Vision and the Brain

8:45-10:15

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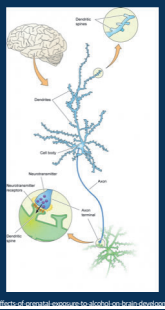
Why does/should neuroanatomy matter to the TVI, O&M, OT, PT, SLP…?

- Brain structure is intimately tied to brain function, which governs behavior
- Knowing neuroanatomy and the developmental timeline of the nervous system enables the development of appropriate assessments, and also provides a context for interpreting the outcomes and facilitates the potential effects of interventions
- Knowledge is power. The more knowledge we have, the better we can understand and serve the individuals with visual dysfunctions secondary to brain injury on your caseloads

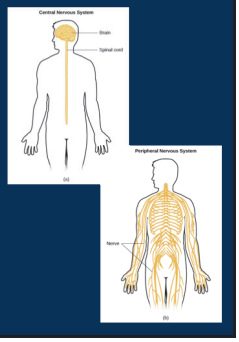
Brain Basics



https://sites.duke.edu/flasd/chapter-3-effects-of-prenatal-exposure-to-alcohol-on-brain-development-and-post-natal-function/prenatal-brain-development/

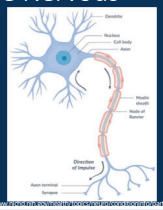
Fundamental Building Blocks of the Nervous System

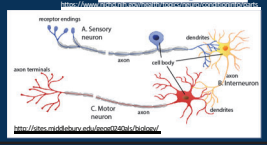
- Nervous system controls the body's response to internal and external stimuli.
  - Consists of the brain, spinal cord, nerves, and ganglia
  - Comprised of 2 main classes of cells: Neurons and Glia
- Neurons: Cells that carry and process information via a combination of electrical and chemical signals
- Glia: Support cells that outnumber neurons 10:1



Fundamental Building Blocks of the Nervous System: Neurons

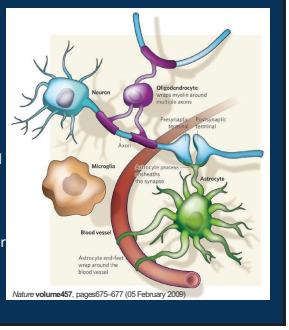
- 3 Main parts of a neuron:
  - Dendritic tree: receives input
  - Cell body: contains nucleus and sustains cell functioning
  - Axon: carries information across long or short distances to other neurons
- Classes of neurons:
  - Sensory neurons: bring information into the central nervous system (CNS)
  - Interneurons: information within the CNS
  - Motor neurons: send information from brain and spinal cord to the muscles





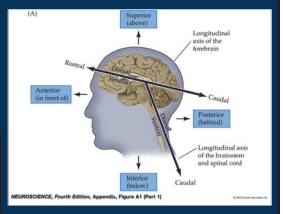
Fundamental Building Blocks of the Nervous System: Glia

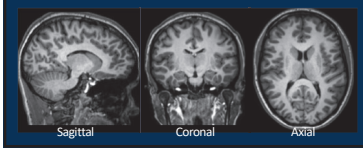
- Less is known about glia, but they play a critical role in CNS functioning
- Influence communication between neurons by modulating the chemical milieu surrounding them
- Play a role in refining connections between neurons
- During development, glia help with neuronal migration, making sure that the neurons get to their final position within the brain
- Following damage, they remove dead neurons and provide structural support
- Critical to maintaining the blood brain barrier (BBB)



Terminology/Brain Geography

- Anterior (rostral), posterior (caudal), dorsal, ventral, medial, lateral
- Sagittal, Coronal, Axial/Horizontal
- Contralateral, ipsilateral
- Unilateral, bilateral
- Proximal (near), distal (far)



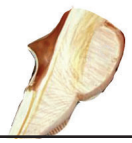


Major Subdivisions of the CNS

- Spinal Cord: sensory neurons relay information to the brain (dorsal portion) and motor commands sent to muscles (ventral portion)
- Medulla: control of basic functions (reflexes, respiration, heart rate, etc.), contains most cell bodies of the 12 cranial nerves (sensory and motor control of the head and neck), where motor pathways cross to contralateral side, reticular activating system (RAS) - important for overall arousal and attention, sleep/wake cycles

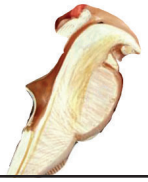
Major Subdivisions of the CNS

- Pons: connective bridge between brain and cerebellum, brain and cranial nerves. Important for some eye movements and vestibular functions (e.g. balance). Site of superior olive (auditory localization of sounds)



Major Subdivisions of the CNS

- Midbrain: orienting by sound and sight. Inferior colliculus (auditory) and superior colliculus (visual) orienting. IC and SC: relay stations for auditory and visual information – perceive and orient to large moving objects in the periphery

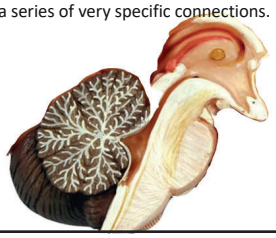


Major Subdivisions of the CNS

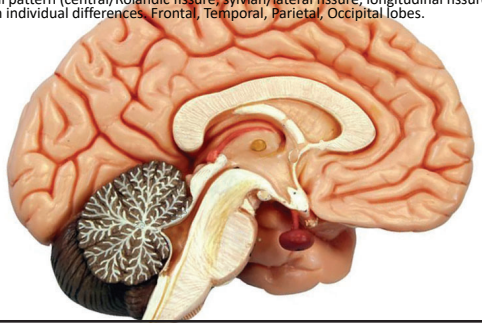
- Cerebellum: fluidity/precision of movement and regulation of muscle tone and motor guidance (punch drunk syndrome)

Major Subdivisions of the CNS

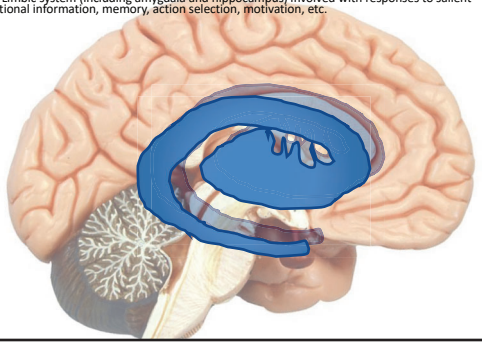
- Hypothalamus and Thalamus (diencephalon): Hypothalamus – control behaviour to maintain homeostasis/equilibrium (e.g. warmth, hunger, thirst, etc.). Thalamus – major sensory relay centre for information going to and from the cortex (gateway to the cortex) through a series of very specific connections.

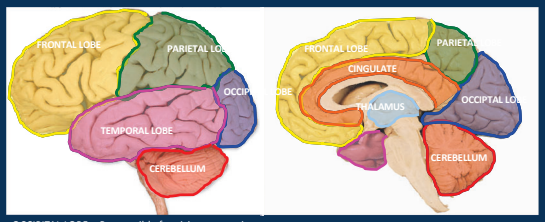


- Cerebral Cortex: exterior grey matter playing a primary role in many functions. Divided into two hemispheres, bumps (gyrus) and valleys (sulcus) cover the surface of the brain, allowing more surface area to fit inside the skull. Same basic gyral pattern (central/Rolandic fissure, sylvian/lateral fissure, longitudinal fissure), with individual differences. Frontal, Temporal, Parietal, Occipital lobes.



- Subcortical Structures: basal ganglia (motor control) and limbic system (emotions). Basal Ganglia damage often leads to involuntary movements (tremors, twisting of limbs, extra movements, etc). Limbic system (including amygdala and hippocampus) involved with responses to salient emotional information, memory, action selection, motivation, etc.





OCCIPITAL LOBE – Responsible for vision processing

TEMPORAL LOBE – Responsible for auditory processing, object identification, ventral visual stream

PARIETAL LOBE – Multimodal integration area, dorsal visual stream

FRONTAL LOBE – Higher order cognitive functions, i.e. executive function, decision making, attention, eye movements, etc.

THALAMUS – Important relay station and modulation/feedback area

CINGULATE – Part of limbic system, i.e. emotion formation and processing, learning, memory, etc.

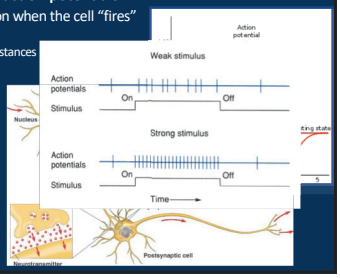
CEREBELLUM – Coordination, balance, refinement of motor control

Neurons

- Transfer information through a combination of electrical and chemical signals
- Electrical signals are in the form of **action potentials**
- Chemical signals occur via neurotransmitters
- An axon can have many branches, connecting to (synapsing with) as many as 1,000 other neurons.

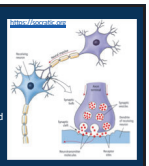
How neurons communicate: Action Potentials

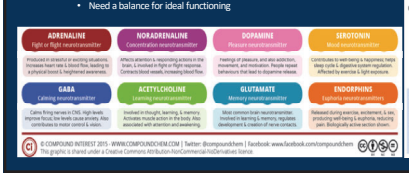
- Electrical signals are in the form of **action potentials**
  - Change in voltage within the neuron when the cell "fires"
    - Self-propagating
    - Strength remains consistent across distances
    - All-or-nothing response
  - The action potential once started near the cell body (axon hillock) is carried along the length of the axon to the terminal bouton, where the electrical signal gets transformed to a chemical signal.
  - The strength of signal comes from the rate of firing

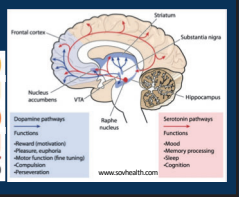


Neurotransmitters

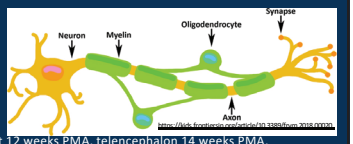
- Chemical signals occur via neurotransmitters, which are in synaptic vesicles and are released at the terminal bouton.
- These are released from the presynaptic neuron and received by special receptors on the postsynaptic neuron. This causes a chain reaction inside the receiving neuron, and the chemical signal is transformed back into an electrical signal.
- Affect neural migration and differentiation, shaping circuits throughout the CNS
- Types of neurotransmitters:
  - GABA, ACh, dopamine, serotonin, etc.
  - Some are excitatory, others inhibitory
  - Need a balance for ideal functioning







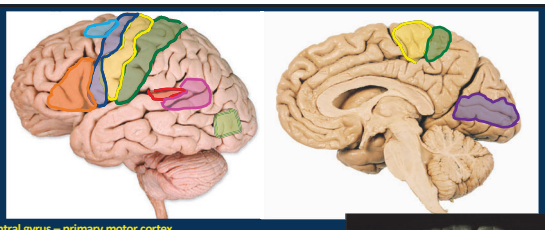
Myelin



- Myelin is a fatty sheath that surrounds and insulates the axon
- Promotes rapid and efficient impulse conduction
- Myelination begins in the spinal cord at 12 weeks PMA, telencephalon 14 weeks PMA, pre/postcentral gyri and optic radiations 35 weeks PMA, and continues throughout development (at least 4 decades)
  - Immature myelin-producing cells are vulnerable to hypoxic-ischaemic injury
- The more myelin, the faster the signal can go
  - Usually for the long distance axons, as many short axons remain unmyelinated
  - Impaired myelination can significantly impact and disrupt neural processing and the formation of neural networks
- Produced by a specific class of glia known as oligodendrocytes
- Gaps between the myelinated sections are called "nodes of Ranvier"
  - Signal "jumps" across the nodes and keep the signal constant in size as it travels down the axon
- The fat in myelin is what gives white matter its characteristic pale appearance
- A large group of axons is called a fibre tract or fasciculus (e.g. corpus callosum)

Closer Look at the Cortices and Their Functions

- Primary Cortices
  - Motor Cortex: different body parts are controlled by specific regions along the motor strip according to the Motor Homunculus
  - Somatosensory Cortex: Proprioception, pressure, pain, tactile stimulation information is received from various body parts along the cortex according to the Somatosensory Homunculus
  - Auditory Cortex: Tonotopic organization.
  - Olfactory bulb: receptors in nasal mucosa and axons travel to the olfactory bulb
  - Gustation: Taste buds are the receptors and the information is sent to the limbic system and to the insula
  - Visual Cortex: first region of the cortex to process visual information. Retinotopic organization. Damage to this region results in difficulty perceiving light-dark contrast, visual field disorders
- Association Cortices
  - Frontal Lobe: primary motor, premotor, and prefrontal regions (motor, motor planning, and higher order functions like executive function, emotional processing, decision making, etc.)
  - Parietal Lobe: integrates information from multiple sensory modalities, integrates sensory information with memories, integrates information about one's internal state with the external sensory world.
  - Temporal Lobe: regions specialized for: memory, visual item recognition, auditory processing, and emotion.

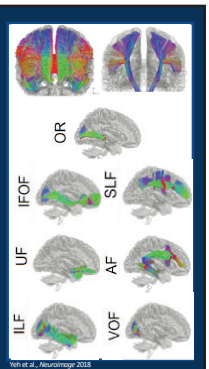


Precentral gyrus – primary motor cortex
Postcentral gyrus – primary sensory cortex
Primary auditory cortex
Pericalcarine gyrus – primary visual cortex
Supplemental motor area – motor planning
Frontal Eye Fields
Broca's area – speech/language production
Wernicke's area – interpretation, comprehension of language

Area MT - motion
Fusiform Face area
Medial Temporal Lobes (hippocampus, parahippocampus, entorhinal cortex) - memory

Main White Matter Tracts

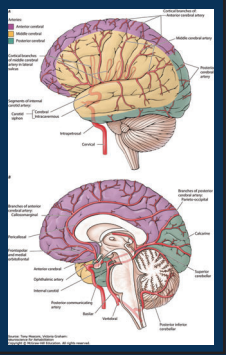
- **Corpus Callosum:** connects hemispheres
- **Corticospinal/Corticobulbar**: motor/sensory to spinal cord
- **Optic Radiations:** visual info. from thalamus to V1
- **Inferior Fronto-Occipital Fasciculus:** occipital to frontal, sensory information
- **Arcuate Fasciculus:** temporal to frontal: language
- **Uncinate Fasciculus:** frontal to anterior temporal: emotion and language
- **Inferior Longitudinal Fasciculus:** parietal/occipital to temporal: object recognition and language processing
- **Superior Longitudinal Fasciculus:** frontal to parietal: attention and executive control
- **Vertical Occipital Fasciculus:** occipital to parietal: spatial processing and attention



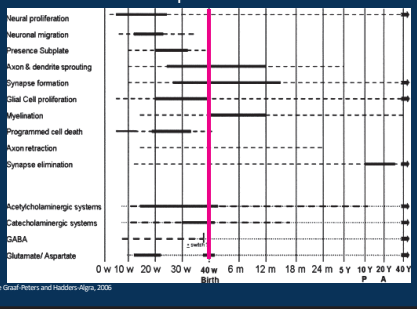
Yeh et al., *NeuroImage* 2018

Vasculature and Blood Supply

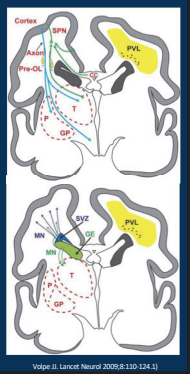
- If know the territory the blood vessel goes to, can understand where and localize the areas of the brain that may be involved
- 2 major blood supplies to the brain
  - Vertebral system
    - Up through cervical vertebra and enters through foramen magnum into cranial vault
    - Supplies the posterior fossa (cerebellum, brainstem (medulla, pons, midbrain, cranial nerves)
    - Posterior Cerebral Artery
      - Supplies inferior surface of temporal lobe (formation of new memories) and another branch supplies parietal-occipital areas (vision)
  - Internal carotid arteries
    - Up through the base of the skull and enters through the cavernous sinus, sitting beside the optic chiasm
    - Anterior Cerebral Artery
      - Supplies medial surface of brain, superior to corpus callosum, and ventral surface of frontal lobe (executive function, motor lower limb)
    - Middle Cerebral Artery
      - Supplies lateral surface of hemisphere – frontal (motor, speech production) and parietal (sensory, comprehension of speech)
- Watershed Zone
  - End vessels have the lowest amount of oxygen and blood flow and are vulnerable to anoxia
  - Between middle and anterior branches, occipital and middle cerebral artery (less involved because posterior artery also supplies)



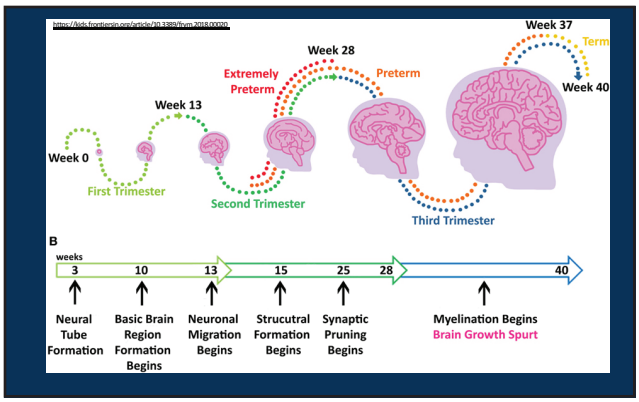
Timeline of Major Neurodevelopmental Processes



De Graaf-Peters and Hadders-Algra, 2006

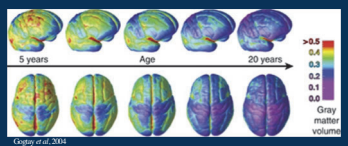


Volpe JJ. Lancet Neurol 2009;8:110-124.1)

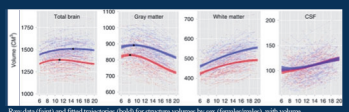


Trajectories of Brain Growth In Childhood

- Region-specific increases and decreases throughout childhood
- Primary cortices maturing first, frontal regions maturing last
- May differ between males and females



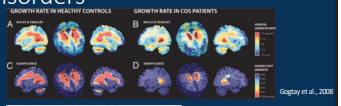
Gogtay *et al*, 2004



Raw data (faint) and fitted trajectories (bold) for structure volumes by sex (females/males), with volume peaks in age range (•). Giedd et al., 2015

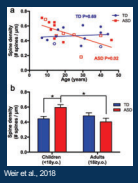
Deviations from Typical Trajectory: Evidence from Neurodevelopmental Disorders

- In child onset schizophrenia (COS), the typical increase in WM volume during adolescence is nearly completely absent, showing a loss of white matter expansion
- In children with ADHD, cortical maturation may be delayed, lagging by ~3 years, most noticeably in the prefrontal cortex
- Children with ASD demonstrate deviations from typical developmental changes in cortical thickness and dendritic spine density, with increased slope of cortical thinning and spine loss

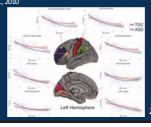


Gogtay et al., 2008

Shaw et al., 2010



Weir et al., 2018



Zielinski et al., 2014

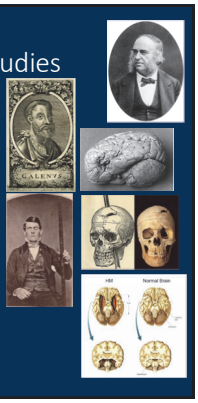
Consequences of neurodevelopmental timeline

- Adult-like brain structure and organization does not occur until 3rd decade, thus there is an age-specific nervous system
- Need evaluations that are adapted to these age/development-specific characteristics
- Injury may have age-dependent outcomes
  - In adults, stroke often results in specific symptoms e.g. in left motor cortex would lead to impairment of the motor functions on the right limbs
  - In infants, the same pattern of stroke has more varied, generalized, and less specific dysfunctions
    - Generalized hypotonia, hypertonia, hypokinesia, hyperexcitability syndrome, abnormal general movements, or no clinical abnormality
- Difficult to predict outcomes following early developmental brain injury
  - Dysfunctions may improve over time
    - E.g. acuity improving over time in CVI
  - Dysfunctions may only appear with increasing age, once the complexity of the task and functions increases
- Windows of specific vulnerability whereby adverse outcomes may be more likely
  - Vulnerability of brain areas following hypoxic-ischemic injury shows different patterns in preterm (periventricular region) vs. term infants (cortical areas, thalamus, basal ganglia, and brainstem)
  - Exposure to radiation differential effects depending on PMA at exposure
    - Hiroshima and Nagasaki – most detrimental impact on mental outcomes when exposed between 10-17 weeks PMA
- Optimal timing for different types of early intervention??
  - E.g. Effective interventions prior to term age may be different from those at team equivalent age

Methods for Studying the Brain

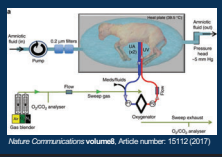
Neuroscience Methods: Lesion Studies

- The concept that the brain was linked to mental functions dates back to Roman times and a physician named Galen. He noticed that gladiators who sustained injury to the head or brain did not retain their power of thought, whereas those with injury to other parts of the body did.
- **Lesion studies** assume that damage to a particular brain region results in impairment in specific mental functions (localization of function). Allows for cause and effect.
  - Some famous examples:
    - 1860s, Paul Broca had a patient nicknamed "Tan" who had difficulty with speech output due to brain damage, while he had intact language understanding. At autopsy, damage to a specific frontal area was observed
    - Phineas Gage
    - WWI and WWII veterans sustaining head wounds with localized lesions
    - Milner colleagues and patient HM
  - Limitations of the lesion method:
    - Individual cases rather than larger groups
    - Can only observe the absence or impairment of function without that area
    - May underestimate the importance of a brain region – individual may develop compensator strategies, reorganization of function, etc.

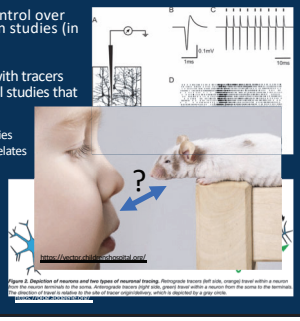


Neuroscience Methods: Animal Models

- **Animal Models** allow for better control over experimental variables than human studies (in many cases)
  - Single cell recordings
  - Studies on neuronal connectivity with tracers
  - Controlled lesion or developmental studies that would be unethical in humans
  - Limitations:
    - Not necessarily the same across species
    - Difficult to measure behavioural correlates



Nature Communications volume8, Article number: 15112 (2017)



Neuroscience Methods: Neuroimaging

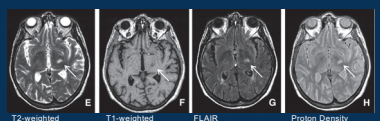
- Structure:
  - Ultrasound
  - X-ray
  - Computed tomography (CT)
  - Magnetic Resonance Imaging (MRI)
- Function:
  - Positron Emission Tomography (PET) and Single Photon Emission Tomography (SPECT)
  - Functional Magnetic Resonance Imaging (fMRI)
  - Electroencephalography (EEG)
  - Magnetic encephalography (MEG)
  - Near Infrared Spectroscopy (NIRS)
- Targeted molecules:
  - Relaxometry and Myelin Water Fraction
  - Magnetic Resonance Spectroscopy (MRS)
  - PET and SPECT

Important things to keep in mind with neuroimaging techniques

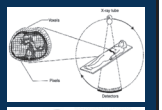
- **Signal-to-Noise Ratio**
  - Signal from the tissue of interest compared to signal from random noise
- **Tissue Contrast**
  - How well different tissues can be differentiated
- **Spatial Resolution**
  - How well two points in space can be discriminated
- **Temporal Resolution**
  - How well two points in time can be discriminated
- What are the different trade-offs between different modalities?

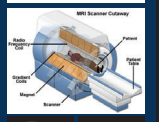
Neuroimaging Methods: Brain Structure

- Computer (Assisted) Tomography (CT/CAT)
  - 3-dimensional X-ray
  - Brightness corresponds density of tissue to x-rays
    i.e. bone = bright; soft tissue = shades of gray
- Magnetic Resonance Imaging
  - Can manipulate the pulse sequence to be better tuned to different aspects of the tissue



T2-weighted T1-weighted FLAIR Proton Density



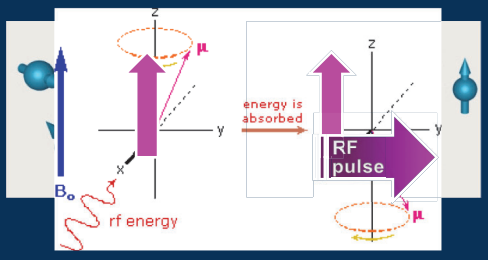


Yi-Cheng Zhu et al. Stroke. 2011;42:1140-1145

http://www.physicscentral.com/explore/action/scans.cfm

http://www.magnet.fsu.edu/education/tutorials/magnetacademy/mri/fullarticle.html

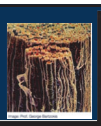
Magnetic Resonance Imaging

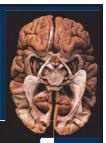


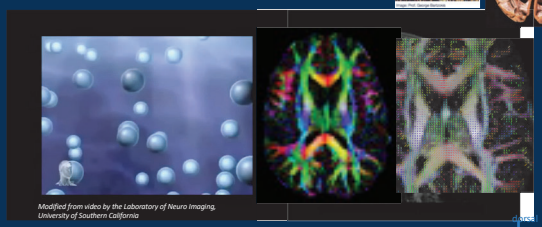
http://www.mridoc.com/physics/

http://web2.uwindsor.ca/courses/physics/high_schools/2006/Medical_Imaging/mriphysics1.html

Imaging White Matter Pathways: Diffusion







Modified from video by the Laboratory of Neuro Imaging, University of Southern California

Not all diffusion MRI is created equal

Diffusion Weighted Imaging (DWI) & Diffusion Tensor Imaging (DTI)

High Angular Resolution Diffusion Imaging (HARDI)

Diffusion Spectrum Imaging (DSI)

Diffusion Kurtosis Imaging (DKI)

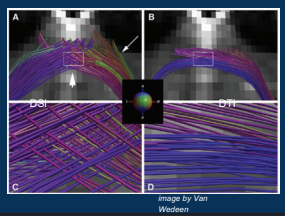
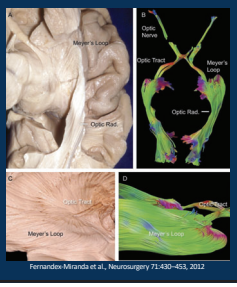


image by Van Wedeen



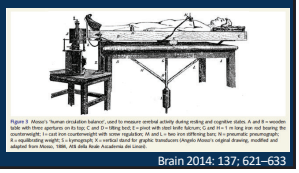
Fernandez-Miranda et al., Neurosurgery 71:430–453, 2012

- ***Structural neuroimaging*** deals with visualizing structure (e.g. shows contrast between different tissues: cerebrospinal fluid, grey matter, white matter, etc.).

- ***Functional neuroimaging*** deals with measuring brain function (neural activity) associated with performance on a particular mental/behavioral task (directly or indirectly).

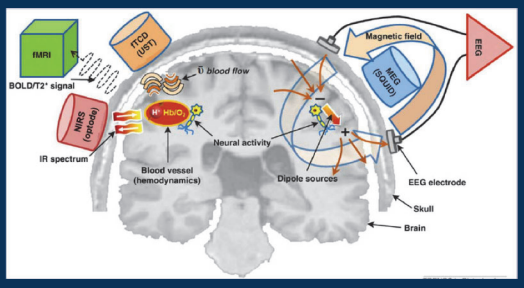
Neuroimaging Methods: Brain Function

- 1890: Charles Smart Roy & Charles Scott Sherrington suggest link between brain circulation and metabolism
- 1870/80s: Angelo Mosso established the conceptual basis of non-invasive functional neuroimaging techniques
- Plethysmograph could measure cerebral blood flow variations in patients with skull defects
- Human circulation balance enabled change in circulation to be measured in subjects with intact skulls
  - Critical variables relevant to modern neuroimaging identified:
    - Signal to noise ratio, appropriate experimental paradigm, need for simultaneous recording of different physiological parameters, control for confounding variables (head motion, breathing, etc.)



Brain 2014: 137; 621–633

Neuroimaging Methods: Brain Function



http://dx.doi.org/10.1016/j.tibtech.2010.08.002

Functional magnetic resonance imaging

Indirect measure of brain function based on activity-dependent changes in regional blood flow

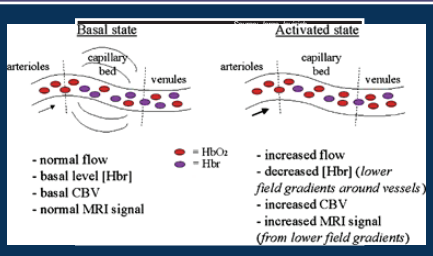
The BOLD (Blood Oxygenation Level Dependent) contrast measures inhomogeneities in the magnetic field due to changes in the level of oxygen in the blood.

Deoxygenated blood is paramagnetic distorts the surrounding magnetic field
→ signal loss

BOLD signal

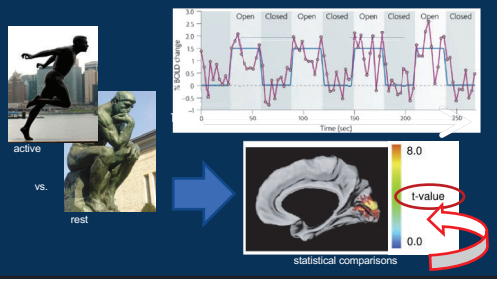
Blood Oxygen Level Dependent signal

↑neural activity → ↑blood flow → ↑oxyhemoglobin → ↑T2* → ↑MR signal

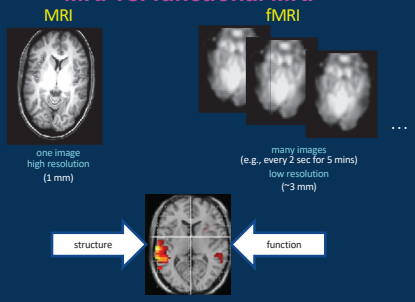


Functional task/state comparisons and statistical analyses

- statistical images are generated that identify activated brain structures (i.e. associated) with the performance of a given task performed.



MRI vs. functional MRI



fMRI has come to dominate the brain mapping field due to its low invasiveness, lack of radiation exposure, and relatively wide availability.

Neuroimaging: Limitations

- Can be difficult to determine causality
- Limited spatial and/or temporal resolution
- Cost
- Time
- Access

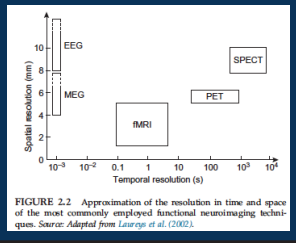
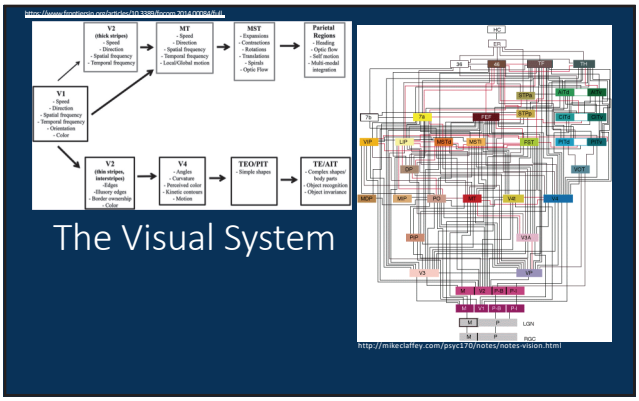


FIGURE 2.2 Approximation of the resolution in time and space of the most commonly employed functional neuroimaging techniques. *Source: Adapted from Laureys et al. (2002).*



The Visual System

http://mikeclaffey.com/psyc170/notes/notes-vision.html

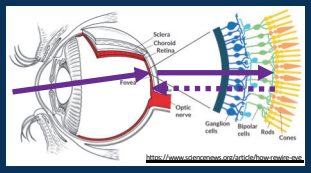
Development of the Vision

Age	Functions/capacities
Birth	Blinks (rapid closing and opening of the eye lids) Slow pupil responses to day light Very limited accommodation Visual acuity ~ 20/150 Responses to light, motion, and colour Oculomotor scanning of the visual environment in ~ 5–10 % of waking time Oculomotor scanning and searching movements for e.g. Light stimuli or contours within a radius of about 45°
M 1–2	Threshold for light detection decreases, visual acuity increases Oculomotor scanning and searching eye movements within a radius of 60–90° Increase in precision of smooth pursuit eye movements Incipient binocular vision starting at about 6 weeks
M 2–4	Increase in accommodation power Conjugate eye movements in all directions Eyelids close when stimuli (e.g. hand movements) appear suddenly before the eyes Oculomotor scanning of the visual environment in ~ 30–40 % of waking time Oculomotor scanning and searching eye movements within a radius of 180° Baby observes his own hand(s) when manipulating objects Baby shows defense reactions for objects approaching in collision course
M 4–6	Visual acuity increases further Binocular vision is established Visual identification/recognition of particular objects and faces/persons possible
M 6–12	Visual acuity is 20/100 Baby avoids visual depth

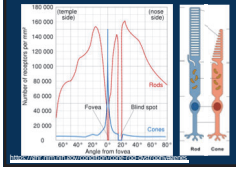
Zihl and Dutton. Modified after Bronn and Goldman (1980)

The Visual System

- Light passes through cornea and is focused by the lens onto the retina
- Photoreceptors - rods and cones
  - Converts light into neural signals
  - Greatest density in fovea
- Bipolar cells - transmit signal from photoreceptors to retinal ganglion cells
- Ganglion Cells - long axons for the optic nerve and carry visual signal to the brain



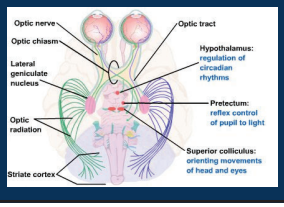
https://www.sciencenews.org/article/how-rewire-eye



	Rod Cells	Cone Cells
Location in retina	Found around periphery	Found around centre (fovea)
Optimal light conditions	Dim light ('night' vision)	Bright light ('day' vision)
Visual acuity	Low resolution (many rods : one bipolar cell)	High resolution (one cone : one bipolar cell)
Colour sensitivity	All wavelengths	Certain wavelengths (red, green, blue)
Type of vision	Achromatic (black and white)	Colour
Number of types	One (all contain rhodopsin)	Three different iodopsin pigments
Relative abundance	Many	Fewer

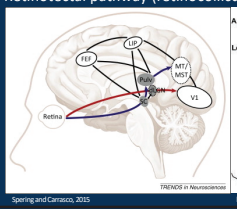
Optic Tract

- Axons in optic tract terminate in four locations in the brain
  1. Lateral geniculate nucleus (thalamus) – visual perception
  2. Superior colliculus (midbrain) – control of eye movements
  3. Pretectum (midbrain) – pupillary light reflex
  4. Hypothalamus – circadian rhythms

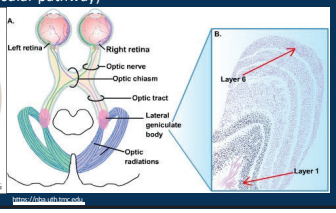


Visual Pathways

- Retinogeniculostriate Pathway
  - Parvocellular: sensitive to colour, high contrast, high spatial frequency, low temporal frequency
  - Magnocellular: insensitive to colour, low luminance, low spatial frequency, high temporal frequency
- Retinotectal pathway (retinocollicular pathway)



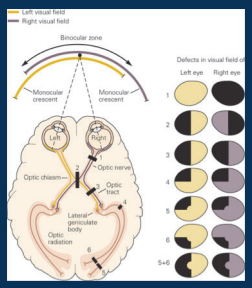
Spering and Carrasco, 2015



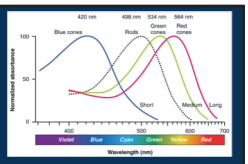
https://ohsu.edu.ca/s...

Visual Field Deficits: Relationship to Lesion Location

1. A lesion of an optic nerve causes a total loss of vision in one eye.
2. A lesion of the optic chiasm causes a loss of vision in the temporal half of each visual hemifield (bitemporal hemianopsia).
3. A lesion of the optic tract causes a loss of vision in the opposite half of the visual hemifield (contralateral hemianopsia).
4. A lesion of the optic radiation fibers that curve into the temporal lobe (Meyer's loop) causes loss of vision in the upper quadrant of the contralateral visual hemifield in both eyes (upper contralateral quadrantic anopsia).
5. Partial lesions of the visual cortex lead to deficits in portions of the contralateral visual hemifield. For example, a lesion in the upper bank of the calcarine sulcus (5) causes a partial deficit in the inferior quadrant, while a lesion in the lower bank (6) causes a partial deficit in the superior quadrant. The central area of the visual field tends to be unaffected by cortical lesions because of the extent of the representation of the fovea and the duplicate representation of the vertical meridian in the hemispheres.



Visual Processing: Colour

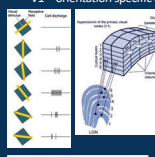


- Colour is coded at several levels in the visual system
  - Cones in the retina
  - Parvocellular layers of the LGN
  - Striate, extrastriate (V2, V3), V4, and anterior regions
- Humans have a 3-cone system, whereby each cone type is most sensitive to a certain range of wavelengths of light
  - Short (S cones): blue, fewest, absent in fovea
  - Medium (M cones): green, equally distributed with L cones
  - Long (L cones): red, equally distributed with M cones
- V1: colour blobs (contrast and size invariant, not orientation specific)
- V2: colour processed in interstripes
- V4: hue that is unaffected by luminance and not limited to colours along cardinal colour axes (e.g. red-gree, blue-yellow), as seen in V1
  - Center-surround interactions produce encoding of perceived colour, rather than physical colour
  - First representation of perceive colour
- In humans: 2 regions sensitive to colour information: V4 – retinotopically organized (Bartels and Zeki, 2000) and V4alpha (not retinotopically organized)

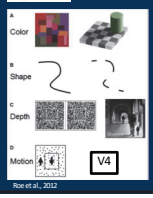
Visual Processing: Form

- Orientation selectivity in V1
  - Retinal and geniculate cells respond to all orientations, but many cells in V1 are orientation specific (video of Hubel and Weisel cat experiment)
- Input to layer 4C of V1 mainly from parvocellular layers of LGN with additional magnocellular input
- V2: Sensitive to orientation of edges as defined by illusory contours or texture
  - Starting pout of contour-based object representation
- V4: combines multiple spatially-adjacent, orientation responses from V1 and V2 to encode angles and curvatures
  - Colour and lightness constancy
  - Shape (curvature)
  - Depth (binocular correspondence, size constancy)
  - Motion-defined shape
- Inferior Temporal Cortex:
  - Specialized areas for representations and recognition of object, complex shapes, body parts, etc.
  - Position and size invariant
  - Invariant to luminance, texture, and relative motion

V1 – orientation specific cells

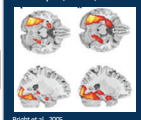


V2 – edges, illusory contours



Roe et al., 2012

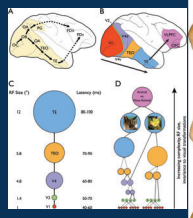
Inferior Temporal Lobe: Identification of objects, shapes, faces, etc.

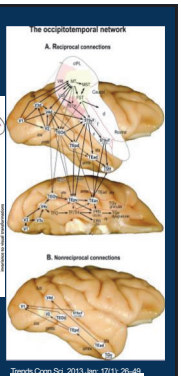


Bright et al., 2005

Ventral Stream Anatomy

- Many areas involved with object recognition, forming a complex network of feed-forward and feed-back projections
- Processes form and colour, integrating the information into intermediate and full object representations, culminating with object recognition
- Cells along the ventral stream fire to increasingly complex and specific stimuli.
- Receptive fields become correspondingly larger, which enables objects to be identified regardless of its size or location in space

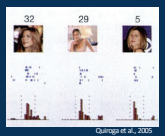




Trends Cogn Sci. 2013 Jan; 17(1): 26–49.

Object Recognition

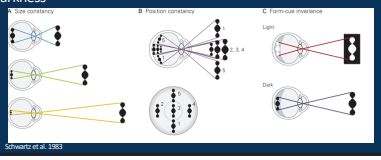
- Two main theories for how individual cells in the ventral stream code for objects
  - Sparse coding: a small specific group of cells responds to the presence of a particular given object in our perception (e.g. Jennifer Aniston cell, grandmother cell)
  - Population coding: the pattern of activity of a large group of cells codes for individual objects (e.g. pattern of activity across cells differs based on object)
    - More resilient to injury or damage
- Likely that both systems are used, rather an either extreme, with populations cells in somewhat localized regions being more tuned to types/categories of stimuli (e.g. tools, houses, animals, etc.)



Quiroga et al., 2005

Inferior temporal cortex properties

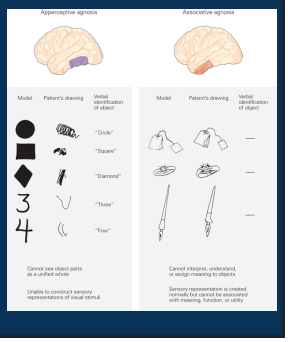
- Many cells in inferior temporal lobe are selective for certain types of stimuli (e.g. preferentially respond to objects, faces, etc.)
- The are also *invariant* to object size, position, and reflectance.
  - Size constancy: Perceive an object as the same even when retinal image size decreases with the distance of the object
  - Position constancy: Perceive an object as the same despite change in position on the retinal
  - Form-cue invariance: Perceive an object the same despite changes in light/darkness



Schwartz et al. 1983

Agnosias

- Impairments in object identification/recognition are known as agnosia
- Apperceptive: difficulty forming a mental impression, such that the data cannot be put together to allow the person to perceive a meaningful whole
  - Associated with diffuse occipital damage
- Associative: perceptual knowledge cannot be linked to stored knowledge
  - Can perform copying tasks, but are slow and do a point-by-point comparison, rather than perceiving an entire form
  - Often best at recognizing real object, then photographs, and worst with line drawings
  - Errors are often related to visually similar items (e.g. baseball bat called a paddle)
  - Associated with more localized damage to bilateral occipitotemporal border



Kandel et al., 2013

Top-down guidance of object recognition

- Higher-order representations of objects can influence how our visual system perceives stimuli (e.g. top-down control)

Porter 1954

Developmental changes in object recognition areas

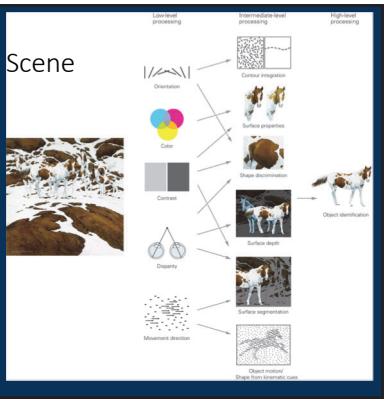
- Lateral occipital complex (LOC) involved with perceptual constancy and form-cue invariance
  - shapes > textures,
  - size and location independent,
  - line drawings = photographs,
  - not selective for particular category
- Invariance for viewpoint develops between 5-10 years of age, while size invariance develops earlier

Lateral Occipital Complex
Adults, Adolescents, & Children

Nishimoto et al., 2015

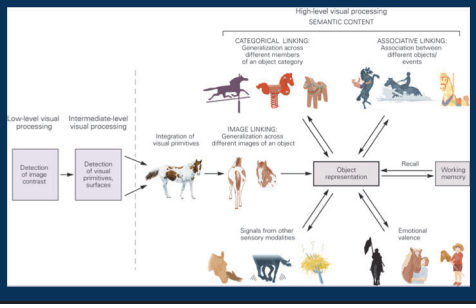
Processing Visual Scene

- Low-level
  - Orientation
  - Colour
  - Contrast
  - Disparity
  - Movement
- Mid-level
  - Contour integration
  - Surface properties
  - Shape discrimination
  - Depth
  - Segmentation
  - Object motion/shape from kinematic cues
- High-level
  - Object identification



Kandel et al., 2013

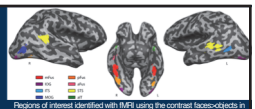
Object Representation: Beyond Vision



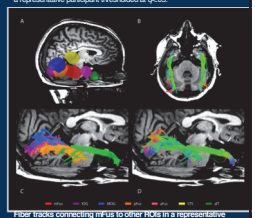
Kandel et al., 2013

Face Recognition

- Network of brain areas particularly sensitive to faces compared to other types of stimuli
  - Main area is the fusiform face area (FFA), although a network of other areas is also involved
  - OFA – occipital face area – earlier stages of perceptual face processing (e.g. parts of face)
  - FFA – later stages, e.g. configuration of parts into a whole face
  - STS – superior temporal sulcus – changeable aspects of face (e.g. gaze, expression, lip movement, etc.) – social significance
  - Right anterior fusiform – identifying specific faces
- Face processing involves many brain regions and sub-processes. In prosopagnosia, some face processes may be intact
- Is it a face? Old/young? Male/female? Emotion being expressed?
- Whole face versus parts of face
- Encoding of the face to memory or retrieval from memory stores?



Regions of interest identified with fMRI using the contrast faces>objects in a representative participant thresholded at $q<.05$.

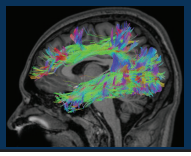


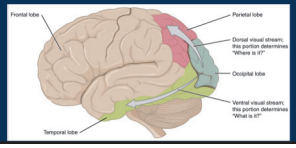
Fiber tracks connecting mFus to other ROIs in a representative participant. *a*, Expanded right-hemisphere ROIs rendered in 3D space with a high-resolution T1 anatomical co-registered to the diffusion data in the background. *b*, Fiber tracks connecting bi-lateral mFus to hemisphere respective ROIs shown from above. *c*, Fiber tracks connecting mFus-R to other ROIs with streamlines colored to correspond to the target ROI. *d*, The same fiber tracks as in *c* colored to indicate local directional information.

*https://doi.org/10.1371/journal.pone.0061611

Dorsal Stream Anatomy

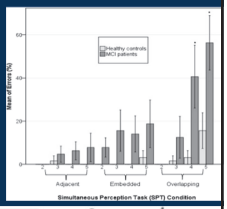
- Specialized for motion and spatial processing
- Involves connections from visual cortex to multisensory areas in the posterior parietal cortex and frontal lobe
  - Supports spatial working memory, visually guided actions, spatial navigation, motion perception, etc.
- Cells are not very sensitive to form or colour

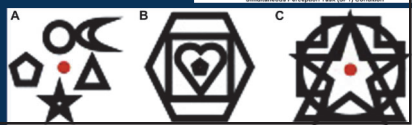




Simultaneous Object Perception

- Visual system is able to perceive multiple objects at the same time
- When patients have damage to the posterior parieto-occipital lobes, this ability may be impaired, resulting in simultanagnosia
- Simultanagnosia – the restriction of visual attention such that the individual is only aware of one object at a time

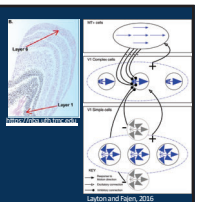




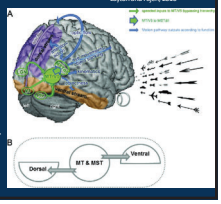
Ruiz-Rizzo et al., 2017

Motion Perception

- Magnocellular cells in the retina and LGN provide input to motion processing areas of dorsal stream
  - Sensitive to low luminance, lower spatial, and higher temporal frequencies
  - Not sensitive to colour
- V1 complex cells are sensitive to motion of oriented moving edges, bars, or gratings
  - Selective to direction, speed, and local motion
- MT receives input from V1, thalamus, and superior colliculus
  - Sensitive to direction, speed, and spatial frequency
  - Processing of both local and global 2D motion
  - Not colour selective
- MST: Implicated in processing complex 3D and self-motion
- Posterior Parietal Cortex: more complicated optic flow and self-motion, e.g. motion of objects while the viewer is also moving

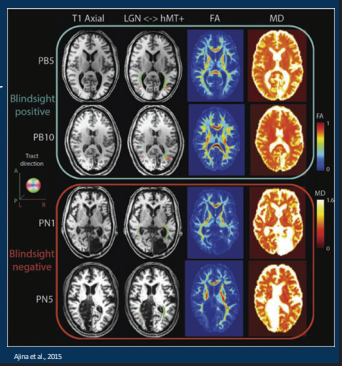


Layton and Fajen, 2016



Blindsight

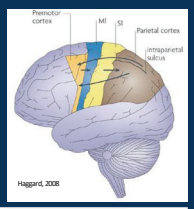
- Ability to see moving stimuli or navigate around objects without conscious perception of objects when no movement
- May be mediated by a direct LGN to MT pathway



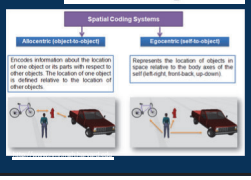
Ajina et al., 2015

Spatial Processing

- Representation of object location in 3-dimensions with reference to eyes, body, or external reference point
  - Trajectory as moving through space
  - Important for accurate reach, grasp, movement through space, etc.
- Left-right spatial coding disrupted by lesions to occipito-parietal boundary
- Depth perception
- Frames of reference: Allocentric vs. egocentric
  - Subserved by different neural networks
  - Allocentric: dorsal and ventral streams
  - Egocentric: dorsal stream (occipito-parietal areas)
- Left hemisphere – more serial processing
  - Egocentric navigation
- Right hemisphere – more global, holistic processing
  - Map-based, allocentric navigation

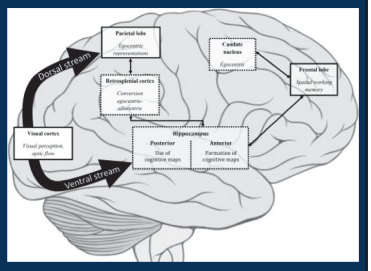


Haggard, 2008



Spatial Navigation

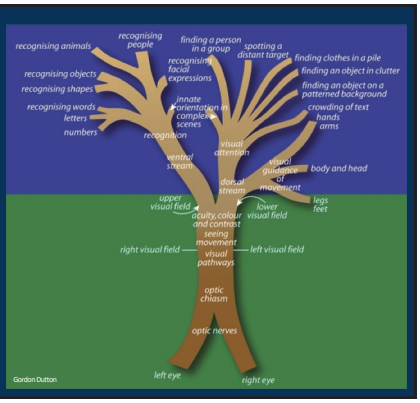
- Multiple areas involved with spatial navigation:
  - PPA – parahippocampal place area – recognizing landmarks for navigation
  - Retrosplenial cortex – codes for space in multiple reference frames, memory retrieval regarding location in the environment
  - Medial temporal lobe – hippocampal place cells code for location within an environment; grid cells in entorhinal cortex respond to several spatial locations in a grid-like pattern



Lithfous et al., 2013

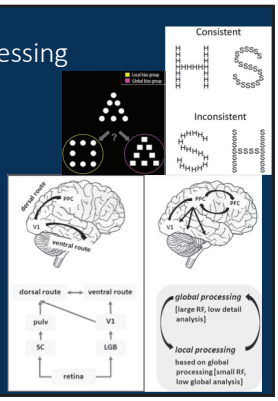
Dorsal Stream Dysfunction

- A common outcome following posterior parietal lobe damage
- Can manifest in multiple ways



Local vs Global Visual Processing

- Gestalt processing develops after 10 months
- Children younger than 6 prefer local visual information
- Around 6 years of age, this switches to a preference for global visual information



Brain pathways for global–local visual processing. (a) Normal hierarchy bottom-up pathways from the eye to the dorsal and ventral visual processing streams. SC superior colliculus (midbrain), pulv the pulvinar (posterior thalamus), LGB (lateral geniculate body), V1 visual area 1 (striate cortex). PPC posterior parietal cortex. (b) Reversed hierarchy pathways reaching first PPC for global processing (based on large receptive fields (RF) of neurons for coarse analysis), which guides subsequently local processing in the ventral route (based on smaller receptive fields of neurons for fine analysis) (Zihl and Dutton, Modified after Hochstein and Ahissar 2002)

Something to think about during the break

- How might brain injury/damage/dysfunction impact brain development?
- How might the alterations in brain development influence visual processing?

Some Resources

- https://neurologicexam.med.utah.edu/adult/html/brain-dissections.html#01
- https://www.youtube.com/channel/UC-_JaCxgqtv-4ugFhpPYkZg
- https://www.ulster.ac.uk/research/topic/biomedical-sciences/research/optometry-and-vision-science-research-group/vision-resources/resources-for-professionals/cerebral-visual-impairment-assessment
- https://www.teachcvi.net/
- https://www.youtube.com/watch?v=9wvGZiTDwa8&fbclid=IwAR3tatBKTTVz4_kjpr7c-7IztgJHtFrQxl41sA7SQA45tpWr97XzixBe5WI