Trends in NeuroSciences

PUBLISHED BY ELSEVIER/NORTH-HOLLAND BIOMEDICAL PRESS

Contents

September 1980
Volume 3, No. 9

foreign innervation, closely parallel the phenomena found in the reinnervation of vertebrate muscle. The opportunity to work with a single motor neurone and single muscle fibres, the innervation of which is exactly known, makes the examination of the reinnervation process not only easier but more exact. Insects may yet provide excellent model systems for single unit studies of plasticity in the central nervous system as well.   J. S. ALTMAN

Reading list

1 Denburg, J. L. (1975) *Nature (London)* 258, 535–537
2 Denburg, J. L. (1978) *J. Neurobiol.* 9, 93–110
3 Donaldson, P. L. and Josephson, R. K. (1979) *J. Physiol. (London)* 300, 35P
4 Donaldson, P. L. and Josephson, R. K. (1980) *J. Comp. Neurol.* (submitted for publication)
5 Fambrough, D. M. (1976) in *Neuronal Recognition* (Barondes, S. H., ed.), pp. 25–67, Chapman and Hall, London
6 Pearson, K. G. and Bradley, A. B. (1972) *Brain Res.* 47, 492–496
7 Tyrer, N. M. and Johnson, K. A. (1977) *Nature (London)* 268, 759–761
8 Whitington, P. (1977) *J. Exp. Zool.* 201, 339–344
9 Whitington, P. (1979) *J. Comp. Neurol.* 186, 465–472
10 Young, D. (1972) *J. Exp. Biol.* 57, 305–316
11 Young, D. (1973) in *Developmental Neurobiology of Arthropods* (Young, D., ed.), pp. 179–202, Cambridge University Press, Cambridge

J. S. Altman is a lecturer in the Department of Zoology, University of Manchester, Manchester M13 9PL, U.K.

The laminar organization of thalamic projections to neocortex

In 1938, Lorente de Nó provided the classic description of thalamic fiber terminations in rodent neocortex. More than 40 years later, modern tract-tracing techniques have filled in important details, pinpointing the thalamic origins and uncovering varieties of cortical afferent lamination patterns.

The mammalian neocortex is composed of several classes of neurons aggregated to form a six-layered sheet[13]. Axons arriving in cortex also distribute themselves in layered arrays. The main gateway into the cortex is by way of the thalamus, which has discrete nuclei sending axons into cortex with a variety of laminar patterns. Our goal is to describe these patterns in relation to the existing cortical lamination.

Golgi impregnations

The early Spanish neuroanatomists used rodent Golgi preparations to trace axons entering cortex. The classic illustration of these fibers was provided by Lorente de Nó (Fig. 71, Ref. 11). Significant portions of that figure are duplicated on the left of Fig. 1. The neocortex has a granular layer IV, composed predominantly of short-axoned granule cells, and adjacent layers containing pyramidal neurons characterized by apical dendrites that ascend into a cell-free layer I[13]. Against this backdrop, thalamic fibers terminate in two distinct fashions. The first is called 'specific', and such fibers arise from cell bodies in the thalamic relay nuclei for vision[4], audition[12] and somesthesis[6,9]. In the somatosensory cortex (Fig. 1, axons a and b), axons from the ventroposterior nucleus (vp) ascend to the granular layer and terminate in dense networks extending through layers III and IV[6,9]. Additional ramifications and terminations may be found in layer VI[6,10]. By these contacts, fibers accurately and topographically convey sensory signals to the local cortical processing mechanisms initiated by synapses on the small, short-axoned granule cells.

Within the same cortical area, Lorente de Nó described a second thalamic fiber type[11]. The 'unspecific' afferent fibers (Fig. 1, axons c and d) are so named because they extend over wide cortical areas and issue collaterals that ascend through all cortical layers, reaching as far as layer I. Widespread sparse fibers aimed primarily at layer I will synapse on apical dendrites of pyramidal cells located in deeper layers. Thus, a subtle but direct access to the long-axoned outflow elements, the pyramidal neurons, can provide a universal biasing mechanism, altering threshold levels for neural excitability and providing

Somatosensory Cortex

Motor Cortex
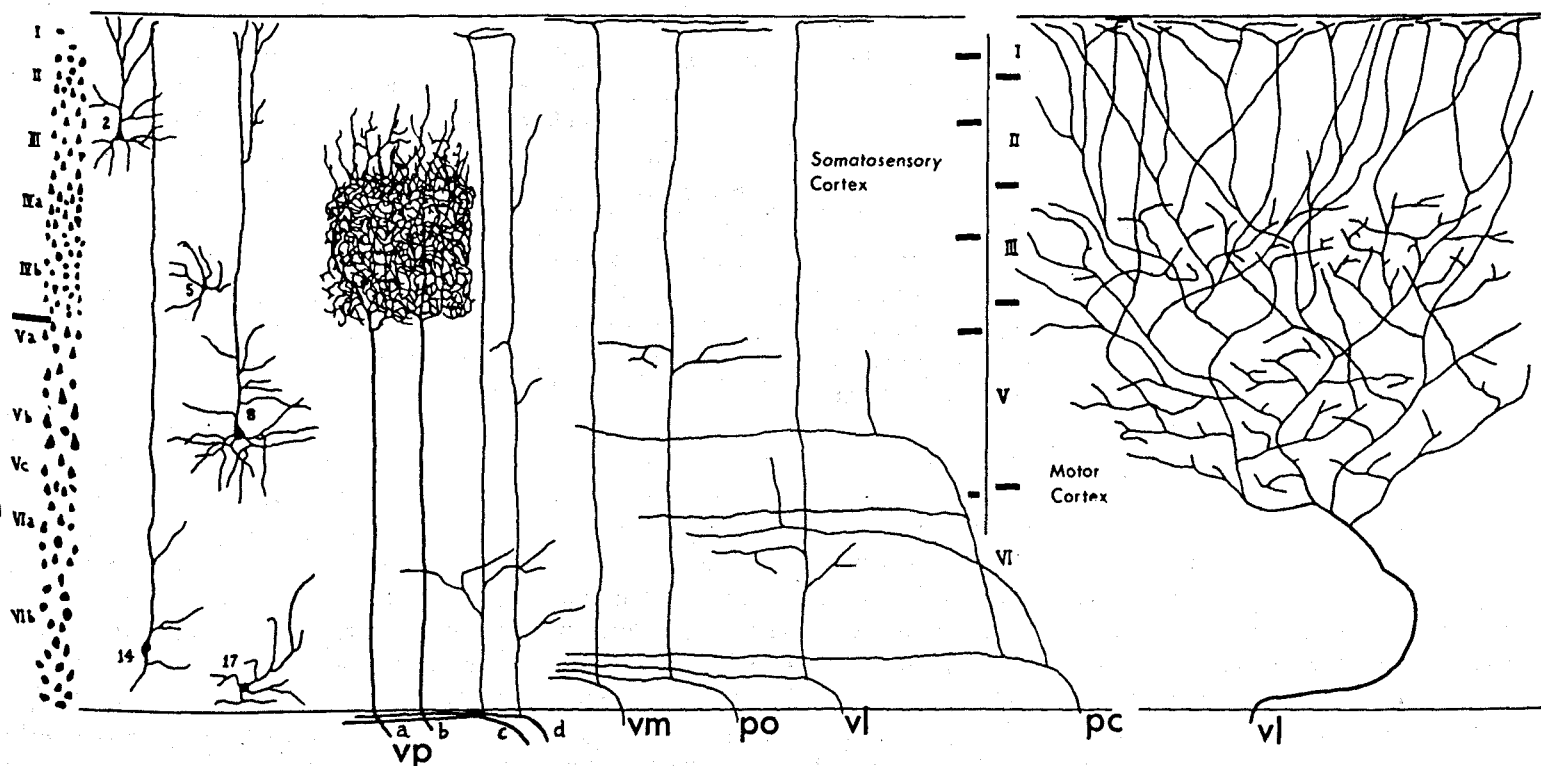
Fig. 1. Drawings of individual cell types and thalamic axons in rodent neocortex. At far left the various classes of neural cell bodies aggregate to form cortical layers. Numbered cells have dendritic processes outlined. Granule cells in layer IV (cell no. 5) have short dendrites and axons. Pyramidal cells of varying sizes in other layers (cells 2, 8 and 14) have characteristic apical dendrites that ascend to layer I. Thalamic axons entering cortex are 'specific' (a and b) or 'unspecific' (c and d) as depicted by Lorente de Nó. To the right of these are updated renditions based on autoradiographic evidence[6,8]. The thalamic origins are given by the letters vp, vm, po, vl, and pc (see text for full names).

a basis for integrating cortical activity as a whole[5,8].

Tracing unspecific thalamocortical fibers

The thalamic sources for unspecific afferents have been determined by the methods of axoplasmic flow of marker substances. Tritiated amino acids deposited into individual thalamic nuclei in the rat reveal the laminar distribution of labeled terminals. Alternatively, the retrograde marker horseradish peroxidase, HRP, deposited on the cortical surface, diffuses into axon terminals in the upper layers and is transported back to label source neurons in the thalamus.

The autoradiograms reveal a surprising variety of unspecific fiber types. Depicted in the Golgi style of Lorente de Nó (Fig. 1), fibers project exclusively to layer I of the somatosensory cortex from the ventromedial thalamic nucleus (vm)[5], to layers I and Va from the posterior nucleus (po) and to layers I and VI from the ventrolateral nucleus (vl)[6].

A third thalamic fiber type, not originally shown by Lorente de Nó arises from neurons in the paracentralis nucleus (pc) of the intralaminar complex and runs horizontally in layers V and VI[6]. These axons might synapse *en passage* with cell bodies or basal dendrites of the pyramidal neurons. Like the unspecific fibers, therefore, they bypass the local processing initiated by specific afferents that synapse on granule cells located more superficially.

Some cortical areas lack a clearly defined granular layer IV, and their thalamic inputs may share characteristics of specific and unspecific fiber types. Within the motor cortex, an axon from the ventrolateral nucleus, vl, branches repeatedly within a broadly confined area and terminates with moderate density in layers I, III, and V (Fig. 1, right side)[2,6,14].

Within any cortical area, a confluence of inputs to layer I from several thalamic nuclei can be found. The black dots in Fig. 2 mark locations of cells marked by HRP infused into layer I of somatosensory cortex. The restriction of the deposit to the upper layers is indicated by the absence of cells labeled in the vp nucleus, the relay to layer IV. Also unlabeled are the intralaminar nuclei that project to deeper layers. Yet three other nuclei are labeled as shown. Autoradiography shows subtle differences in layer I terminations: vm afferents end in the outer one-quarter of the layer[5], vl in the outer half and po in the middle third[6]. The significance of the fine differences may depend on the nature of apical dendrite distribution in layer I.
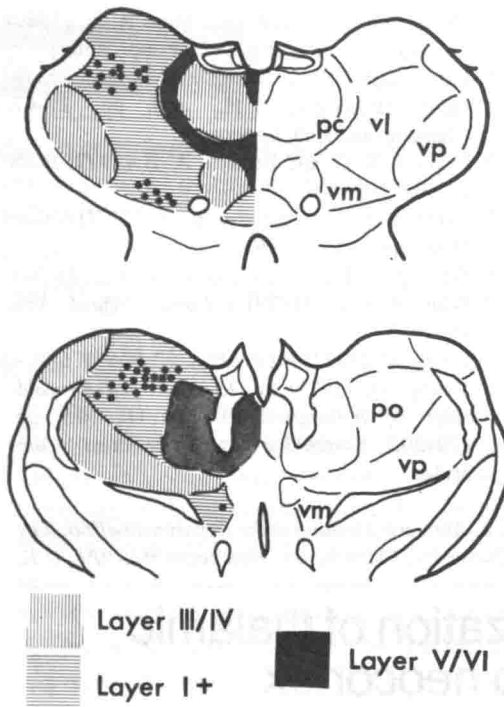

Fig. 2. Drawings of two thalamic levels in the rat. Hatched and shaded areas mark nuclei with projections directed predominantly to superficial intermediate or deep cortical layers, based on autoradiographic evidence[8]. In a collaborative effort with Dr S. Moon Edley here at the NIMH, HRP was infused into layer I of somatosensory cortex. In confirmation of the autoradiography, retrogradely labeled cells (black dots) are found only in areas indicated by horizontal lines.

In the past, thalamic nuclei have been parcelled on the basis of cell types and connections. Fig. 2 shows a parcelling scheme based entirely on laminar distributions of cortical afferents: thalamic nuclei project primarily to intermediate, superficial or deep cortical layers and may be designated on this basis. Future electrophysiological studies should reveal how these elements differentially affect cortical activity[1]. Biochemical studies will focus on the lamination of receptors for transmitter substances[7]. Finally, laminar analyses of cortical function may help us to understand how cortex and thalamus mediate behavioral phenomena[3].

Reading list

1 Araki, T. and Endo, K. (1976) *Brain Res.* 113, 405–410
2 Asanuma, H., Fernandex, J., Scheibel, M. E. and Scheibel, A. B. (1974) *Exp. Brain Res.* 20, 315–330
3 Gabriel, M., Foster, K. and Orona, E. (1980) *Science* 208, 1050–1052
4 Hendrickson, A. E., Wilson, J. R. and Orgren, M. P. (1978) *J. Comp. Neurol.* 182, 123–136
5 Herkenham, M. (1979) *J. Comp. Neurol.* 183, 487–518
6 Herkenham, M. (1980) *Science* 207, 532–535
7 Herkenham, M. and Pert, C. B. *Proc. Natl. Acad. Sci. U.S.A.* (in press)
8 Jasper, H. H. (1954) in *Brain Mechanisms and Consciousness* (Delafresnaye, J. F., ed.), Blackwell, Oxford
9 Jones, E. G. (1975) *J. Comp. Neurol.* 160, 167–204
10 LeVay, S. and Gilbert, C. D. (1976) *Brain Res.* 113, 1–19
11 Lorente de Nó, R. (1938) in *Physiology of the Nervous System* (Fulton, J., ed.), Oxford University Press, New York
12 Ryugo, D. K. and Killackey, H. P. (1974) *Brain Res.* 82, 173–177
13 Sholl, D. A. (1956) *The Organization of the Cerebral Cortex*, Hofner, New York
14 Strick, P. L. and Sterling, P. (1974) *J. Comp. Neurol.* 153, 77–106

MILES HERKENHAM

Miles Herkenham is at the National Institute of Mental Health, Laboratory of Neurophysiology, Bethesda, Maryland, U.S.A.

Separate representations of the body in primary somatosensory cortex

Microelectrode mapping experiments suggest that the classical primary somatosensory cortex of monkeys consists of as many as four separate body representations rather than just one.

The region of postcentral parietal cortex of primates known as primary somatosensory cortex or S-I has long been conceptualized as a single systematic representation of the body. This representation is often portrayed on the brain surface as a homunculus with the tail medial, the head lateral, and the digits of the hand and foot pointing rostrally. A long-standing puzzle has been why this single subdivision of the brain contains four histologically distinct fields, Areas 3a, 3b, 1 and 2. To add to this puzzle, it later became clear that each of the fields responds differently to somatosensory stimuli, and that these fields are anatomically interconnected. These observations all suggest four subdivisions of the brain rather than one. The answer to the puzzle is that evidence for separate representations of the body, one in each of the architectonic zones, is provided by recent detailed electrophysiological reinvestigations of the organization of postcentral cortex in monkeys. Because these separate representations have similar medial to lateral organizations, roughly proceeding from tail to tongue, and therefore are in parallel, they would have been difficult to distinguish by earlier surface-recording mapping methods.

Evidence for four separate representations was obtained from owl, squirrel, cebus, and macaque monkeys[1–3]. A typical experiment involved determining recep-