexions could then be viewed as a minimalization of error with respect to both systems simultaneously.

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