De-centering the Vertebrate Brain: The Hypothalamus and Basal Ganglia

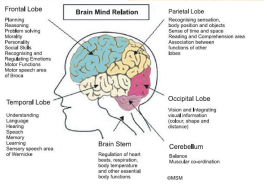
Discussion Question

Where in your body would you look to find your mind (aka the thinking thing)?

- The cerebral cortex—it is the cortex that makes us unlike other animals
- In the whole brain—from the cortex to the mid and forebrains to the cerebral cortex
- In your stomach—the little guys down there (bacteria) are really in control send signals through the vagal nerve and neuromodulators
- Throughout you whole body—your thinking depends on your hands, mouth, feet, etc.
- Other

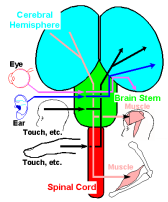
The Assumed Autonomy of Neocortex

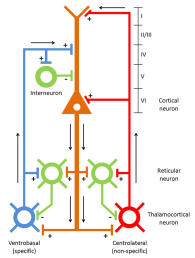
- We tend to think that mental activity occurs in the neocortex
  - The neocortex gets inputs from elsewhere and send outputs to other areas
  - It carries out its own processing and send motor commands to the rest of the body



Beyond a Cortico-Centric Perspective

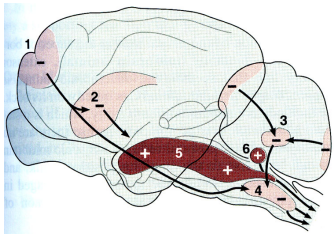
* The neocortex only operates in conjunction with other brain areas
  * Connections up and down are as prevalent as those within cortex itself





Multiple Layers of Control in the Brain Itself

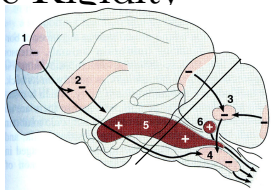
* Areas in the cat brain where stimulation facilitates (+) or inhibits (-) muscle activity
  1. Motor cortex
  2. Basal ganglia
  3. Cerebellum
  4. Reticular inhibitory area
  5. Reticular excitatory area
  6. Vestibular nuclei

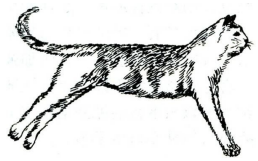


Lindsley, Schreiner, & Magoun (1949).

Decerebrate Rigidity

* Sectioning the brain just above the pons leads to full activation of antigravity muscles
  * extended posture of the upper and lower extremities, extended tail, retracted head, extended neck, and upward-drawn chin
* Due to
  * preserved activation of these muscles by the pons
  * elimination of inhibition from medullary reticular nuclei





Preserved Abilities in Decorticate Preparations

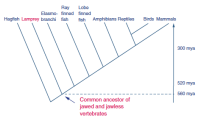
- Thalamic decorticate preparation: spares the thalamus while removing the striatum
  - cats become hyperactive (although perhaps transiently)
  - their complex behaviors are dissociated into component behaviors
- Striatal decorticate preparation: spares the striatum and thalamus
  - cats feed spontaneously
  - localize auditory stimuli
  - associate sounds with food
  - clean and groom themselves
    - exhibit habituation and conditioning

- "Rather than a sine qua non of acquired behavior, the cortex would appear to be required largely for discrimination of complex, subtle stimulus properties and for the integration of the organism's behavior tendencies in general" (Buckwald and Brown,1973)

The Vertebrate Brain Bauplan

- The finding of the same structures in lamprey and humans
  - nearly the most distinctly separated of surviving vertebrate species (they separated 560 million years ago)

  suggests that the same brain plan was present in the earliest evolved vertebrates



Grillner and Robertson (2016)

Clicker Question

What is the hypothalamus?

A mini version of the neocortex that is found in many organisms

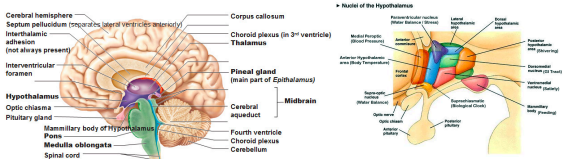
A structure that regulates basic physiological processes such as breathing or body temperature, but is irrelevant to overt behaviors

A single nucleus that receives commands from the basal ganglia and passes them on to lower brain regions

A collection of nuclei that each receive a variety of inputs and send outputs regulating a wide range of activities (altertness, reproduction, eating, etc.)

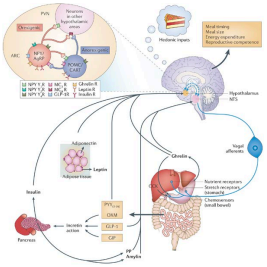
The Hypothalamus: "The Heart of the Brain"

* Hypothalamus is a region of the brain consisting of multiple (interconnected) nuclei the coordinate a large number of basic physiological processes (including overt behaviors)
* Different nuclei receive inputs from different parts of the body and send outputs that regulate physiological, motor, and other neural systems



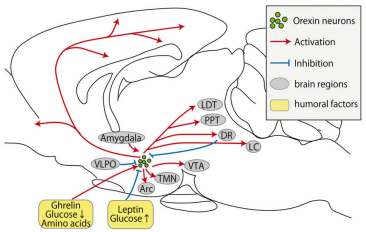
Arcuate Nucleus: Regulating Food Behavior

* Two populations of neurons that respond to peripheral signals indicating the state of satiety of the organism.
  * Pro-opiomelanocortin (POMC) neurons respond to leptin, a peptide released by adipocytes
    * suppresses food consumption
  * Neuropeptide Y/agouti-related peptide neurons are inhibited by leptin but activated by ghrelin, a peptide synthesized in the stomach that signals a lack of food
    * increases food intake
* But watch out—the arcuate nucleus does not operate in isolation



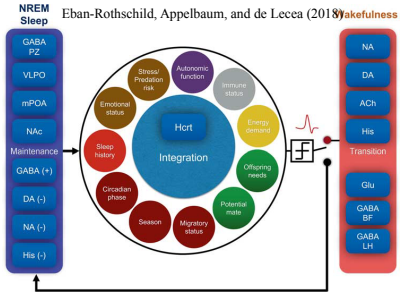
Hypocretin/Orexin Network

* Discovered in 1998 hypocretin/orexin neurons were thought to be involved in promoting feeding
* But then they were also determined to affect arousal
  * fired just before sleep-to-wake transition
  * silencing resulted in slow wave sleep
* Project to many areas already identified with arousal
  * Also receive inputs from a host of brain regions



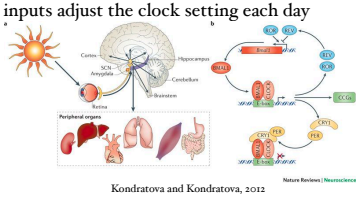
Arc, arcuate nucleus; DR, dorsal raphe nucleus; LC, locus coeruleus; LDT, laterodorsal tegmental nucleus; PPT, pedunculopontine tegmental nucleus; TMN, tuberomammillary nucleus; VTA, ventral tegmental area; VLPO, ventrolateral preoptic nucleus.

Hypocretin Neurons as Integrators



Suprachiasmatic Nucleus: Timing, Timing, Timing

- The Suprachiasmatic nucleus (SCN) regulates daily timing of almost all physiological and behavioral processes (including taking tests and playing sports)
- Internal structure generates an approximately (circa) 24 hour (dies) rhythm
- Sensory inputs adjust the clock setting each day



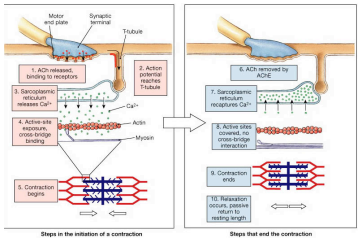
Kondratova and Kondratova, 2012

Lessons from the Hypothalamus

- The hypothalamus is a collection of distinct nuclei in which neurons receive inputs (neuronal and chemical) from different regions of the body and send outputs (neuronal and chemical) to other parts of the brain as well as to the body
  - Different nuclei regulate specific behaviors (feeding, sexual activity, awareness)
  - But do so by
    - integrating signals from many locations
    - projecting to many locations
- Like invertebrate neuromodulators, the hypothalamus makes extensive use of neuropeptides and volume transmitters

Control of Muscles

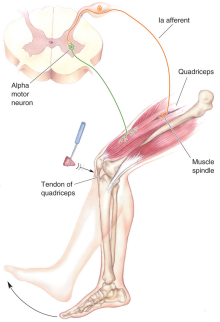
- Within muscle cells there is a rich control system
- Multiple control mechanisms operate on muscles
  - Having different effects on muscle behavior



https://droualb.faculty.mjc.edu/Lecture Notes/Unit 3/chapter_9_muscle_movement with figures.htm

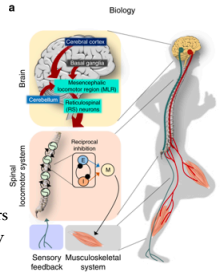
Local Muscle Control in Mammals

- The majority of the neurons innervating a muscle originate not in cortex, but more locally
- For example, the stretch reflex is due to the activity of local neurons that respond to length and tension
- When the spinal cord is transected, the stretch reflex is not lost
  - but become hyperactive as a result of loss of inhibition from higher centers



Muscles Under Control of Central Pattern Generators

- Just as in the SCN, feedback loops in central pattern generators (CPGs) create oscillations
  - These serve to coordinate individual muscles to contract in a coordinated manner
    - Sensory feedback can alter pattern generator
    - Higher control systems such the mesocephalic locomotor region (MLR) operate on pattern generators
      - These are, in turn, operated on by other brain structures



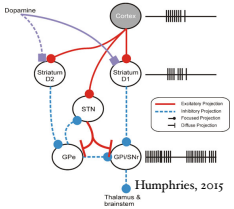
Clicker Question

What are the basal ganglia?

- A set of nuclei that are linked to each other in a manner to facilitate making decisions
- The structure in the brain that is responsible for initiating sleep
- A set of nuclei that are linked together to efficiently control neuromodulators like dopamine
- Structures found in the brains of some species that do what the neocortex does in us

Basal Ganglia: A Decision-Making Architecture

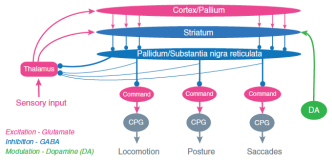
* Inputs from the thalamus and cortex arrive at the striatum
* Output regions—Substantia Nigra pars reticulata (SNr) and the Globus Pallidus internus (GPi) send inhibitory outputs by default
* D1 regions of the striatum send inhibitory signals to the SNr and the GPi, releasing their inhibition (direct pathway)
* D2 regions of the striatum send inhibitory signals to the Globus Pallidus externus, which in turn inhibits the output regions, enhancing their inhibition (indirect pathway)
* Subthalamic nucleus functions as a hyper-direct pathway, enhancing the inhibition of all outputs

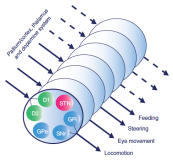


Humphries, 2015

Selecting Behaviors/ Behavioral Sequences

* The ability of decorticate animals with the basal ganglia to perform a host of activities of daily life activities suggests it is sufficient to decide on and sequence motor activities
* Different subsystems within the Basal Ganglia for different types of decisions

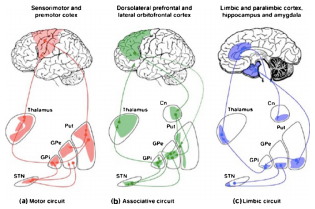




Grillner and Robertson (2016)

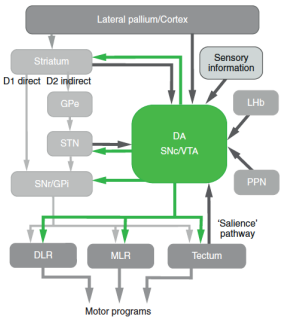
Cortical-Thalamic-Basal Ganglia Loops

- Different areas of cortex each project to a different region of the striatum
  - which then send back signals to the same region either inhibiting or letting activity in those regions continue
- Suggests that the basal ganglia is determining what information cortical areas will process



Dopamine and the BG

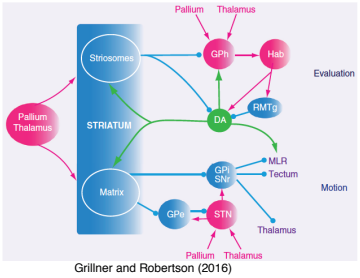
- Activity in the basal ganglia is heavily modulated by neuromodulators, especially dopamine
  - produced in the Substantia Nigra compacta (SNc) and the Ventral Tegmental Area (VTA)
- Dopamine modulates D1 and D2 receptors, affecting whether inhibition (reduced DA) or release from inhibition (increased DA) dominates
  - Overall modulator of exploration of new options vs exploitation of current ones



Grillner and Robertson (2016)

BG Control of Motion and Evaluation

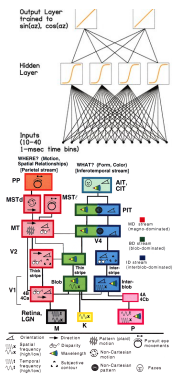
- The SNc receives inputs from numerous other structures which determine levels of dopamine, serotonin, and histamine



Grillner and Robertson (2016)

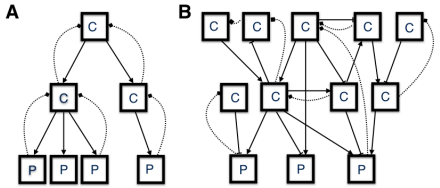
Neo-Cortex: Pattern Recognition

* Although cats and other animals can live with their neocortex cut off, it clearly plays an important role in us
  * The hierarchical, feedforward architecture of the neocortex was the model for artificial neural networks
  * Such networks are powerful pattern recognition systems
* Detecting patterns can provide information very useful for action
  * What are the objects around us?
  * What can you do with a given object
  * How could you change things to achieve a goal?
* That reasoning doesn't directly produce behavior
  * but only when it is utilized by other structures (such as the basal ganglia and the hypothalamus



Revisiting the Organization of Control

* Standard accounts of control involve a hierarchy of control mechanisms, topped by a central executive
* The brain seems to exhibit heterarchy
  * More controllers than controlled production mechanisms
  * Individual controllers work largely on their own, although they do communicate
  * There is no overall pyramid with an executive at the top



The Return of the Skin-Brain

* The skin brain provided a refocusing away from input-output processing to the role of the nerve net in jellyfish as coordinating muscle activity
  * Different input information all got put together in the skin-brain that ultimately determined behavior
* Might something like that be true of all organisms
  * Local networks that control behavior (central pattern generators) are the ultimate integrators of information
  * Different brain regions carry out specialized tasks, interacting with each other
  * But ultimately the whole package comes together at the level of the local effectors (muscles) and the networks that directly control them

Who Are We?

* We often think of ourself as a "self"—a agent that is in control of what we do
  * Where does the self reside in the brain?
* A hypothesis
  * The self is a useful fiction that we construct
    * Goals
    * Values
* This self does not exist as an entity regulating our lives
  * But we can invoke it in our reflective moments and try to life up to the goals, values, etc., that we have embraced
    * Sometimes
    * When we are reminded to do so
* Or is your professor just too cynical about the mighty capacities of our brain (cortex)?