

Neocortical Development

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AUTHORS' NOTE:

This book is out of print. Raven Press no longer exists. The copyright to this book is being transferred to us. We want to make this information available to all who are interested in neocortical development. In the files available for download, we add a few pages that review some of the relevant literature that has been published since 1991. Our observations in 1991 are relevant to the multitude of gene expression studies done since the mid-90s and up to the present day. Many of the hypotheses that we proposed in this book have been confirmed by these studies. We also re-examine cell migration in the neocortex; the labeling patterns in our autoradiograms are consistent with studies showing tangential migration of GABA-ergic cells from germinal zones in the basal ganglia into the developing neocortex. We invite your comments on our work, and would like to answer any questions that you want to ask about how your research correlates with our findings.

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Preface

The neocortex is the crown of the mammalian central nervous system both literally and figuratively. Because an animal can carry out many of its vital functions after structural or functional decortication, the neocortex is not essential for survival in the strict sense of the term. However, there is an abundance of direct and indirect evidence that suggests that the neocortex plays a crucial role in the control of higher perceptual processes, cognitive functions, and intelligent behavior. Ascending the phylogenetic scale, the six-layered neocortex steadily expands relative to the rest of the brain, a phenomenon referred to as progressive neencephalization. This expansion first becomes manifest as the smooth neocortical mantle (lissencephalic pallium) spreads over the rest of the forebrain and the midbrain. A later manifestation of progressive neencephalization, one especially pronounced in larger mammals, is the increasing convolution of the cortical surface. This brings about an increase in the ratio of nerve cell bodies and dendrites relative to the cortical afferents and efferents, reflecting gains in processing capability and computing power of the cortical gray matter. In parallel with progressive neencephalization, there is an increase in the number of different cytoarchitectonic subdivisions of the neocortex, particularly of those regions traditionally referred to as "association areas." It is widely assumed that the evolutionary growth of mental life that reaches its zenith in humans is attributable to the progressive expansion and elaboration of the neocortex.

Neuroanatomists have been studying the structural organization of the neocortex for centuries. This began with dissections aided by the naked eye and was followed by light microscopic examinations of regional differences in neocortical cytoarchitectonics. There is still an effort to unravel the gross and fine circuitry of the neocortex using chemical, biochemical, and physiological tracer techniques at light and electron microscopic levels of resolution. The investigation of the functional organization of the neocortex became possible with the introduction of electrical stimulation and recording techniques in the last century, and advances in electronics and computer techniques in this century are helping us to understand how information is conveyed to, and processed in, the neocortex. Neuropsychologists using ablation techniques, as well as electrical stimulation and recording procedures with implanted electrodes in conscious animals, have contributed their share to our current understanding of how the neocortex controls behavior. However, the investigation of the morphogenetic development of the neocortex was lagging behind the anatomical, physiological, and psychological studies of its structure and function. Gross descriptions of the developing neocortex in animals and humans were beginning to become available at the turn of the century. But the initial efforts of neuroembryologists to analyze the cytological processes underlying neural development tended to focus on the relatively simple caudal portion of the neural tube that gives rise to the spinal cord. This state of affairs began to change in the second half of this century. A steadily growing number of articles are now being published in various journals that deal with the development of the neocortex in a great variety of species and at different stages through the embryonic, fetal, and early postnatal periods. A few edited volumes have also appeared that contain valuable contributions by experts who deal with some selected aspect of neocortical development in one or another species. However, to our knowledge there is not a book currently available, written by a single team of investigators, that specifically deals with the development of the mammalian neocortex as a whole.

This book is the outcome of our own current investigations on neocortical development in which we relied on a limited number of techniques and concentrated on a single species, the rat. The lissencephalic cortex of the rat is far less complex structurally than the convoluted cortex of a carnivore or primate. This represents an advantage from the experimental point of view because

a study of the entire cortical mantle is possible. The major techniques and materials that we have used are limited to the following: (a) We have prepared a large collection (several hundred specimens) of high quality, methacrylate-embedded Nissl-stained sections that cut through the neocortex in the three cardinal planes. This material was used, first, to describe daily changes in the growth of the neocortex at the histological and cytological levels, and second, as normative material for comparisons with observations made in experimentally manipulated embryos; (b) A large collection (several hundred specimens) of embryos that received injections of [³H]thymidine to label multiplying precursors of neurons and glia were prepared for autoradiography. Three variants of this technique were used. First, long-survival autoradiography after multiple injections was used to determine the time of origin of different classes of neurons in different regions of the developing cortex on successive embryonic days in neonates and adults. Second, short-survival autoradiography (2 hours) after single injections was used to locate the sites of cell proliferation and their magnitude as a function of embryonic age. Third, sequential-survival autoradiography (consecutive 24 hour intervals) after single injections was used to follow the dynamics of cell proliferation in the cortical germinal matrices; to trace the migration and temporary pause of cells through the subventricular and intermediate zones of the cortex; and to determine the time of arrival, final distribution, and settling of young neurons in the cortical gray matter. Finally, we used low-level x-irradiation as an ancillary technique to study changes in the cellular dynamics of the germinal matrices giving rise to neurons and glia, and to investigate certain aspects of neuronal differentiation. Because our techniques are best suited to study developmental change during the embryonic period at the histological level, developmental changes during the postnatal period at the cellular and subcellular levels, i.e., dendritic differentiation and synaptogenesis, have not been investigated.

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Abbreviations

| | | | |
|----------|--|----------|---|
| a, A | anterior | FM | foramen of Monro |
| abt | anterior basal telencephalic neuroepithelium | FR | motor area |
| ABT | anterior basal telencephalon (differentiating) | FR1 | frontal cortex, area 1 |
| AC | anterior commissure | FR2 | frontal cortex, area 2 |
| AD | anterodorsal thalamic nucleus | FR3 | frontal cortex, area 3 |
| AI | agranular insular cortex | fu | site of fusion of prosencephalon |
| AID | agranular insular cortex, dorsal part | GCC | genu of corpus callosum |
| AIP | agranular insular cortex, posterior part | GU | gustatory cortex |
| AIV | agranular insular cortex, ventral part | h | head of lateral cortical stream |
| AL | anterolateral | HC | hippocampal commissure |
| AM | anteromedial thalamic nucleus | hi | hippocampal neuroepithelium |
| ap | alar plate of neuroepithelium | HI, HP | hippocampus (differentiating) |
| APO | anterior primary olfactory cortex | HL | hindlimb motor area |
| AV | anteroventral thalamic nucleus | hy | hypothalamic neuroepithelium |
| bg | basal ganglia neuroepithelium | HY | hypothalamus (differentiating) |
| BG | basal ganglia (differentiating) | ib1 | first inferior band |
| bp | basal plate of neuroepithelium | ib2 | second inferior band |
| bt | basal telencephalic neuroepithelium | ibt | intermediate basal telencephalic neuroepithelium |
| BT | basal telencephalon (differentiating) | IBT | intermediate basal telencephalon (differentiating) |
| caz | callosal zone | ic | inferior collicular neuroepithelium |
| cc | cerebral cortical neuroepithelium | IC | internal capsule |
| CC | corpus callosum | ICP | insular cortical plate |
| ce | cerebellar neuroepithelium | IL | infralimbic area |
| CG | cingulate cortex | inr | infundibular recess |
| CG1 | cingulate cortex, area 1 | iz, IZ | intermediate zone |
| CG2 | cingulate cortex, area 2 | izl | lower intermediate zone |
| CG3 | cingulate cortex, area 3 | izm | middle intermediate zone |
| ch1, Ch1 | channel 1 of developing cortex | izu, IZu | upper intermediate zone |
| ch2, Ch2 | channel 2 of developing cortex | l, L | lateral |
| chp | choroid plexus rudiment | lcs, LCS | lateral cortical stream |
| CL | claustrum | LL | lateral limbic cortex |
| col | collapsed neuroepithelium | lo, h | low, heavy (labeling pattern in late cortical neuroepithelium) |
| CP | cortical plate | lo, l | low, light (labeling pattern in early cortical neuroepithelium) |
| CPa | cortical plate, anterior | LT | lower tier of the cortical plate (layers VI–V) |
| CPp | cortical plate, posterior | lv, LV | lateral ventricle |
| d, D | dorsal | m, M | medial |
| DC | diencephalon | mc | mitotic cells |
| DL | dorsolateral | MC | mesencephalon |
| DM | dorsomedial | ML | medial limbic cortex |
| DP | dorsal peduncular cortex | mn | zone of migrating neurons |
| E | embryonic day | MOC | motor cortex |
| ECL | lateral entorhinal cortex | mr | mammillary recess |
| ECM | medial entorhinal cortex | MS | mesencephalon |
| ez | ependymal zone | mSP | migrating subplate neurons |
| FI | fimbria | mz, MZ | mitotic zone of neuroepithelium |
| FL | forelimb area | NC | neocortex |
| | | ne, NE | neuroepithelium (ventricular zone) |
| | | OB | olfactory bulb |

| | | | |
|--------|--|--------|--|
| OC | orbital cortex | SE | septum (differentiating) |
| OC1B | occipital cortex, area 1 binocular part | SL | lateral somatosensory area |
| OC1M | occipital cortex, area 1 monocular part | SM | medial somatosensory area |
| OC2L | occipital cortex, area 2 lateral part | SP | subplate (layer VII) |
| OC2M | occipital cortex, area 2 medial part | SSC | somatosensory cortex |
| OCL | lateral occipital cortex | sSP | temporary positions of subplate neurons |
| OCM | medial occipital cortex | sv, SV | subventricular zone |
| ole | olfactory epithelium | sv1 | lower subventricular zone |
| olp | olfactory placode | svu | upper subventricular zone |
| olv | olfactory ventricle | sz, SZ | synthetic zone of neuroepithelium |
| op | olfactory pit | sIV | sojourn zone of layer IV neurons |
| or | optic recess | sV | sojourn zone of layer V neurons |
| ov | optic vesicle | sVI | sojourn zone of layer VI neurons |
| p, P | posterior | TC | telencephalon |
| PAR | parietal cortex | te | tegmental neuroepithelium |
| PAR1 | parietal cortex, area 1 (Somatosensory) | TE | temporal cortex (Auditory) |
| PAR1l | parietal cortex, area 1 lateral part (Somatosensory) | TE1 | temporal cortex, area 1 (Auditory) |
| PAR1m | parietal cortex, area 1 medial part (Somatosensory) | TE2 | temporal cortex, area 2 (Auditory) |
| PAR2 | parietal cortex, area 2 (Somatosensory) | TE3 | temporal cortex, area 3 (Auditory) |
| pbt | posterior basal telencephalic neuroepithelium | tf, TF | transitional field of neocortex |
| PBT | posterior basal telencephalon (differentiating) | th | thalamic neuroepithelium |
| PCP | primordial cortical plate | TH | thalamus (differentiating) |
| PI | pineal gland | tlv | telecephalic vesicles |
| PICP | piriform cortical plate | TT | tenia tecta |
| pl, PL | primordial plexiform layer | up, h | up, heavy (labeling pattern in late cortical neuroepithelium) |
| PM | posteromedial | up, l | up, light (labeling pattern in early cortical neuroepithelium) |
| PO | preoptic area | UT | upper tier of the cortical plate (layers IV–II) |
| POST | posterior | v, V | ventral |
| PPL | primordial plexiform layer | VB | ventrobasal thalamic nucleus |
| PPO | posterior primary olfactory cortex | VBL | ventrobasal thalamic nucleus, lateral |
| PR | perirhinal | VBM | ventrobasal thalamic nucleus, medial |
| prc | prosencephalic central canal | VC | visual cortex |
| prv | prosencephalic neuroepithelium | VL | ventrolateral |
| pt | pretectal neuroepithelium | VM | ventromedial |
| PT | pretectum | VM | ventromedial thalamic nucleus (Fig. 16–3) |
| r | reservoir of lateral cortical stream | VPm | ventroposteromedial thalamic nucleus (also called VM) |
| RC | rhombencephalon | vz, VZ | ventricular zone (neuroepithelium) |
| RF | rhinal fissure | VZa | anterior ventricular zone |
| Rp | Rathke's pouch | VZp | posterior ventricular zone |
| RS | retrosplenial cortex | v3 | third ventricle |
| RSA | agranular retrosplenial cortex | v3d | third ventricle, dorsal |
| RSG | granular retrosplenial cortex | v3v | third ventricle, ventral |
| sb | superior bridge | WH, WM | white matter |
| sb1 | first superior band | I | layer I of neocortex |
| sb2 | second superior band | II | layer II of neocortex |
| sb3 | third superior band | III | layer III of neocortex |
| sc | superior collicular neuroepithelium | IV | layer IV of neocortex |
| SSC | splenium of corpus callosum | V | layer V of neocortex |
| se | septal neuroepithelium | VI | layer VI of neocortex |