Psy393: Cognitive Neuroscience
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Week 3

Part 4: Gross and Functional Neuroanatomy

CNS: Ontogeny & Phylogeny
- Increase in brain structural complexity: e.g., Neocortex
- Development (infants --> adults)
- Evolution (reptiles --> humans)

Comparative Neuroanatomy

Development of Sulci
- Sulci appear at predictable points in fetal development with the most prominent sulci (e.g., Sylvian fissure) appearing first.
- Cortical wrinkling increases during development

Triune Brain: 3 in 1
- Triune brain (Maclean)
  - 3 brains in 1
    - Neocortex
    - Limbic system
    - Reptilian complex (BG)
- Computer metaphor?
  - Old wrapped around new
Axis nomenclature

Navigating the brain

Axis?

Axis?

Axis?

What perspective?
What perspective?

Additional useful terms
- Contralateral
  - opposite side
- Ipsilateral
  - same side
- Unilateral
  - on one side only
- Bilateral
  - on both sides

Division of nervous system
- Central (CNS)
  - Brain
  - Spinal cord
- Peripheral (PNS)
  - Afferents (Input)
    - Sensory nerves
  - Efferents (Output)
    - Somatomotor
      - Autonomic (ANS)
        - Sympathetic
        - Parasympathetic

Major divisions of CNS
- Reflex/Vital functions
  - Spinal cord
  - Brainstem
    - Hindbrain (Pons, Medulla), Midbrain
  - Cerebellum
  - Diencephalon
    - Thalamus and hypothalamus
  - Forebrain
    - Basal Ganglia
    - Cortex (older)
    - Neocortex
- Cognition
  - Primary sensory, Association

PNS/CNS Interface: Spinal cord
- Division of I/O
  - Dorsal: Sensory
  - Ventral: Motor
- PNS
  - Sensory/Motor Ganglia
- CNS
  - Spinal cord
- Simple reflexes
  - Little cognitive control/intervention

PNS: Autonomic nervous system
- Visceral motor System
- Innervates smooth muscles and glands
- Antagonistic action
**Brainstem: Medulla**
- Medulla
  - Continuous w/ spinal cord
  - Primary relay for somatosensation and cranial nerves
  - Controls many vital functions
    - Respiration
    - Heart rate
  - Crossing of motor fibers
  - Contralateral control
  - Reticular activating system
    - Arousal
    - Sleep/wake cycles
  - Damage: death, coma

**Brainstem: Midbrain**
- Inferior colliculus
  - Sound localization
  - Reflexive orienting to sounds
- Superior colliculus
  - Orienting to visual events
  - Foveation
- Substantia nigra
  - Dopamine projection to subcortical motor system (BG)

**Brainstem: CNS: Brainstem: Pons**
- Pons
  - Superior to medulla
  - Main connection b/wn cortex & cerebellum
  - Superior olive: major auditory relay
- Function: Diverse
  - Eye movements
  - Vestibular (balance)

**Brainstem: Neurotransmitter systems**
- 4 main systems
  - Cholinergic
  - Dopaminergic
  - Noradrenergic
  - Serotonergic
- Multiple receptor types
  - E.g., Serotonin has at least 9 types
- Cells bodies largely in midbrain
- Project throughout brain
  - Distinct and overlapping sites

**Neurotransmitters**
- >100 recognized NTs
- Definition of a NT
  - Synthesized in presynaptic neuron
  - Released when terminal boutons activated by AP
  - Postsynaptic neuron has selective receptors for substance
  - When artificially applied postsynaptically leads to same response as presynaptic release
  - Blocking NT release blocks AP

**Cholinergic system**
- ACh Origin
  - Basal forebrain, Midbrain
- Function
  - Arousal, Waking EEG
  - Cortical excitability
  - REM
  - Memory
- Disease: Alzheimer’s
Dopaminergic system
- **DA Origin**
  - Substantia Nigra
  - Ventral tegmental area
- **3 subsystems:**
  - Nigrostriatal (NS), mesolimbic (ML), mesocortical (MC)
- **Function**
  - Regulates action (NS)
  - Mental (MC) and emotional (ML)
    - Working memory
    - Anticipation of reward
- **Disease:** Parkinson's, Schizophrenia, Addiction

Noradrenergic system
- **NE Origin**
  - Locus coeruleus (LC)
- **Function**
  - LC
    - Arousal/Attention
    - LTM: Emotional memory
- **Disease:** ADHD

Serotoninergic system
- **5-HT Origin**
  - Raphe nuclei
- **Function**
  - Arousal
  - Mood, Anxiety
  - Pain
  - Aggression
  - Sexual behavior
  - Sleep
  - Memory
- **Disease:** Depression
  - Serotonin specific reuptake inhibitors (SSRIs)

Cerebellum
- **Like cerebrum:** “Little brain”
  - Cortex
  - Deep nuclei
- **Function**
  - Voluntary movement
  - Coordinated movement
  - Walking, piano playing, speech
  - Ipsilateral control
  - Higher cognitive functions
    - Timing
  - Working memory
- **Damage:** Not loss of motor function, but precision of movement

Diencephalon: Thalamus
- **Subcortical nuclei**
- **Deep/midline**
- **Sensory gateway to cortex (thalamo-cortical)**
  - Every modality
    - Med. geniculate (Aud)
    - Lat. Geniculate (Vis)
    - Except olfaction
- **Cortico-thalamic feedback**
  - From same cortical areas
    - Visual cortex —> L. Geniculate
- **Function:** Tune sensory transmission

Diencephalon: Thalamus
- **Effect of damage**
  - Depends on nuclei
  - Sensory, motor, Cognitive (memory)
  - Similar to cortical projection sites
Diencephalon: Hypothalamus

- Ventral to thalamus
- Controls
  - ANS
  - Endocrine function: Hormone release
- Function
  - Homeostasis: Regulation of eating, drinking
  - Fight or flight
  - Light-Dark cycles
  - Retina —> suprachiasmatic nucleus

Basal ganglia

- Basal = Base, Ganglia = cell bodies
- 3 main subdivisions
  - Neostriatum
    - Caudate
    - Putamen
    - Globus pallidus
- Function
  - Motor control
  - Executive functions

Limbic system

- Limbic = "border"
- Controversial definition
- Older primitive cortex
  - Archicortex
  - Hippocampus
- Subcortical nuclei
  - Amygdaloid complex
- Functions
  - Sense of smell
  - Emotion
  - Memory

Cerebral cortex

- Greatest expansion across phyla
- 5/6ths of total brain mass evolved over last million years
- What makes us (and dolphins?) special
  - 1-5 mm thick
  - Up to 6 layers of cells
    - Neocortex (6)
    - Archi or allocortex (1-4)
- Heavily wrinkled

Cortex: Laminar organization

- Layers of distinct cell bodies
- Basis for cytoarchitecture
  - Brodmann
- Strict I/O org
  - Input layer
  - Output layer
  - Not random

Cortical surface: Sulci and Gyri

- Increased surface area
- Decreased axonal distance
**Lobes**
- Frontal lobe
- Temporal lobe
- Occipital lobe
- Parietal lobe
- Central (rolandic) sulcus
- Sylvian (lateral) sulcus

**Longitudinal Fissure**
- Divides brain in 2 hemispheres

**Sylvian Fissure (or lateral sulcus)**
- Deep, mostly horizontal
- Insula is buried within it
- Separates temporal lobe from parietal and frontal lobes

**Parieto-occipital Fissure and Calcarine Sulcus**
- Parieto-occipital fissure (red)
- Calcarine sulcus (blue)
- Cuneus (pink)
- Lingual gyrus (yellow)

**Collateral Sulcus**
- Colateral
- Divides lingual (yellow) and parahippocampal (green) gyrus from fusiform gyrus (pink)

**Superior and Inferior Temporal Sulci**
- Superior Temporal Sulcus (red)
- Divides superior temporal gyrus (blue) from middle temporal gyrus (yellow)
- Inferior Temporal Sulcus (blue)
- Not usually very continuous
- Divides middle temporal gyrus from inferior temporal gyrus (red)
**Cerebral cortex – primary somatosensory and motor cortices**

- **Central sulcus**
- **Postcentral sulcus**

Primary motor cortex: final exit point from cortical neurons for fine motor control
Primary sensory cortex: first region in cortex to receive information from specific sensory modality

**Superior and Inferior Frontal Sulci**

- **Superior Frontal Sulcus** (red)
  - divides superior frontal gyrus (mocha) from middle frontal gyrus (pink)
- **Inferior Frontal Sulcus** (blue)
  - divides middle frontal gyrus from inferior frontal gyrus (gold)

Orbital gyrus (green) and frontal pole (gray) also shown

**Medial Frontal**

Superior frontal gyrus continues on medial side
Frontal pole (gray) and orbital gyrus (green) also shown

**Cingulate gyrus**

**Cingulate sulcus**

**Corpus callosum**

- Massive interhemispheric highway
- Make 2 brains 1

**Primary and Association cortices**

- Primary
  - Sensory/motor maps
  - Clear organization
- Association
  - Cognitive maps
  - Organization?

**Primary somatosensory and motor cortices: Organization**

- Topographic mapping
- Inverse mapping
- Distortion
- Contralateral representation
Primary visual cortex

- Topographic mapping
  - Retinotopic
- Inverse mapping
  - Up is down
  - Down is up
- Distortion
  - Foveal over representation
- Contralateral representation

Extra info

- The following slides have been inserted to provide you with a more detailed resource for brain surface anatomy
Part 2: Methods of Cognitive Neuroscience

- Cognitive Psychology
- Lesion method: Cognitive Neuropsychology
- Brain recording
  - Single cell, Intracranial recording, Scalp recording (EEG, ERP)
  - Metabolic imaging (PET, fMRI)

Cognitive Psychology

- Information processing depends on internal mental representations
- Say goodbye to behaviorism!
- Mental representations undergo systematic transformations
- Flowchart models of operations

Characterizing mental operations: Normal human performance

Same or different category?

5 different conditions:
- physical identity: A A
- phonetic identity: A a
- same category
  - both vowels: A U
  - both consonants: S C
- different category: A S

Mental Chronometry

- Mental chronometry
  - Accuracy
  - Response time
  - Sternberg memory scanning
    - mental operations
      - encoding - visually process letter,
      - comparison - match to template,
      - decision making - make category decision,
      - response selection - execute action
  - Parallel vs. serial processing
  - Functional independence: Donder’s method
    - Additive factors logic
      - Red line high luminance
      - Blue line low luminance
      - Does not interact with memory set size

- Derive multiple representations from same stimulus (physical, phonetic identity, conceptual category)
- Each require finite amount of time (serial stages)
**Does functional decomposition map onto structure?**
- Flow chart of transformations relate to neuroanatomy?
- Functional independence
  - Additive factors
  - Concurrent task
  - Supported by different brain regions?

**Brain lesion method**

IF: Function X is disrupted by lesion to brain region Y

THEN: Brain region Y supports function X

**Human & nonhuman lesion studies**

**Human Neuropsychology**
- Not under control of experimenter
- Acquired brain damage
  - Naturally occurring neurological condition or surgical treatment of condition
  - Single-case or group studies

**Nonhuman animals**
- Under control of experimenter
- Lesioning of selected brain structures
- Surgical or neurotoxic procedures
- Much more precise

**Single & Double dissociations**

- Single dissociation
  - Patient with damage to area X is impaired in function A but not function B
- Double dissociation
  - Patient with damage to area Y is impaired in function B but not cognition A

lesion to Broca’s area (X) impairs speech production (A) but not comprehension (B)

lesion of Wernicke’s area (Y) impairs comprehension (B) but not production (A)

**Why are double dissociations so important?**

- May not reflect distinct functions supported by brain regions
- Differences in task difficulty, required attention, etc.
- E.g., Prosopagnosia
  - Faces have less distinctive features, more difficult classification than objects
Lesion method: Limitations

- Issues
  - Variability in patients and lesions
  - Due to IQ differences
  - Quasi-Correlational in humans
  - Due to adjacent cortex
  - Achromatopsia/Prosopagnosia
- Possible solutions
  - Group studies can control for age, IQ, etc.
  - Lesion overlap across patients

More limitations: Disconnection Syndromes

- Is a brain region critical for a specific function?
- Lesion may disconnect two critical brain regions that are critical for cognition A

Split-brain patients

- Severing the corpus callosum leads to certain cognitive impairments
- But it's not the corpus callosum that carries out these functions

Lesion method: Sitting on a 2 legged stool

- Function not of area X but of brain without area X
- E.g., Ascribe function to missing leg: hold up stool on own?
  - All legs participate
  - Falling is a result of System level dysfunction

Brain measurement: Extracellular recording

- Rather than disrupt function measure neural correlates during its normal operation
  - Electrode inserted into brain near neuron or inside of neuron (intracellular)
  - Records voltage changes pooled over just a few neurons (or a single neuron)
  - Record # of action potentials
  - Logic
    - More AP, more participate in function

Receptive fields

- The area of space in which a neuron can be influenced (maximally)
  - Visual, auditory, somatosensory

Cellular recording: Limitations

- Done in nonhuman animals
  - Generalize to humans?
- How do workings of a few neurons relate to macroscopic/population level
  - Multi-cellular recording
    - 100+ neurons simultaneously
  - Still correlational
    - How relate to observed behavior
    - Correlated but not causally related
      - Motion perception: Record/stimulate
Epilepsy patients
Cortical mapping for cortical resection: Stim & Record
Cons: Neurologically dysfunctional brain

Intracranial recording: Humans

- Exposed cortex of epilepsy patient
- Grid work of electrodes laid over the surface for stimulation and recording

Functional imaging

- Brain recording in neurologically intact brains
- Not static: Anatomical/structural imaging
  - CT, MRI
- Dynamic: Physiological imaging
  - How vary over time (function)
  - Electrical
    - Intracranial EEG, ERP
    - Scalp EEG, ERP
  - Metabolic
    - PET, fMRI