Neurobiology of Cortical Systems

Week 3: Introduction to the Cortex
(first Crair Lecture)

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Readings for Thursday:
• Anderson et al., Science 1997
Fresh, un-fixed Brain

3 lbs, 120 Billion Neurons (about 20 billion in the telencephalon; 100 billion in cerebellum - granule cells). In cortex, glia outnumber neurons by about 2 to 1. In cerebellum, neurons outnumber glia by more than 25 to 1.

176,000 km of axons.
Defining feature of Mammalian Brain is the Cerebral Cortex
Bigger bodies, bigger brains
Primate brains have relatively high density, and more neurons.
Scaling of non-neuronal cells in mammalian brain

Herculano-Houzel et al., 2014
Scaling of neurons in mammalian cortex

Herculano-Houzel et al., 2014
Cerebral cortex consists of neocortex and allocortex

Neocortex: 6 layers
Allocortex: < 6 layers (hippocampus, olfactory cortex)
The Cortical Sheet

Circle 7” Diameter

Circle about 16” Diameter

Sincich et al., Visual Neuroscience (2003) 20:663
Cerebral cortex divided into gray matter, white matter
Highly interconnected nature of cortex requires a lot of axons
Highly Interconnected

Van Weeden, Sporns
The Neocortex is Parcellated into Areas with Different Functions

Brodmann, 1909
Neocortex Arealization

How are neocortical areas different?

• Cytoarchitecture
• Chemoarchitecture
• Connectivity (input, output, intra)
• Gene Expression
• Function!
Areas of Cortex: Somatosensory and Motor Cortex

Foerster and Penfield, 1930

Penfield and Boldrey, 1937
Cortical Areal Organization is Similar Between Species
Input/Output to Cortex from Thalamus

Plus: modulatory input from the brainstem (cholinergic, histamanergic, serotonergic).
Input/Output to Cortex from Thalamus

(A) Motor and premotor cortex
    Prefrontal cortex
    Auditory cortex

(B) Motor and supplementary cortex
    Prefrontal cortex
    Somatosensory cortex
    Parieto-occipital cortex

(C) Cingulate gyrus
    Prefrontal cortex
    Widespread cortical regions
    Frontal cortex
    Motor and premotor cortex
    Somatosensory cortex
    Auditory cortex
    Parieto-occipital cortex
    Visual cortex
Input/Output to Cortex from Thalamus

- **Inputs of Thalamic Nuclei**
- **Input/Output to Cortex from Thalamus**

- **Amygdala, olfactory cortex, basal ganglia**
- **Internal globus pallidus, brainstem reticular formation, sensory pathways**
- **Superior colliculus**
- **Inferior colliculus**

**Labels:**
- Mammillothalamic tract, fornix
- Substantia nigra pars reticulata, internal globus pallidus
- Deep cerebellar nuclei
- Medial lemniscus, spinothalamic tracts
- Trigeminal lemniscus, trigeminothalamic tract, gustatory inputs
- Optic tract
- Ant.
- VA
- LD
- LP
- VLo
- VLc
- VPL
- VPM
- In
- Pulvinar
- LGN
- MGN

The Auditory System

- Heschl’s transverse gyri (area 41)
- Superior temporal gyrus
- Medial geniculate nucleus (MGN)
- Brachium of inferior colliculus
- Inferior colliculus
- Lateral lemniscus
- Superior olivary nuclear complex
- Inferior cerebellar peduncles
- Trapezoid body
- Dorsal cochlear nucleus
- Cochlea
- Spiral ganglion cells
- CN VIII
- Ventral cochlear nucleus

Cortex also Projects Densely to the Basal Ganglia, Brainstem and Spinal Cord
The Neocortex is Stereotypically Layered

Brodmann

Nissl and Golgi (Cajal)
The Neocortex is Stereotypically Layered
Layers have stereotypical inputs, outputs.
Different layers contain different types of cells
Different areas have different relative proportion of layers

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<th>Primary sensory cortex</th>
<th>Association cortex</th>
<th>Primary motor cortex</th>
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Common Morphological Cell Types:

**Excitatory:**
- Pyramidal (layers II-VI)
- Stellate (layer IV)
- Polymorphic (layer VI)

**Inhibitory:**
- Basket
- Chandelier
- Martinotti
- Neurogliaform
- Bitufted
- Bipolar

*Figure 13. One spiny stellate cell (b) and one cell with smooth dendrites and an ascending axon (c) in a cluster of cells (Gl) in sublayer IVC. The large pyramidal cell (a) in the lower part of layer III has a descending axon with horizontal and recurrent collaterals. Golgi method. Camera lucida drawing, *Macaca mulatta.*"
Excitatory (spiny) and Inhibitory (non-spiny) Cells

Figure 12. Basic cell types in the monkey cerebral cortex. Left: spiny neurons that include pyramidal cells and stellate cells (A). Spiny neurons utilize the neurotransmitter glutamate (Glu). Right: smooth cells that use the neurotransmitter GABA. B, cell with local axon arcades; C, double bouquet cell; D, H, basket cells; E, chandelier cells; F, bitufted, usually peptide-containing cell; G, neurogliiform cell.
Pyramidal Cells are the Major Neuron in the Cortex (about 70-80%) and the Major Excitatory Cell
Layer 5 Pyramidal Cell

Local Connections, Projections to Layers 2/3 above and laterally
Excitatory and inhibitory neurons have stereotypical synaptic relationships.
Cannonical microcircuit of the cortex

Costa, Martin
Frontiers Neuroanatomy
4: 16 (2010)
Principal (Excitatory) Cell Migration is Radial

Gao et al., 2015
Cortical Excitatory Neuron Migration is Radial

Modified from Rakic, P. Science 241:170-176, 1988
Interneuron Migration is Tangential
Cortical Columns

Primary Somatosensory Cortex of some Rodents Exhibits Barrels in Layer IV
Cortical Columns

Van Hooser
Neuroscientist
Ice Cube Model of Primary Visual Cortex

Cortical Columns

Orientation and ocular dominance columns

Figure 23. The ice-cube model of the cortex. It illustrates how the cortex is divided, at the same time, into two kinds of slabs, one set of ocular dominance (left and right) and one set for orientation. The model should not be taken literally: Neither set is as regular as this, and the orientation slabs especially are far from parallel or straight.

Hubel and Wiesel
Cortical Areas are Densely Interconnected

From Felleman and Van Essen
Cerebral Cortex 1 (1991) 1-47.
Existence of the neocortex is one of the defining features of mammals. It plays a key role in memory, attention, perceptual awareness, thought, language, consciousness. Most everything that defines us as humans.

Grey matter.
White matter.
Area. Number of neurons. Wiring ‘length’.
Cortex is broken into areas.
  * Neocortex and allocortex.
    * Neocortex is most (e.g. visual cortex, motor cortex) with six layers.
    * Allocortex is smaller (evolutionarily older) with three or four layers. E.g. Olfactory cortex and hippocampus (technically part of the cortex).
  * Areas have different functions.
  * Main input from the thalamus (glutamatergic) with reciprocal connections.
  * Modulatory input from the brainstem (cholinergic, histaminergic, serotonergic).

Laminated.
Stereotyped intracortical micro-circuitry.
Cell types.
Cortical columns.
Ferrier (~1875). Different areal functions (can change dramatically and quickly as you move laterally).
Penfield (~1930s) – somatosensory and motor maps.
Mountcastle (in somatosensation – 1950s) and Hubel and Wiesel (in vision – 1960s) showed functionally distinct cortical columns (within an area).
Diseases: Alzheimers, Schizophrenia, Autism, Mood disorders are all principally associated with the neocortex.