Sensory and Motor Maps in the Brain

Lecture 17

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Some Definitions

**Afferent** – information projecting to a neuron or system. If a specific system is not mentioned, usually means sensory info projecting to the brain

**Efferent** – information projecting from a neuron or system. If a specific system is not mentioned, usually means motor info projecting from the brain

**Decussation** – place where a pathway crosses the midline of the CNS
Afferent Somatosensory Information

Somatosensory information from the trunk and limbs projects from the periphery to the thalamus and on to primary somatosensory cortex.

This information involves a three-nucleus path to cortex:

- Dorsal root ganglia through the spinal cord
- Medullary nuclei
- Ventral posterior lateral nucleus (VPLN) of the thalamus

Orderly maps of the body are maintained at each stage.
Somatosensory Homunculi of Other Vertebrates

Actually, each of Brodmann’s areas 1, 2, 3a, and 3b (which together make up the primary somatosensory cortex) have a separate map of the body surface.

Cortical magnification: areas with more dense receptors have larger cortical space – increased resolution.
Preferentially stimulating certain digits has been shown to result in an increase in the number of cells devoted to those digits in somatosensory cortex (Jenkins, Merzenich, Ochs, Allard, and Guíc-Robles, 1990):

Normal

Stimulated (2D and 3D)
In addition to position on the skin surface, cells in the primary somatosensory areas code more complex aspects of tactile stimuli, such as their orientation on the skin surface (top figure at right) or direction of movement on the skin surface (bottom figure at right).

These examples come from Brodmann’s area 2.
Afferent Visual Information

90% of the axons from the retina pass through the lateral geniculate nucleus (LGN) of the thalamus on their way to cortex.

Both the LGN and primary visual cortex contain orderly topographic maps of the retina (retinotopic representation).
Magnocellular division: receives projections from large retinal ganglion cells with large receptive fields
  - These cells are sensitive to rapid changes and are important for processing motion
Parvocellular division: receives projections from smaller retinal ganglion cells with small receptive fields (and thus higher spatial acuity)
  - These cells are important for the analysis of form, color, and fine detail in the image
Orientation Selectivity in Visual Cortex

The orderly representation of line orientations in visual cortex was discovered by Hubel and Wiesel in the 1960s. They noted that individual cells in primary visual cortex (V1) of monkeys fire maximally for lines of a particular orientation.

(PNS, p. 534)
Hubel and Wiesel also noted that neighboring cells in visual cortex tend to like similar line orientations.

Figure 6.4. Reconstruction of an electrode penetration through an area of a monkey's primary visual cortex. Lines to the left indicate preferred orientations of the cells traversed. Areas numbered 17 and 18 are standard terms for subdivisions of the cortex. (Adapted from Hubel and Wiesel, 1968, with permission of Cambridge University Press.)
More recently, researchers such as Blasdel and colleagues have used optical imaging to measure orientation selectivity across the entire visual cortex. In the figure at right, different colors represent different orientation preferences in a 9mm by 12mm patch of visual cortex. The insets show an aspect of the map referred to as a “pinwheel.” Iso-orientation lines are shown in white.
Cortical Columns

The cortex can be thought of as a convoluted sheet.

A **cortical column** is an abstraction that represents a group of cells that spans the width of this sheet.

There is no anatomical basis for a definition of a cortical column, so the picture here is wrong.

The column is defined based on the response properties of the cells.
Cortical Columns

Cells with the similar response properties constitute a column.

E.g., cells in a cortical column of visual cortex all fire for lines of the same orientation, and different columns prefer different orientations.

We can take this abstraction further and define a hypercolumn: a set of columns that cover all orientations.
Cortical Columns

Couple more issues:
There are no well-defined borders between columns, response properties usually change gradually between nearby cells.
Short range excitatory projections is the likely cause of similar response properties of the nearby cells.
These map properties are not limited to visual cortex and persist through a majority of map-like cortical representations.
Multiple Signal Properties in Visual Maps

In addition to line orientation, cells in primary visual cortex have preferred retinal locations (receptive fields) that are mapped in an orderly fashion on the visual cortex.

This map includes the same cells that make up the line orientation map described on the previous slides.

Note another example of cortical magnification.
Blindsight

With extensive damage to the primary visual cortex, visual perception is lost. However, some residual visual abilities seem to persist, e.g.:

- Pointing to stimuli (even though the patient insists he/she cannot see them)
- Detection of visual motion

These residual visual abilities, referred to as blindsight, are likely mediated by retinal projections to the superior colliculus, an area of the midbrain involved in reactive eye movements.
Afferent Auditory Information

Cochlear nuclei – located in the medulla.

Lateral superior olive (LSO) – area of the pons involved in sound localization based on interaural intensity differences

Medial superior olive (MSO) – area of the pons involved in sound localization based on interaural time differences

Nucleus of the lateral lemniscus
Inferior colliculus – located in the midbrain; important for sound localization.

Medial geniculate nucleus – portion of the thalamus that transmits auditory information to cortex.

Primary auditory cortex located in Heschl’s gyrus on the supratemporal plane.

Tonotopic maps are found in many areas in this pathway.
Neural Maps in Auditory Cortex

Cells in primary auditory cortex typically have a “preferred frequency.” That is, each cell fires maximally for sounds (e.g. pure tones) of a particular frequency, and neighboring cells in cortex tend to like sounds with similar frequencies.

The auditory cortex is thus described as having a tonotopic organization.
Studies by Merzenich and colleagues have shown that exposure to tones of a particular frequency (9 kHz in following plots) can lead to an increase in the size of the auditory cortical representation for tones of this frequency:

From Kilgard and Merzenich (1998)
Multiple Signal Properties in Auditory Maps

Many cells in auditory cortex prefer frequency “sweeps” rather than sounds with a constant frequency. The signal property “sweep velocity” is topographically represented in auditory cortex, in addition to center frequency of the tone or frequency sweep.

Though cortical maps are usually studied with an eye toward one signal property at a time (e.g., line orientation or tone frequency), multiple signal properties are actually represented simultaneously in the primary cortical areas. For the remainder of today’s lecture, we will concentrate on the representation of a single signal property in a cortical map.
Taste Map

Harder to define space for the map
Are basic tastes coordinates?

In the insular cortex of a mouse there are areas specifically sensitive to bitter taste
Taste Map

Sweet, umami and salty tastes are also represented (*Chen et al 2011*)

Difference from auditory, visual, and somatosensory maps is that
- receptors are mixed on the tongue
- space is 5D?

Many neurons do not respond to basic tastes

No sour taste location was found in that study
Olfactory Tract

Direct input from receptors to the olfactory bulb, from there to piriform cortex

Evolutionary probably the oldest sensory system

Some metrics suggest that odor representation in the cortex is also map-like

Hard evidence is missing because it is hard to define good metrics for odor space
Efferent Motor Commands

Some commands to the fingers and hand are mediated by direct connections from motor cortex to the spinal cord.

However, most motor output commands involve subcortical structures such as the red nucleus and cerebellum.
In humans, the speech articulators and fingers have very large primary motor cortex representations.

The somatosensory and motor homunculi are approximately aligned with each other.

Corresponding parts of primary somatosensory cortex and primary motor cortex are interconnected.
Basal Ganglia and Cerebellum in Movement Control

Four pathways to convey the signal:

- Direct projection
- Projection through brainstem
- Basal Ganglia-Thalamo-Cortical loop
- Cerebello-Thalamo-Cortical loop

Projections are topological, but keep in mind numbers of neurons
Primary, Higher-order, and Association Cortices

Unimodal association cortex is also called higher-order sensory cortex (as compared to primary sensory cortex)
Higher-order Motor Cortex

The lateral premotor cortex (lateral Brodmann’s area 6, usually simply called *premotor cortex*) is important for the planning of movements in response to external stimuli, including sensorimotor transformations.
Higher-order Motor Cortex

The medial premotor area (medial BA 6), is called the supplementary motor area (SMA) and is important for the planning of internally generated movements and mental rehearsal:
Higher-order Motor Cortex

Brodmann’s areas 8 (frontal eye fields) and 44/45 (Broca’s area) can be considered to be premotor areas specialized for eye movements (area 8) and speech (areas 44/45).
Higher-order Visual Cortex

Visual information separates into “what” and “where” pathways:

Figure 28-2 The magnocellular (M) and parvocellular (P) pathways from the retina project through the lateral geniculate nucleus (LGN) to V1. Separate pathways to the temporal and parietal cortices course through the extrastriate cortex beginning in V2. The connections shown in the figure are based on established anatomical connections, but only selected connections are shown and many cortical areas are omitted (compare Figure 25-9). Note the cross connections between the two pathways in several cortical areas. The parietal pathway receives input from the M pathway but only the temporal pathway receives input from both the M and P pathways. (Abbreviations: AIT = anterior inferior temporal area; CIT = central inferior temporal area; LIP = lateral intraparietal area; Magno = magnocellular layers of the lateral geniculate nucleus; MST = medial superior temporal area; MT = middle temporal area; Parvo = parvocellular layers of the lateral geniculate nucleus; PIT = posterior inferior temporal area; VIP = ventral intraparietal area.) (Based on Merigan and Maunsell 1993.)
Higher-order Somatosensory Cortex

Higher-order somatosensory cortex lies on the posterior parietal cortex (BA 5, 40) and is involved in more complex representation of the body parts.
Wernicke’s area (Brodmann Area 22) is on the superior temporal gyrus and is important for speech and language perception:

This area has long been hypothesized to connect to Broca’s area, which is more involved in motoric and grammatical aspects of speech, through a pathway called the *arcuate fasciculus*
The parietal association area is involved in spatial representation ("where"), both of external targets and of parts of the body.

The temporal association area is involved in language and object recognition ("what")
Right half of figure shows drawings made by a patient with damage to right posterior parietal cortex, attempting to copy the model drawings on the left. Despite not being able to “see” the left half of objects (even though the visual pathways are intact), neglect patients can typically recognize the objects (but this is “what” pathway).
Self-portraits by a hemifield neglect patient 2 months after stroke (upper left), 3.5 months after (upper right), 6 months after (lower left), and nine months after (lower right)
PPC and Spatial Representation

Hemifield neglect was discovered by an Italian neurologist who noted that patients with right parietal damage could only recall the left half of the main square in Milan relative to the direction they were facing in their imagination.

Question: What does this tell us about the “coordinate frame” in which visual memories are stored?
The frontal association area is important for high-level action planning, the suppression of inappropriate actions, and high-level linguistic function.
The Case of Phineas Gage

In 1848, railway worker Phineas Gage dropped a tamping iron onto a rock, causing some nearby blasting powder to ignite. The tamping iron was propelled through the left side of Gage’s jaw, passing through the frontal association area (skull on display at Harvard).

Miraculously, Gage survived. However, his personality changed dramatically from being a pleasant, responsible fellow before the accident to being impulsive, obnoxious, and showing poor judgment afterward (reduced inhibitions).

In the words of his co-workers: “Gage is not Gage.”
Limbic association area receives projections from posterior ("where"), temporal ("what") and anterior ("how") association areas
Limbic Association Area

Information from posterior ("where") stream arrives at postrhinal (parahippocampal) cortex and is further passed through medial entorhinal cortex to the septal (dorsal) part of the hippocampus.

Information from temporal ("what") stream arrives at perirhinal cortex and is further passed through lateral entorhinal cortex to the temporal (ventral) part of the hippocampus.

Information from anterior ("how") stream arrives directly to entorhinal cortex.

There is some cross-talk between streams in the entorhinal cortex and in the hippocampus.
Limbic Association Area

Temporal
what

Prefrontal

Perirhinal

Parietal
where

Occipital

Postrhinal

Dentate gyrus

Septal

Outer blade
Inner blade
to
CA3

Same transverse slice (spatial scale)

Ventral EC

Medial EC

Lateral EC

Dorsolateral band

Visual and visuo-spatial
where
vanEssen Diagram

Summarizes the visual areas and connectivity between them through what and where pathways.

All roads lead to Rome (limbic association area)
Next Time

Modeling the cortical maps:
von der Malsburg (1973); Grossberg (1976); Kohonen (1982)

Readings:

– D&A Section 8.3