‘Brain Storm’

Neuroanatomy Interprofessional Refresher Course

Professional and Clinical Development Series

School of Rehabilition Therapy

Queen's University

STROKE NETWORK of Southeastern Ontario

Neuroanatomy Workbook by Devon Brisson, 2012

Brain Storm

Workshop Outline

8:45-9:00	Registration
9:00-9:05	Welcome and Introduction
9:05-10:00	Neuroanatomy Review – Devin Brisson PhD (c)
10:00-10:15	Break
10:15-12:15	Hands on learning modules • Module 1 - Dissection • Module 2 – Structural Review • Module 3 – Cranial Nerves/Long Tracts • Module 4 – Sensory System • Module 5 – Motor System • Module 6 – Cortex/Limbic/Autonomic System
12:15-1:00	Lunch
1:00-2:00	Hands on learning modules
2:00:-2:45	Case Review – Dr. Gord Boyd
2:45-3:00	Closing

Note: 30 minutes is allocated to each hands-on learning module. Each station is led by an anatomy educator.

Speaker Biographies

Devin Brisson graduated from Queen's University in 2007 with a Bachelor's degree in Biochemistry. Devin then pursued a Master's degree in Anatomical Education at Queen's, where he gained experience lecturing at both the graduate and undergraduate level. Devin is currently in the final year of this Ph.D. in the department of Biomedical and Molecular Sciences, where he conducts stroke research.

Dr. Gord Boyd received his undergraduate degree in Psychology from Lakehead University in Thunder Bay. He moved to Edmonton to complete a PhD in Neuroscience, which was followed by a post-doctoral fellowship in Neuroanatomy at Queen's University. He completed his medical degree at Queen's University. Dr. Boyd began his critical care fellowship July 1st, 2011.

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MODULE #1

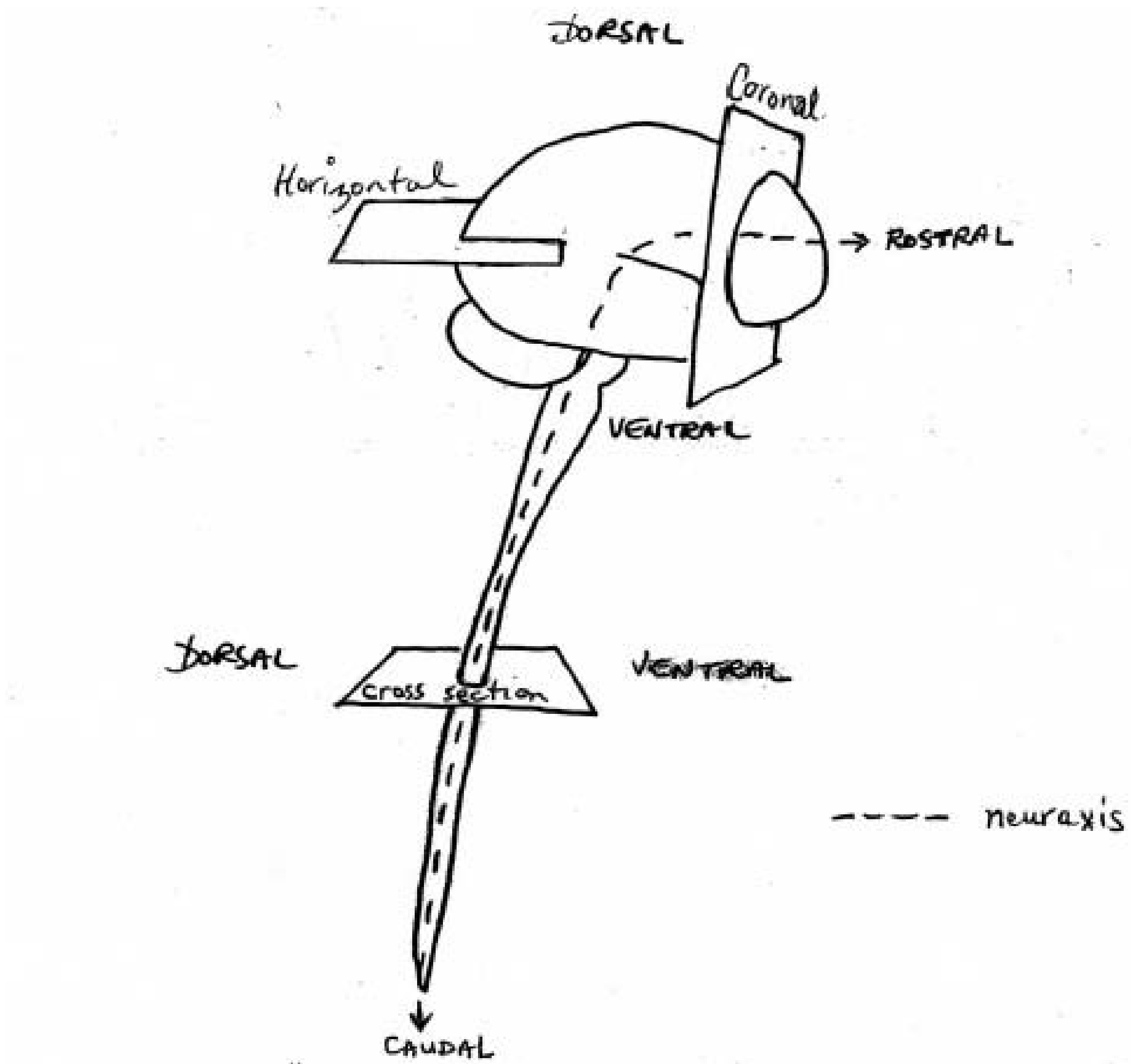
Dissection Notes

MODULE # 2

Structural Overview of the CNS

Anatomical orientation of the CNS

The following diagram summarizes the anatomical orientation of the CNS. Note the ~90^0 curvature of the neuraxis. In quadrapedal animals, this curvature is not present. Much of the terminology like ventral (L. belly), dorsal (L. back), rostral (L. beak) and caudal (L. tail), has been adopted from our quadrapedal ancestors.



Brain divisions of the CNS

Below is a review of the seven brain divisions of the CNS. Note that the CNS originally started out as a long tube similar in structure to the spinal cord with a central canal. The rostral end of the CNS however underwent a number of swellings and folds generating the following brain divisions. Try and identify the following brain divisions and their borders using the specimens and models provided, along with any characteristic surface landmarks.

1. Spinal Cord
2. Medulla
3. Pons
4. Cerebellum
5. Midbrain
6. Diencephalon
7. Cerebral Hemispheres (Telencephalon)

N-12 **Spinal Cord**
Dura □ Denticulate ligament □ Conus medullaris □ Cauda equine □

N-18 **Brainstem:**
Midbrain □ Pons □ Medulla oblongata □ Cerebellum □
Beginning of spinal cord with its central canal □

N-29 **Medial View:**
Midbrain □ Pons □ Medulla oblongata □ Cerebellum □ Corpus callosum: rostrum □, genu □ , body □, splenium □ Septum pellucidum □ Diencephalon: thalamus □ & hypothalamus □ Calcarine sulcus □ Parieto-occipital sulcus □

N-20 **Anterior and Lateral Views of Brainstem:**
Midbrain □ Pons □ Medulla Oblongata □

Questions

- What structure demarcates the anterior border of the diencephalon? What is the embryological significance?
  How can you identify the anterior surface of the spinal cord?
- What landmark distinguishes the medulla from the spinal cord?
- What are the primary functions of the brainstem?
- Name a prominent surface landmark of the posterior midbrain? Anterior midbrain?

C-shaped brain structures

During brain development the rostral end of the neural tube ends at the lamina terminalis of the diencephalon. The lateral ventricles then expand along with the accompanying cerebral hemispheres (telencephalon) with its axis centered about the insula (L. island). A number of C-shaped brain structures develop as a result, many of which come to lie alongside the lateral ventricles.

Build a brain model

In this next exercise try and use the accompanying figures, specimens, cross-sections and rubber brainstem to build a brain model of the various C-shaped and associated structures surrounding the ventricles, using modeling clay and the ventricular casts provided.

- Hippocampus and fornix (main white matter output tract of the hippocampus)
- Caudate nucleus
- Putamen
- Globus Pallidus
- Internal capsule
- Amygdala
- Thalamus

Questions

- Which basal ganglia nucleus is connected to the most anterior end of the caudate nucleus? What structure separates these nuclei postereiorly?
- Where is the globus pallidus located with respect to the internal capsule?
- What structure forms the floor of the 4th ventricle? Roof?
- What structure lies in the inferiomedial border of the inferior horn of the lateral ventricle?
- Which nuclear structure is located adjacent to the tail of the caudate?

Ventricular system

The ventricles are cavities within the brain formed from the neural tube during development. The ventricles contain cerebrospinal fluid (CSF). Using the ventricular casts, try and identify the following structures:

- Lateral ventricles
    - Anterior horn
    - Inferior horn
    - Atrium
    - Posterior horn
- Interventricular foramina (of Monro)

Ventricular Component	Is it a paired structure?	Surrounding brain division or lobe
1. central canal of spinal cord		
2. fourth ventricle		
3. cerebral aqueduct		
4. third ventricle		
5. lateral ventricle • anterior horn • body • posterior horn • inferior horn		

- Thrid ventricle
- Cerebral aqueduct (of Sylvius)
- Fourth ventricle
- Foramina of Luschka
- Fromaen of Magendie
- Central Canal
- Interthalamic adhesion

N-57

Lateral ventricles □ - anterior horn □ posterior horn □ body, □ Choroid plexus in body of lateral ventricles □ Thalamus □ Septum pellucidum □ Corpus callosum – genu, splenium □ Interventricular foramen (of Monroe) □

N-19 Posterior view:

Third ventricle □ Cerebral aqueduct □ Thalamus □ Floor of fourth ventricle □

<u>Questions</u>

- What are two functions of the cerebral spinal fluid?
  Where is cerebral spinal fluid produced?

- Describe the direction of cerebral spinal fluid through the ventricles?
  Where does cerebral spinal fluid exit the ventricles to enter the subarachnoid space?

Meningies

The meningies consist of the following three layers:

- **Dura mater** (L. tough mother): consists of two layers in the brain (only one in the spinal cord!)
  - Periosteal layer (next to bone) *Note this is not continuous in the spinal cord creating a 'real space' the epidural space, which is filled with fat. This is the site of injection of an epidural, that is usually administered in the lumbar region below the level L1/L2or the termination of the spinal cord.*
  - Meningial layer (spits to form venous sinuses). Some notable infoldings:
    - Falx cerebri
    - Flax cerebelli
    - Tentorium cerebelli

- **Arachnoid** (Gr. spider's web) **mater:** is adhered to the overlying dura and contains web-like extentions that connect to the underlying pia, creating the subarachnoid space that contains cerebral spinal fluid and numerous brain vessels.
- **Pia mater** (L. tender mother): forms a thin barrier that adheres to the brain. As blood vessels penetrate the brain from the surrounding subarachnoid space, they are enveloped by pia mater, thereby maintaining the blood-brain barrier. Note that the pia mater is not usually discernable from brain tissue except in the spinal cord as denticulate (L. tooth-like) ligaments.

***Clinically**, as cerebral veins (aka bridging veins) bridge the space between the arachnoid and dura mater, to enter the venous sinuses, a rupture or hemorrhage can occur, creating a potential space known as a subdural hemorrhage. Note that a suduarl hemorrhage usually involves venous blood. If the hemorrhage occurs within the subarachnoid space, a subarachnoid hemorrhage develops.*

Using the following diagram, identify the meningial layers and subarachnoid space. Note the location of the brain vessels.

H-23 Meningies
Falx cerebri □ Tentroium cerebelli □
H-15
H-21

Questions

- What artery is usually involved in an epidural hemorrhage? Where does this occur?
  Can you identify the denticulate ligaments in the spinal cord? What type of meningial layer does this consist of?

- Is the epidural space in the brain a real or potential space? What about the spinal cord?
  What is hydrocephalus and how does this occur? What brain structure(s) would most likely be damaged during hydrocephalus at the level of the tentroium cerebelli?

Sinuses

Try and identify the following brain sinuses on the skulls and specimens provided:

- Transverse sinus
- Sigmoid sinus (Gr. S-shaped)
  - Drains into the internal jugular vein. Note the location of the internal jugular foramen in the skull.
- Straight sinus
- Inferior sagittal sinus
- Superior sagittal sinus
- Confluence of sinuses
- Inferior petrosal sinus
- Superior petrosal sinus
- Cavernous sinus
  - The carotid siphon of the internal carotid artery and cranial nerves III, IV, V (V_1, V_2) and VI traverse this region
  - Connections to ophthalmic and facial veins
  - *Clinical application*:
    Danger area of face (mouth, nose, between eyes)
    Potential drainage to cavernous sinus

Cerebral veins located within the subarachnoid space drain the underlying brain tissue and then enter the venous sinuses. *Note that sinuses are not veins; they are merely a separation of the meningial dura layers*. An example of a cerebral vein is the Great cerebral vein(s) of Galen, which drains the majority of the deep brain structures before entering the inferior sagittal sinus.

H-17 Sinuses

Superior sagittal sinus □ Transverse sinus □ Sigmoid (S-shaped) sinus □ Superior petrosal sinus □ Inferior petrosal sinus □ Confluence of sinuses □

H-16

Questions

- Describe the flow of venous blood from the superior sagittal sinus to the internal jugular vein?

Which major vein drains the majority of venous blood from the brain? Is there another way in which venous blood can flow to exit the brain? What is the clinical significance?

Arteries

Arterial blood enters the brain via the paired vertebral and internal carotid arteries. The internal carotid arteries make a characteristic 90^0 turn transversely as they enter the skull. Upon entering the skull they traverse the cavernous sinus. The internal carotid then makes another characteristic turn known as the carotid siphon (s-shaped) before giving off two main terminal branches, the middle and anterior cerebral arteries. The vertebral arteries travel within the transverse foramen of cervical vertebrae C7-C2 before curving around the transverse process of C1 and entering the base of the skull through the foramen magnum (along with the spinal cord). The vertebral arteries then join to become the basilar artery at the junction of the medulla and pons.

Using the specimens, models and angiograms provided, try and identify the following arteries:

- Posterior spinal arteries
- Anterior spinal artery
- Vertebral arteries
- Basilar artery
- PICA (posterior inferior cerebellar arteries)
- AICA (anterior inferior cerebellar arteries – emerges below CN VI)
- Labyrinthine artery (to bony labyrinth of ear – emerges above CN VI)
- Pontine arteries
- Superior cerebellar arteries (emerges below CN III)
- Posterior cerebral arteries (emerges above CN III)
- Posterior communicating arteries
- Internal carotid arteries
- Middle cerebral arteries
    - Lenticulostriate arteries
        - Small branches of middle cerebral
        - Supply lenticular nuclei (putamen, globus pallidus) and rest of striatum (caudate) including internal capsule
        - Lead to lacunar stroke (Latin for small lake)
        - Can lead to hemiparesis (posterior limb of internal capsule for example)
- Anterior cerebral arteries
- Anterior communicating artery
- Circle of Willis

N-1 Arteries

Basilar artery □ Superior cerebellar arteries □ Vertebral arteries □ Posterior inferior cerebellar arteries (PICA) □ Internal carotid arteries □ Posterior cerebral arteries □ Middle cerebral arteries □ Anterior cerebral arteries □ Anterior communicating artery □ Posterior communicating artery □ Anterior inferior cerebellar artery (AICA) □

N-2

N-3

Try and identify the carotid siphon and cavernous portion of the internal carotid in the angiograms provided.

<u>Questions</u>

- Which arteries are responsible for supplying blood to the region around the lateral fissure (Sylvian fissure)? Medial aspect of occipital cortex? Medial aspect of frontal lobes?

- Which arteries supply the basal ganglia? Why is this important in stroke?

MODULE # 3

Cranial Nerves and Major Long Tracts of the CNS

The Skull

This next station reviews the major fossa (L. concavities) and foramina (L. holes) of the skull with respect to the cranial nerves and major blood vessels. Try and complete the following chart on the foramen of the cranial nerves:

Foramen	Cranial Nerve(s)
Cribriform plate	
Optic canal	
Superior orbital fissure	
Foramen rotundum	
Foramen ovale	
Internal auditory meatus	
Jugular foramen	
Hypoglossal canal	

What brain structure(s) occupy the following cranial fossae?

1. Anterior Cranial Fossae:
2. Middle Cranial Fossae:
3. Posterior Cranial Fossae:

What structure(s) pass through the following foramina?

1. Foramen magnum:
2. Jugular foramen:
3. Carotid canal:

H-23 Cranial Nerves

Optic nerve (CN II) □ Oculomotor nerve (CN III) □ Trochlear nerve (CN IV) Trigeminal nerve (CN V) □ Abducens nerve (CN VI) □ Facial nerve (CN VII) Vestibulocochlear nerve (CN VIII) □ Glossopharyngeal nerve (CN IX) □ Vagal nerve (CN X) □ Spinal Accessory nerve (CN XI) □ Hypoglossal nerve (CN XII)

H-25
H-13
N-10
N-21

Questions

- What is the difference between a fissure and a foramen?
- Which foramen does the medial meningial artery traverse? How can you identify this on the skull? What is its clinical significance?

The Cranial Nerves

Try and fill in the following chart on the cranial nerves and identify them on the specimens and models provided.

Cranial nerve	Functional component	Innervated structure(s)	Cell bodies / 1st synapse	Clinical test(s)
Olfactory	Smell (afferent)	Olfactory epithelium	Olfactory epithelium/ Olfactory bulbs	Apply odours
Optic	Vision (afferent)	Retina (rods and cones)	Retinal ganglion cells/ Lateral geniculate nucleus	Visual acuity charts
Oculomotor	Efferent Parasympathetic	Superior, medial and inferior rectus muscles, inferior oblique Sphincter pupillae and ciliary muscles	Occulomotor nucleus Edinger-Westphal/ Ciliary ganglion	Efferent – ask person to follow your finger while you move it right to left, up and down
Trochlear	Efferent	Superior oblique muscle	Trochlear nucleus	Look right and left, and up and down
Trigeminal	Afferent Efferent	Touch, pain, vibration sensation of face, mouth, nasal, cavity, meninges Muscles of mastication	Mesencephalic nucleus Chief sensory nucleus Spinal trigeminal nucleus Trigeminal motor nucleus	Feel the two masseter muscles as the person bites down, have the person open their mouth, jaw jerk reflex, corneal reflex
Abducens	Efferent	Lateral rectus muscle	Abducens nucleus	Look left to right, up and down
Facial	Taste (afferent) Efferent Afferent Parasympathetic	Taste of ant. 2/3 tongue Facial muscles External ear Lacrimal, nasal,	Geniculate ganglion/ Solitary nucleus Facial nucleus Geniculate ganglion/ Trigeminal nucleus Superior salvitory/	Ask person to wrinkle forehead, close eyes, show teeth, or apply salt to 2/3 anterior tongue

		palatal, submandibular, sublingual glands	Pterygopalatine and submandibular ganglia	
Vestibulo-cochlear	Hearing (afferent) Equillibrium (afferent)	Spiral organ of cochlea Ampullae of semicircular canals, maculae and utricle	Spiral ganglion/ cochlear nuclei (dorsal, ventral) Vestibular ganglion/ vestibular nuclei (lat., sup., med., inf.)	Hearing test, tuning fork, and otoscopic exam
Glosso-pharyngeal	Taste (afferent) Afferent Efferent Para-sympathetic	Post. 1/3 tongue Pharynx, carotid body & sinus, auditory tube, external ear Stylopharyngeus muscle Parotid gland	Inferior ganglion of CN IX/ Solitary nucleus Inferior ganglion/ Solitary nucleus (external ear is sup. ganglion/ trigeminal nucleus) Nucleus ambiguus Inferior salivatory/ Otic ganglion	Gag reflex
Vagus	Taste (afferent) Afferent Efferent Para-sympathetic	Epiglottis Carotid and aortic bodies, external ear Muscles of soft palate, pharynx, larynx and esophagus Smooth, cardiac muscles, glands of thoracic and abdomen	Inferior ganglion of CN X/ Solitary nucleus Inferior ganglion of CN X/ Solitary nucleus (ear is sup. ganglion/ trigeminal nucleus) Nucleus ambiguus Dorsal nucleus of CN X/ target ganglia	Say ‘ah’, listen to speech
Spinal Accessory	Efferent	Trapezius, sternocleidomastoid muscles	Spinal accessory nucleus/ C1-C5	Turn head to each side, shrug shoulders
Hypoglossal	Efferent	Extrinsic and intrinsic muscles of tongue	Hypoglossal nucleus	Protrude tongue

<u>Cranial Nerve Designation</u>

The following chart designates the cranial nerves into their respective sensory and motor functions. Note there are only three cranial nerve nuclei that have more than one function;

solitary, ambiguus and trigeminal (mnemonic SAT). Note that branchiomotor is considered a special motor because of its embryological origin from the branchial (pharyngeal) arches, however it still innervates somatic musculature.

	SENSORY (AFFERENTS)			MOTOR (EFFERENTS)		
CN's	**Special**	**Visceral**	**Somatic**	**Visceral**	**Somatic**	**Special (brainchiomotor)**
1		-	-	-	-	-
2		-	-	-	-	-
3	-	-	-	Edinger-Westphal	Occulomotor	-
4	-	-	-	-	Trochlear	-
5	-	-	**Trigeminal** (face, ant. 2/3 tongue)	-	Motor Nu. Of **Trigeminal**	Y
6	-	-	-	-	Abducens	-
7	**Solitary** (taste, ant. 2/3 tongue)	-	From external ear to **Trigeminal**	Superior Salivatory (Pterygopalatine)	Facial Nu.	Y
8		-	-	-	-	-
9	**Solitary** (taste, post. 1/3 tongue)	**Solitary** (carotid body & sinus)	From post 1/3 tongue, meninges & external ear to **Trigeminal**	Inferior Salivatory (Otic)	**Ambiguus**	Y
10	**Solitary** (taste from epiglottis & pharynx)	**Solitary** (heart, gut, lung)	From pharynx, meninges & external ear to **Trigeminal**	Dorsal Motor Nu. Of the Vagus	**Ambiguus**	Y
11	-	-	-	-	Spinal Accessory	Y
12	-	-	-	-	Hypoglossal	-

Major Long Tracts of the CNS

The following is a review of the three main long tracts of the CNS. Although there are several more tracts, an understanding of these tracts will provide an understanding of general sensory and motor function.

- Medial leminiscus
    - *Function:* fine touch, proprioception, vibration sense
    - *Decussation*: caudal medulla as the internal arcuate fibers
    - *Synapses:* 1° pseudounipolar neurons in the dorsal root ganglia travel in the posterior columns and synapse on 2° neurons in the gracilis (legs) and cuneatus (arms) nuclei. After decussating the fibers form the medial leminiscus and then synapse as 3° neurons in the ventral posterior lateral (VPL) nucleus of the thalamus. Finally thalamic neurons synapse on 4° neurons in the primary somatosensory cortex (amongst other areas). Note similar fibers from the head travel in the trigeminal leminiscus of CN V, and then synapse in the VPM of the thalamus.
- Anterolateral System (ALS)
    - The ALS consists of four tracts:
        - Spinothalamic: important for localization of pain/temp stimuli

Spinoreticular: important for alertness/arousal of pain/temp stimuli
Spinomesencephalic: synapse on PAG in midbrain, for modulation of pain
Spinotectal: important for orienting eyes toward painful stimulus

- *Function:* pain, temperature, crude touch
- *Decussation:* travel up or down one or two vertebral levels in Lissauer's tract before decussating in the anterior commissure of the spinal cord and travelling in the anterolateral compartment
- *Synapses:* 1^o pseudounipolar neurons in the dorsal root ganglia travel via Lissauer's tract for one or two segments before synapsing in the substantia gelatinosa and nucleus proprius. 2^o neurons then project to 3^o neurons in the VPL of the thalamus. The ALS changes its name in the brainstem to the spinal leminiscus. Similar fibers from the head travel via the spinal nucleus of CNV, which descend before decussating to become the trigeminal leminiscus in close association with the medial and spinal leminisci. These fibers then synapse in the VPM of the thalamus.

- Corticospinal tract
  - The corticospinal tract consists of the lateral corticospinal tract and the anterior corticospinal tract
  - *Function:* lateral corticospinal tract (limb musculature), anterior corticospinal tract (axial musculature-)
  - *Decussation:* approximately 85% of the fibers decussate in the pyramidal decussation at the junction of the spinal cord and medulla. These fibers then travel in the lateral cortical spinal tract. The remaining fibers form the anterior cortical spinal tract and do not decussate, and innervate bilateral axial musculature.
  - *Synapses:* 1^o motoneurons in cortex synapse in 2^o neurons in the ventral horn of the spinal cord and interneurons, which then innervate muscles. Some cortical neurons also synapse on 2^o cranial nerve nuclei and are known as corticobulbar fibers.

<u>Questions</u>

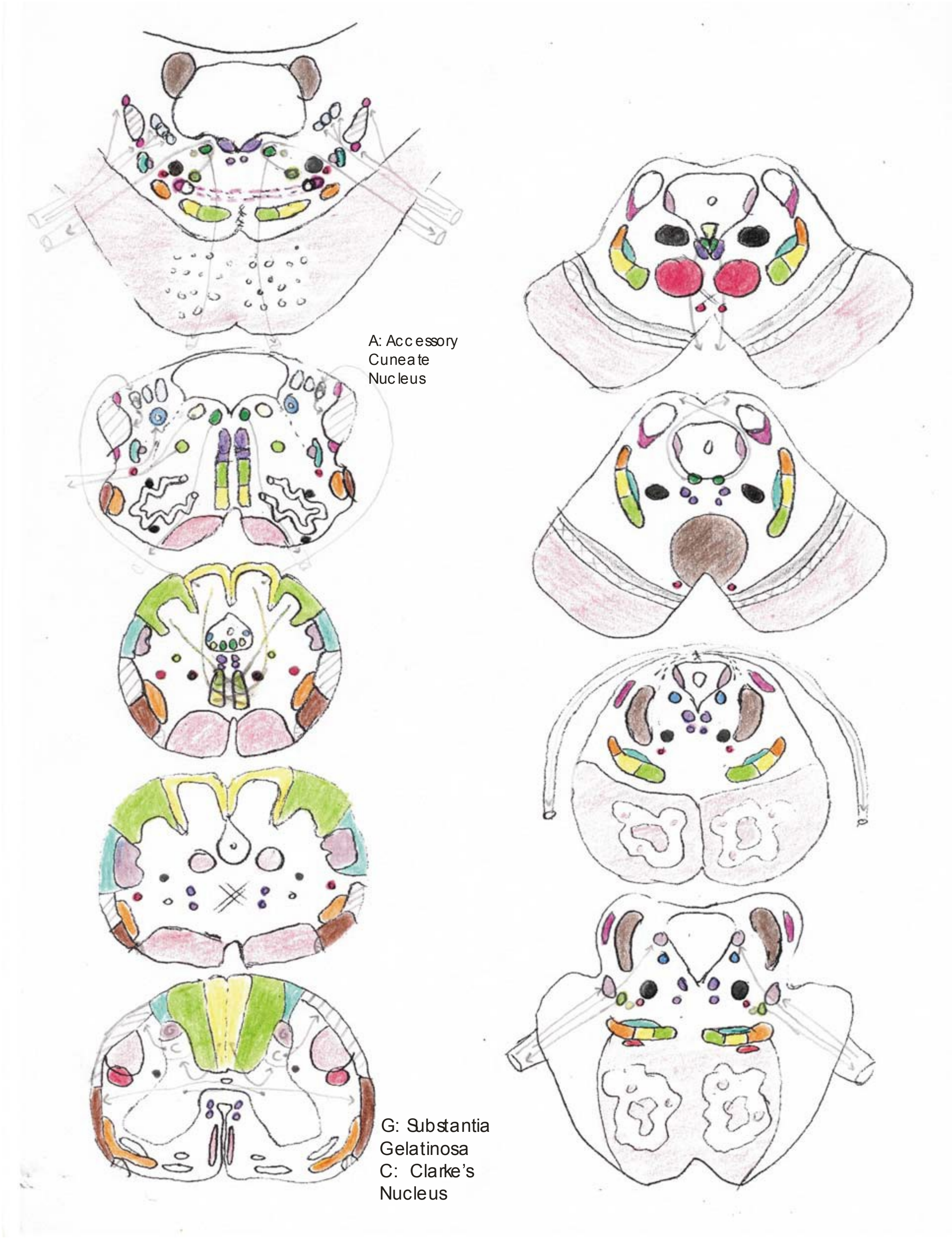
- What cranial nerves are associated with the trigeminal nucleus?
- Where do the afferents from the mesencephalic nuclei synapse? What is unique about mesencephalic neurons?
- Which cranial nuclei are pure motor? What general location do they occupy in the brainstem?
- What spinal cord structure is similar to the trigeminal nucleus? What about the trigeminal tract?
- What structure demarcates the border between sensory and motor nuclei in the brainstem?

Clinical Case Scenario: Try and identify the structures involved (tracts, nuclei, other) and localize the general area of the lesion based on the following clinical features, given a cross-section of the rostral medulla at the level of the olivary nuclei.

Anatomical Structure(s) Involved	Clinical Feature(s)
• Inf. Cerebellar peduncle • Vestibular Nuclei	• Ipsilateral ataxia, vertigo, nystagmus, nasea
• Trigeminal nucleus and tract	•
• Spinal thalamic tract	•
•	• Ipsilateral Horner's syndrome
•	• Hoarsness, dysphagia (trouble swallowing)
•	• Ipsilateral decreased taste

1. Why do you see ipsilateral facial deficits and contralateral body deficits?
2. Which cranial nerves would be involved with dysphagia (swallowing), what about hoarsness?
3. What artery is primarily responsible for this deficit?

Below is a cross-sectional diagram of the brainstem, including the major tracts and brainstem nuclei. Try and label the following diagram using the resources provided.


A: Accessory Cuneate Nucleus
G: Substantia Gelatinosa
C: Clarke's Nucleus

MODULE # 4

Sensory Systems

Below is a summary of the general somatosensory and special sensory systems of the CNS. Try and identify the major tracts, pathways and associated structures of each system with the resources provided.

Somatosensory

The somatosensory system conveys touch, pain, temperature, vibration and pressure sense from cutaneous receptors in the peripheral nervous system. This information is relayed to the primary somatosensory cortex located within the post-central gyrus of the parietal lobe (amongst various other cortical and brainstem areas). The following chart summarizes general somatosensation for the body and head. Using the cross-sectional atlas and brainstem, try and identify the location of the following tracts.

Tract	Modality	Column	Decussation	1st Synapse	Thalamic relay	Destination
Medial Leminiscus	Fine touch, proprioception, vibration sense from body	Posterior	Caudal medulla as internal arcuate fibers	pseudounipolar neurons of DRG on nucleus gracilis (legs), nucleus cuneatus (arms)	VPL	Primary somatosensory cortex of postcentral gyrus
Trigeminal Leminiscus	Fine touch, proprioception, vibration from head	Brainstem	Brainstem	Principal or chief trigeminal nucleus	VPM	Primary somatosensory cortex of postcentral gyrus
Anterolateral System (Spinothalamic, Spinomesencephalic, Spinoreticular, Spinotectal) *Changes name to Spinal leminiscus in brainstem	Pain, temp., crude touch for body	Lissauer's tract to anterolateral column	Anterior commissure	Substantial gelatinosa, nucleus proprius (crude touch)	VPL	Primary somatosensory cortex (localization of pain stimulus) PAG (pain modulation), reticular formation (alertness of pain), superior colliculus of tectum (orient eyes toward painful stimulus)
Trigeminal leminiscus	Pain, temp, crude touch for head	Spinal trigeminal tract of CN V (descends when enters)	Brainstem	Spinal trigeminal nucleus of CN V	VPM	Primary somatosensory cortex and similar areas as above?

Visual System

Embryologically, the eye is formed from the same ectodermal layer of cells that make up the CNS and is therefore considered an extension of the CNS. As evidence of this, the sclera (white of the eye), choroid and retinal layers of the eye are continuous with the dura, arachnoid and pia mater of the CNS, respectively. Using the models provided, try and identify the following components of the eye.

- The Eye
  - Cornea
  - Conjunctiva
  - Sclera (continuation of dura)
  - Choroid (blood vessels – continuous with arachnoid space)
  - Anterior chamber (aqueous humor)
  - Iris
  - Pigmented epithelium of iris
  - Pupillary dialator muscle (longitudinally orientated fibers – sympathetic)
  - Pupillary sphincter muscle (spherically orientated fibers – parasympathetic)
  - Ciliary body
  - Ciliary muscle
  - Suspensory ligaments
  - Lens
  - Vitreous chamber (posterior chamber)
  - Pigmented epithelium
  - Retinal epithelium
  - Optic disk (blind spot)

Try and label Figure 1, a cross-section of the eye

Cross Section of the eye

Using the specimens, models and figures provided, try and identify the following visual pathways.

- Visual pathway
  - Optic disk
  - Optic tract
  - Optic chiasm
  - Lateral geniculate body
  - Optic radiation (Meyer's loop)
  - Primary visual cortex
    - Upper bank (contralateral lower visual field)
    - Lower bank (contralateral upper visual field)

        - Central visual field (occipital pole)
        - Peripheral visual field (deep to occipital pole)
    - Calcarine sulcus
    - Parietal association cortex (where pathway)
    - Occipitotemporal association cortex (what pathway)
- Light/reflex pathway
    - Brachium of superior colliculus
    - Superior colliculi
    - Pretectal area (pupillary light reflex)
    - Ciliary ganglia
    - Edinger-Westphal nuclei
        - Parasympathetic innervations
    - Carotid sympathetic plexus
    - Tectospinal tract (orientation of head and neck toward visual stimuli – from superior colliculi of tectum)
    - Spinotectal (sensory from head and neck to superior colliculi – orientation)
- Neural control
    - Saccades
        - Horizontal
            - Parapontine reticular formation, PPRF
        - Vertical
            - Rostral interstitial nucleus of MLF
            - Interstitial nucleus of Cajal
        - Superior colliculi
        - Suplementary eye field
        - Lateral intraparietal (where targets are)
        - Frontal eye fields
    - Smooth pursuit (cerebellar dependent)
        - Need to have something to focus on
        - Frontal eye fields
        - Parietal cortex
        - Pontine nuclei (Middle cerebellar peduncle)
        - Flocconodular lobe
        - Vestibular nuclei
        - MLF
    - Vergence
        - Retina
        - LGN
        - Primary cortex
        - Secondary association cortex

CN III
Edinger-Westphal
Near triad
- Medial recti (eyes in - CN III)
- Ciliary muscle contracts (suspensory ligaments relax, lens becomes spherical, accomadation - parasympathetic)
- Pupillary constrictor muscle (reduces light – parasympathetic)

- Reflexes
  - Vestibulo-ocular reflex (VOR)
    Maintenance of gaze
    Head turns one direction, eyes opposite

What are the visual field deficits for the corresponding lesions in Figure 2?

H-10 Eye
Superior rectus □ Medial rectus □ Inferior rectus □ Lateral rectus □ Superior oblique □ Levator palpabrae superioris □ Inferior oblique □ Opthalmic nerve □ Optic nerve □ Optic chiasm □ Optic tract □ Lacrimal gland □ Supraoptic nerve (V_1) □ Ciliary ganglion □ Optic radiation □
H-14
H-54
H-57
H-58
N-62

<u>Questions</u>

- What would happen if you lost sympathetic innervation to the right eye?

- Describe the resulting visual field with a lesion to the optic chiasma? The lower right bank of the calcarine sulcus?

<u>Auditory</u>

Try and identify the following components of the auditory system using the specimens and models provided. Note: The bony and membranous labyrinths are common parts of the auditory and vestibular systems.

- External ear
  - Ear canal (2/3 cartilage outer, 1/3 bone inner)
  - Middle ear
    - Tympanic membrane (ear drum)
    - Tensor tympani (muscle innervated by CN V – dampens loud noise)

  - Ossicles (Malleus, Incus, Stapes)
  - Stapedius (muscle innervated by CN VII – dampens loud noise)
  - Oval window
  - Eustachian tube (or auditory tube)
- Inner ear
  - Vestibule
  - Cochlea (within bony labyrinth surrounded by perilymph)
    - Auditory portion of membranous labyrinth (cochlear duct - endolymph)
    - Helicotrema
    - Scala vestibule, scala tympani, cochlear duct comprise cochlea
    - Spiral ligament
    - Organ of Corti (spiral organ within cochlear duct)
    - Tectorial membrane
    - Inner hair cells (main sensory component)
    - Outer hair cells (help amplify signal)
    - Basilar membrane
  - Endolymphatic duct and sac (in dura – absorption of endolymph)
  - Spiral ganglia
  - Vestibulocochlear nerve (CN VIII)
- Auditory pathway
  - Ventral cochlear nuclei (localization of sound – synapses in superior-olivary complex)
  - Dorsal cochlear nuclei (no synapse in superior-olivary complex)
  - Trapezoid body
  - Superior-olivary complex
  - Lateral leminisci
  - Nuclei of lateral leminisci (relay nuclei)
  - Medial geniculate body
  - Brachium of inferior colliculus
  - Inferior colliculus
  - Medial geniculate nucleus
  - Primary auditory cortex (Heschl's transverse gyri – Broadman area 41)
    - Tonotopic arrangement

Try and label the following diagram of the auditory pathway in Figure 3.

H-55 Ear

Tympanic membrane □ External auditory canal □ Eustachian tube (auditory) □ External auditory meatus □ Auditory tude in nasopharynx □

H-46

Vestibular

Try and identify the following components of the vestibular system using the specimens and models provided.

- Semicircular canals and ampulla (anterior, posterior, horizontal are the vestibular portion of the membranous labyrinth and are located within the bony semicircular canals)
  - Cristae ampullaris (in ampulla of semicircular ducts)
    - Cupula (gelatinous)
    - Stereocilia
    - Sensory hair cells (receptor cells)
  - Utricle & Saccule
    - Otoliths (ear stones – calcium carbonate crystals embedded in the otolithic membrane)
    - Otolithic membrane (gelatinous structure)
    - Sensory hair cells (receptor cells)
  - Vestibular ganglia (superior and inferior)
  - Vestibulocochlear nerve (CN VIII)
  - Vestibular nuclei
    - Medial
      - Ascending MLF (yokes vestibular inputs with CN III, IV, VI for maintenance of gaze, vestibulo-ocular reflex - VOR)
      - Descending MLF (head and neck movements)
    - Lateral
      - Lateral vestibulospinal tract (all spinal levels – extensor movements)
    - Superior
      - Contributes to ascending MLF
    - Inferior (checkerboard appearance – traversed by lateral nuclei fibers)
      - Contributes to descending MLF
  - Vestibulothalamic tract (to ventral posterior lateral (VPL) nucleus of thalamus)
- Primary vestibular cortex

Figure 4 summarizes the vestibular nuclei and tracts. Note the medial vestibular nucleus gives rise to the ascending and descending MLF responsible for control of ocular and head and neck movements, respectively.

Try and label the following diagram of the vestibular pathway in Figure 5.

Gustatory

Try and identify the following components of the gustatory system using the specimens and models provided.

- Papillae
    - Circumvalate (literally circular wall - at back of tongue)
    - Filiform (thread shape)
    - Fungiform (mushroom shape)
    - Foliate (leaf shape)
- Taste buds
- Taste pore
- Taste hairs (microvilli)
- Receptor cells
- CN VII (taste anterior 2/3 tongue – taste)
    - Chorda tympani to geniculate ganglia
- CN IX (posterior 1/3 tongue - taste and general sensation)
    - Lingual branch to inferior glossopharyngeal ganglia
- CN X (epiglottis, pharyngeal palate (oropharynx) – taste)
    - Inferior vagal ganglia
- CN V (general sensation anterior 2/3)
- Solitary nucleus (nucleus of the solitary tract)
- Rostral is for taste afferents
- Caudal is for visceral from rest of body (CN IX – carotid body & sinus, CN X – heart, gut, lung)
- Some reflexive connections (coughing, salivation, swallowing etc. – to reticular formation, CN X – bilateral pathway p.328)
- Central tegmental tract (ipsilateral pathway)
- Ventral posterior medial (VPM) nucleus of thalamus
- Primary gustatory cortex (insula)
- Orbital cortex of frontal lobe (integrated with taste)
- Amygdala (limbic structure – emotional aspect of food)
- Hypothalamus (autonomic/visceral response)
- Parabrachial nuclei (surround superior cerebellar peduncle or **brachium** conjuctivum – Latin for joined together arm referring to decussation of superior cerebellar peduncle)
- Direct connections to hypothalamus and amygdala for nociceptive info

Try and label the following diagram of the gustatory pathway in Figure 6.

Olfactory

Try and identify the following components of the olfactory system using the specimens and models provided.

- Olfactory pathway
  - Nasal cavity
  - Olfactory receptors
  - Olfactory ensheathing cells (unmyelinated axons)
  - Cribriform plate
  - CN I
  - Glomeruli
  - Mitral cells
  - Olfactory tract
  - Olfactory bulb
  - Anterior olfactory nucleus
  - Medial olfactory stria (contralateral fibers)
  - Medial olfactory tract
  - Anterior commisure
  - Lateral olfactory stria (ipsilateral and contalateral fibers)
  - Lateral olfactory tract
- Anterior perforated substance
- Higher processing
  - Amygdala (attachment of emotional associations – emotional colouring)
  - Primary olfactory cortex (3 layered cortex)
    - Piriform cortex
    - Periamygdaloid cortex
    - Uncus
- Parahippocampal gyrus (secondary olfactory cortex)
  - Entorhinal cortex
  - Parahippocampal cortex
- Associated sulci & gyri
  - Rhinal sulcus
  - Collateral sulcus
  - Olfactory sulcus
  - Orbital frontal gyrus
  - Gyrus rectus

Try and label the following diagram of the olfactory pathway in Figure 7.

N-3 Olfactory

Olfactory bulbs □ Olfactory tract

Questions

- What is the function of the utricle? Saccule? Semicircular canals?
- What is the main cause of sensorineuronal hearing loss? Conductive hearing loss?
- Describe the role that limbic structures play in taste and smell?
- What is the vestibulo-ocular reflex (VOR)? What would happen if you damaged the right MLF? Left CNIII?

MODULE #5

Motor Systems

The motor system can be divided into both medial (responsible for control of axial musculature, posture and balance), and lateral motor systems (responsible for control of appendicular musculature and voluntary movement). Motor systems can be further divided into the following regions; spinal cord/peripheral nervous system, brainstem and cortex. Moreover, the cerebellum and basal ganglia are added onto this structural framework, which have a modulatory influence on motor control but do **not** initiate movement.

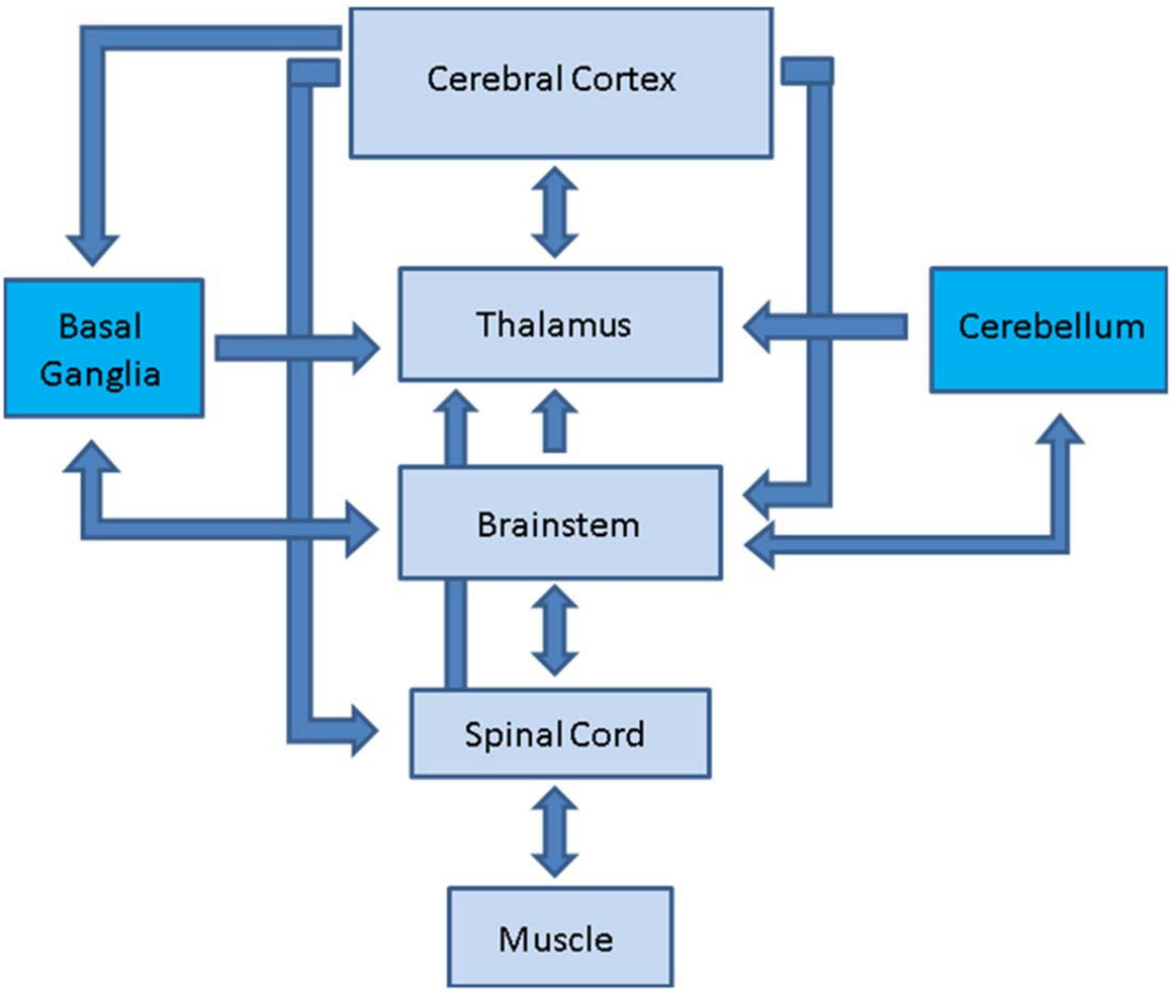


Figure 1. Schematic of hierarchical muscular control

Spinal Cord/PNS

At the level of the spinal cord, motor function can be classified as reflexive, volitional (voluntary) or repetitive. In the periphery, the functional unit of the motor system is known as the motor unit, consisting of the motoneuron and muscle fibers. Muscle fibers consist of extrafusal muscle fibers, which provide the force of contraction and are innervated by alpha motoneurons, and intrafusal muscle fibers (muscle spindle), which provide information about the stretch and tone of the muscle, innervated by primary and secondary afferents and gamma motoneurons. Additional classification of the muscle fibers is described below.

- Classification
  - Reflexive
  - Volitional (voluntary)
  - Repetitive
- Medial motor systems (posture)
- Lateral motor systems (volitional)
- Motor unit
  - Motoneuron
  - Muscle fibers
- Extrafusal muscle fibers
  - Example: Biceps
  - Provides force of contraction
  - Alpha motoneuron
- Intrafusal muscle fibers (muscle spindles)
  - Nuclear bag fibers
  - Nuclear chain fibers
  - Primary afferents (Ia)
    - Annulospiral endings
    - Nuclear bag fiber
    - Velocity of stretch
  - Secondary afferents (II)
    - Flower spray endings
    - Chain fiber
    - Responds to length
  - Gamma motorneuron (efferents)
    - Maintains sensitivity of muscle spindle
- Golgi tendon organs
  - Between muscles and tendons
  - Collagen fibers (similar to Ruffini)
  - Primary afferents (Ib)
  - Monitor tension of muscle contraction

N-12 Spinal cord

Cervical enlargement □ Dura mater □ Arachnoid and pia mater □ Denticulate ligament □ Conus medullaris □ Filum terminale □ Lumbar enlargement □ Cervical enlargement □ Cauda equine □ Ventral fissure □ Posterior sulcus □ Anterior spinal artery □

Brainstem

At the level of the brainstem a number of nuclei are responsible for posture and gait related movements, as well as coordination of eye and head movements. The red nucleus is an example of a brainstem nucleus mediating voluntary control at this level. The red nucleus plays a role in gait in animals that do not have a significant corticospinal tract, although it's function in humans is often considered vestigial. Try and identify the following nuclei in the brain atlases provided.

- Medial motor systems
  - Responsible for Posture & Gait
  - Innervate Axial musculature
  - Vestibular
    - Lateral vestibulospinal tract
      - Lateral vestibular nucleus (Dieter's nucleus)
      - Entire cord
      - Ipsilateral
    - Medial vestibulospinal tract
      - Ascending for eye movements
        - Medial and superior nuclei
        - Yokes CN III, IV, VI
      - Descending for head & neck movements
        - Medial and inferior nuclei
      - Bilateral
  - Reticular
    - Pontine reticulospinal tract
      - Pontine reticular formation
      - Ipsilateral
    - Medullary reticulospinal tract
      - Medullary reticular formation
      - Ipsilateral
  - Tectum
    - Tectospinal tract
      - Superior colliculus
      - Contralateral
      - Coordination of head and neck to visual (auditory?) stimulus
- Lateral motor systems
  - Innervate Limb musculature
  - Responsible for Voluntary movement
  - Rubrospinal tract
    - Red nucleus (magnocellular part)
    - Contralateral

N-21 Brainstem

Oculomotor nerve (CN III) □ Trochlear nerve (CN IV) □ Trigeminal nerve (CN V) □ Midbrain □ Pons □ Medulla oblongata □ Olive □ Pyramids □ Superior colliculus □ Inferior colliculus □ Fourth ventricle □ Cerebral aqueduct □

N-20

N-19

N-18

<u>Neocortex</u>

The neocortex exerts descending motor control at both the spinal and brainstem levels via the corticospinal and corticobulbar tracts, respectively. Cortical projections primarily innervate limb musculature, but also axial musculature via the anterior corticospinal tract. Most corticobulbar fibers exert a bilateral influence, except for the lower face (contralateral) and CN IX (ipsilateral). *Note, although corticobulbar projections may be bilateral, they receive primarily contralateral input. Therefore during the initial phases of an injury, a contralateral deficit may be observed, which may eventually disappear due to compensation via the bilateral projection.* Try and identify the following structures on the specimens and atlases provided.

- Cortical descending projections
  - Responsible for Voluntary movement
  - Innervate Limb & Axial musculature
  - Lateral corticospinal tract
    - Limb musculature
    - Contralateral
    - Pyramidal decussation
  - Anterior corticospinal tract
    - Axial musculature
    - Bilateral
    - Decussates at spinal level
  - Corticobulbar tract
    - CN V
      - Bilateral
      - Branchiomotor (motor nucleus of CN V)
        - Muscles of mastication (chewing)
    - CN VII
      - Bilateral (upper face)
      - Contralateral (lower face)
      - Branchiomotor (facial motor nucleus)
        - Facial muscles
    - CN IX
      - Bilateral
      - Branchiomotor (nucleus ambiguus)
        - Stylopharngeus muscle (swallowing)
    - CN X
      - Bilateral

- Branchiomotor (nucleus ambiguus)
  - Pharyngeal muscles (swallowing)
  - Laryngeal muscles (vocalization)

CN XI
- Ipsilateral
- Branchiomotor (nucleus ambiguus)
- Sternocleidomastoid & trapezius (neck muscles)

CN XII
- Bilateral
- Somatic motor
  - Tongue muscles

- Primary motor cortex
  - Some direct connections to lower motor neurons
  - Motor homunculi
  - Corticospinal tract
    - Contralateral (lateral corticospinal tract)
    - Bilateral (anterior corticospinal tract)
    - Volitional
    - Primary motor cortex
    - Corona radiate
    - Internal capsule (posterior limb)
    - Basis pedunculi (cerebral peduncles, crus cerebri – same)
    - Pyramids
    - Pyramidal decussation (lateral corticospinal tract)
    - Lower motor neuron
- Somatosensory cortex
- Association cortex
  - Supplementary motor area
    - Mental rehersal
    - Motor imagery
    - Bimanual (2 hands, different task)
  - Premotor cortex
    - Selection of action
    - Builds up motor associations (green light go)
    - Observation of action
  - Prefrontal cortex
    - Executive function (planning of movements)
  - Parietal association cortex (damage to dominant hemisphere usually right equals left side neglect)
    - Inputs from visual cortex (where pathway)

N-18 Corticospinal/bulbar fibers

Corticospinal fibers □ Corticobulbar fibers □ Cerebral peduncle □ Internal capsule □ Corona radiata □

N-16

Questions

- Try and localize the lesion giving the following information; Left facial weakness sparing the forehead, left arm weakness, hyperreflexia (upper motoneuron sign), mild dysarthria (slurred speech). What if left leg weakness was also involved?
- In pure motor hemiparesis, usually involving damage to the posterior limb of the internal capsule, the forehead is often spared. Why does this occur?

- What is sacral sparing? How does it occur?

- Why does ipsilateral damage to CN XII cause the tongue to protrude to the same side?
- Alternating syndromes, in which long-tract symptoms occur on one side of the body and cranial nerve symptoms occur on the other, are a hallmark feature of brainstem lesions Describe the symptoms caused by right medial medullary syndrome of the rostral medulla (level of the olives)? (ie. damage to medial structures of the medulla).

Cerebellum

The cerebellum has a modulatory influence on the motor system (ie. It does not initiate movement, but plays a role in coordination and timing). Cerebellar afferents from the body are relayed to the ipsilateral cerebellum. Efferents are mainly relayed via the superior cerebellar peduncle, which arrive at the contralateral cortex after decussating in the rostral midbrain. Therefore ispislateral damage of the cerebellum, will affect the ipsilateral body. Try and identify the following structures on the specimens and models provided.

- Primary fissure
    - Anterior lobe
    - Posterior lobe
- Horizontal fissure
- Posterolateral fissure
    - Flocculonodular lobe
        - Flocculus
        - Nodulus
- Functional zones
    - Vermis (medial zone – balance – axial musculature)
    - Paravermal (intermediate zone – volitional movements - limbs)
    - Lateral hemispheres (lateral zone – motor planning, learning)
- Deep nuclei (output nuclei – medial to lateral)
    - Fastigial (summit – hence top of 4th ventricle)
    - Interpositus (located in between fastigial and dentate nuclei)
        - Emboliform
        - Globose
    - Dentate
- Peduncles
    - Superior (main output)
        - Input
            - Ventral spinocerebellar tract (interneuron input legs)

- Rostral spinocerebellar tract (?)

Output

- Red nucleus
- Tectum (eye movements)
- Thalamus (consciousness)

- o Middle

Input

- Pontine nuclei

- o Inferior

Input

- Vestibular nuclei
- Spinal cord
  - o Dorsal spinocerebellar tract (proprioception legs)
  - o Rostral spinocerebellar tract (?)
  - o Cuneocerebellar tract (proprioception arms)
- Olive climbing fibers

Output

- Vestibular nuclei
- Reticular formation (balance)
  - o pontine
  - o medullary
- MLF (eye movements)

- Gyri
- Sulci
- Folia
- Lingula (tongue of vermis)
- Uvula (uvula of vermis)
- Tonsils (of paravermis)
- Granule cell layer
  - o Parallel fibers run perpendicular to purkinjie cell dendrites
- Purkinjie cell layer
  - o Inhibitory output
  - o Output to deep nuclei
- Molecular layer
  - o Parallel fibers, Purkinjie cell dendrites, other cells
- Climbing fibers
  - o From olive
  - o Excitatory
- Mossy fibers
  - o Many inputs
  - o Excitatory
- Vestibular connections (balance)
  - o Vestibulo-ocular reflex (VOR)
  - o Smooth pursuit eye movements

Try and label the following diagram of the cerebellar afferents in Figure 2.

N-26 Cerebellum

Primary fissure □ Horizontal fissure □ Pontocerebellar fibers □ Middle cerebellar peduncle □ Superior cerebellar peduncle □ Dentate nucleus □ Arbor vitae □ Nodulus □ Lingula □

N-27
N-28
N-23
N-18

Basal Ganglia

The basal ganglia also have a modulatory influence on the motor system. All efferents from the basal ganglia are inhibitory, therefore release of this inhibition results in activation of motor systems. The basal ganglia in this way are believed to be involved in task switching behaviours. Several channels or circuits exist within the basal ganglia including occulomotor, prefrontal, limbic and motor. As a result, the basal ganglia are thought to be responsible for initiation of eye movements, cognitive processes, emotions and motor functions. Try and identify the following structures and pathways on the specimens and figures provided.

- Corpus striatum
    - Caudate (neostriatum)
    - Lentiform nucleus
        - Putamen (neostriatum)
        - Globus pallidus (paleostriatum – pale globe)
            - External segment (Gpe)
            - Internal segment (Gpi)
    - Nucleus accumbens (ventral striatum)
- Subthalamic nucleus
- Substantia nigra
    - Pars reticulata (SNr)
    - Pars compacta (SNc)
- Direct pathway (template)
    - Cortex
    - Input nuclei
    - Output nuclei
    - Thalamus
    - Cortex
- Indirect pathway (template)
    - Cortex
    - Input nuclei
    - Gpe
    - Subthalamic
    - Output nuclei
    - Thalamus
    - Cortex

- Dopaminergic influences
    - SNc
        - Melanin pigment (from monamine breakdown –dopamine)
    - Nigrostriatal (SNc -> putamen)
    - Overall excitatory
    - Excite direct pathway
    - Inhibit indirect pathway
- Circuits (p. 702 Blumenfeld)
    - Motor
        - Modifies movement
        - Somatosensory cortex (corticostriatal)
        - Primary motor cortex (corticostriatal)
        - Premotor cortex (corticostriatal)
        - Putamen, SNc (input)
        - GPi (body), SNr (head & neck) – output nuclei
        - VL,VA
        - Primary motor cortex (thalamocortical)
        - Premotor cortex (thalamocortical)
        - Supplementary motor cortex (thalamocortical)
    - Oculomotor
        - Eye movement
        - Posterior parietal cortex (corticostriatal)
        - Prefrontal cortex (corticostriatal)
        - Caudate (body), SNc (input)
        - GPi, SNr
        - VA,MD
        - Frontal eye fields (thalamocortical)
        - Supplementary eye fields (thalamocortical)
    - Prefrontal
        - Cognition
        - Posterior parietal cortex (corticostriatal)
        - Premotor cortex (corticostriatal)
        - Caudate (head), SNc (input)
        - GPi,SNr (output)
        - VA,MD
        - Prefrontal cortex (thalamocortical)
    - Limbic
        - Initiation of rewarding behaviour
        - Temporal cortex (corticostriatal)
        - Hippocampus (corticostriatal)
        - Amygdala (corticostriatal)
        - Nucleus accumbens, SNc (input)
        - Ventral caudate (input)
        - Ventral putamen (input)
        - Ventral pallidum (output)
        - Gpi,SNr (output)

MD,VA
Anterior cingulate cortex (thalamocortical)
Orbital frontal cortex (thalamoocortical)

- Related structures (external – internal)
  - Insula
  - Extreme capsule
  - Claustrum
  - External capsule
  - External medullary lamina
  - Internal medullary lamina
  - Internal capsule
- Ipsilateral pathways
  - Therefore contralateral effect due to cortex which is contralateral
- All output from striatum is inhibitory
- Parkinson's
  - Loss of SNc neurons (dopaminergic)
  - Resting tremor (versus intention tremor – cerebellum)
    - Stops/diminishes during movement
  - Problems initiating movement
  - Hypokinetic
- Huntington's
  - Loss of striatopallidal (putamen -> GPe)
  - Loss of indirect
  - Excitatory movments
  - Hyperkinetic

N-55 Basal ganglia
Head of caudate nucleus □ Putamen □ Claustrum □ Extreme capsule □ External capsule □ Lentiform nucleus □ Globus pallidus □

N-59
N-60
N-63
N-65

<u>Oculomotor System</u>

The occulomotor system consists of six extraocular muscles, muscles of the eyelid and associated nuclei of the brainstem as listed below. Additionally, a number of neural pathways and nuclei are listed, involved in neural control. Try and identify the following structures and pathways with the specimens and models provided.

- Recti muscles (straight muscles)
  - Superior (CN III) (Test: look out & in) - contralateral
  - Inferior (CN III) (Test: look out & down) - ipsilateral
  - Middle (CN III) (Test: look medial) - ipsilateral
  - Lateral (CN VI) (Test: look lateral) - ipsilateral
- Superior Oblique (CN IV) (Test: look in & down) - contralateral

- Inferior Oblique (CN III) (Test: look in & up) - ipsilateral
- Levator palpabrae superioris (eyelid, CN III)
- Superior tarsal muscle of Muller (smooth muscle eyelid– sympathetic)
- Carotid sympathetic plexus (pupillary dilator)
- Edinger-Westphal nucleus (parasympathetic – pupillary constrictor)
- Neural control
    - Saccades
        - Horizontal
            - Parapontine reticular formation, PPRF
        - Vertical
            - Rostral interstitial nucleus of MLF
            - Interstitial nucleus of Cajal
        - Superior colliculi
        - Suplementary eye field
        - Lateral intraparietal (where targets are)
        - Frontal eye fields
    - Smooth pursuit (cerebellar dependent)
        - Need to have something to focus on
        - Frontal eye fields
        - Parietal cortex
        - Pontine nuclei (Middle cerebellar peduncle)
        - Flocconodular lobe
        - Vestibular nuclei
        - MLF
    - Vergence
        - Retina
        - LGN
        - Primary cortex
        - Secondary association cortex
        - CN III
        - Edinger-Westphal
        - Near triad
            - Medial recti (eyes in - CN III)
            - Ciliary muscle contracts (suspensory ligaments relax, lens becomes spherical, accomadation - parasympathetic)
            - Pupillary constrictor muscle (reduces light – parasympathetic)
- Reflexes
    - Vestibulo-ocular reflex (VOR)
        - Maintenance of gaze
        - Head turns one direction, eyes opposite

H-10 Oculomotor

Medial rectus □ Lateral rectus □ Superior rectus □ Inferior rectus □ Superior oblique □ Optic nerve □

Questions

- Why does damage to the ipsilateral cerebellum affect the ipsilateral body?
- Why does damage to the ipsilateral basal ganglia affect the contralateral body?
- Which of the above eye movements are the only eye movements that can easily be performed voluntarily? Why?
- What effect would sympathetic innervation have on the ciliary body?
- Locked-in syndrome leaves a patient with no motor control but complete sensation of the extremities, as well as a loss of horizontal eye movements. Vertical eye movements are maintained, which is the only form of communication that these individuals have. The editor of Elle magazine was diagnosed with locked-in syndrome and wrote an entire book using these vertical eye movements. Based on what you know, where is this lesion most likely to occur? Why? (Check out the movie "The Diving Bell and the Butterfly").

MODULE #6

Cerebral Hemispheres, Limbic and Autonomic Systems

Autonomic Nervous System (ANS)

The autonomic nervous system is responsible for innervating cardiac muscle, smooth muscle and glands. The main autonomic center is located in the hypothalamus, which then projects to various brainstem and spinal centers (intermediolateral horn) via the medial forebrain bundle and dorsal longitudinal fasiculus (amongst other pathways). Note there are numerous cortical connections with the hypothalamus that influence autonomic output, including prefrontal cortex (executive function) and other limbic regions (memory and emotional influences). Using the cervical spinal model and specimens provided, try and locate the following structures and pathways:

- Hypothalamus (autonomic center)
- Medial forebrain bundle (MFB)
- Dorsal longitudinal fasiculus (DLF)
- Brainstem parasympathetic nuclei (CN III, VII, IX, X)
    - Edinger-Westphal nucleus
        - Oculomotor nerve
        - Ciliary ganglia
        - Pupillary constrictor and ciliary muscle
    - Superior salivatory nucleus
        - Facial nerve
        - Pterygopalatine ganglion
        - Submandibular ganglion
        - Submandibular, sublingual, lacrimal, nasal, palatine glands
    - Inferior salivatory nucleus
        - Glossopharyngeal nerve
        - Otic ganglion
        - Parotid gland
    - Dorsal motor nucleus of CN X
        - Vagus nerve
        - Intramural ganglia (within wall of organs)
        - Heart, gut, lung
- Sacral parasympathetic
    - S2-S4
    - Pelvic nerves
    - Gut, pelvis
- Sympathetic division
    - Intermediolateral horn (T1-L2)
    - Ventral root
    - Spinal nerve
    - White rami (T1-L2) (get on white and off on gray)
    - Parasympathetic trunk (sympathetic chain)

- Gray rami (entire cord)
- Splanchnic nerve (Latin for viscera – nerves to visceral organs of body via prevertebral ganglia)
  - Splanchnic nerves to heart, lung and rest of viscera
  - Carotid plexus to head
- Prevertebral ganglia (aka collateral ganglia – travel with lateral sympathetic trunks) to:
  - Superior mesenteric
  - Inferior mesenteric
  - Celiac
  - Renal
- Preganglionic synapses in the remaining viscera occur in various plexi that do not coalesce into named ganglia
- Adrenal medulla (norepinephrine, epinephrine) – fibers synapse directly on cells of the medulla, which are modified neuroendocrine cells that secrete norepinephrine and epinephrine into the blood

Note there are **five** main pathways in which sympathetic neurons reach their targets:

1. Preganglionic neurons from intermediate column get on to the sympathetic trunk via the white ramus and synapse with postganglionic neurons at that level before exiting via gray rami to their target structure.
2. Preganglionic neurons from intermediate column get on to the sympathetic trunk via the white ramus and travel up or down the sympathetic trunk before synapsing with postganglionic neurons and then exiting via gray rami to their target structure.
3. Preganglionic neurons from intermediate column get on to the sympathetic trunk via the white ramus and then travel with the splanchnic nerves to reach preverterbral ganglia or plexi before synapsing and reaching their target structure.
4. Preganglionic neurons from intermediate column get on to the sympathetic trunk via the white ramus and then travel via the carotid plexus before synapsing in various ganglia of the head (including eye).
5. Preganglionic neurons from intermediate column get on to the sympathetic trunk via the white ramus and then travel with splanchnic nerves bypassing the prevertebral ganglia before synapsing directly on modified neuroendocrine cells in the adrenal medulla (chromaffin cells).

<u>Questions</u>

- Where do the preganglionic sympathetic fibers destined for the viscera synapse? Adrenal medulla?
- Where are the white rami communicantes located with respect to the gray? What spinal levels are they located? What about the gray rami?
- Why is it named white rami?

Limbic System

The limbic system is ideally situated both structurally and functionally between our ‘higher’ brain congnitive center (neocortex) and our ‘lower’ brain autonomic center (hypothalamus), allowing us to exert control over our more primitive emotions and drive-related behaviours. Although there is no clear consensus on the exact structures that make up the limbic system, generally they can be summarized by the acronym HOME, to which one main structure can be assigned:

- **H**omeostasis (hypothalamus)
- **O**lfaction (olfactory cortex)
- **M**emory (hippocampus)
- **E**motions & Drives (amgydala and hypothalamus)

The circuit of **Papez** is one example of a limbic system pathway, discovered in 1937 by James Papez. The circuit of Papez is often chosen for identifiying key limbic system structures and general pathways, although many more pathways, structures and reciprocal connections exist. Using the specimens and models provided try and identify the following structures:

- **Bold = Circuit of Papez** (one example of a limbic circuit)
- **Amygdala** (emotions/drive/memory associations)
- **Hippocampus** (consolidation of memory)
    - Dentate gyrus (can identify on gross examination)
    - Hippocampus proper (Latin for seahorse)
        - CA1-CA4 (cornu Ammonis – Latin for horn of egyption ram-headed god Ammon – due to ram horn shape)
    - **Parahippocampal gyrus** (association cortex)
        - Parahippocampal cortex
        - Piriform and Periamygdaloid cortices (1^0 olfactory cortex – located in this gyrus)
- **Hypothalamus** (autonomic responses)
    - Many nuclei
    - **Mammillary bodies** (main input from fornix – outputs to anterior thalamic nucleus)
- Thalamus
    - **Anterior nucleus**
    - Medial dorsal nucleus
- **Septal nuclei** (note general location)
        - Medial
        - Lateral
- Habenular nuclei
- Limbic association cortex (also to other association cortices – higher cognition)
    - **Cingulate gyrus**
    - **Parahippocampal gyrus**
    - Uncus

- Tracts (note many reciprocal connections between nuclei listed)
  - **Fornix** (from fimbria of hippocampus to mammillary bodies and anterior nucleus of thalamus)
  - **Stria terminalis** (from amygdala to septal nuclei)
  - **Mammilothalamic tract** (from mammillary body to anterior nucleus)
  - **Cingulum**
  - Stria medullaris (from septal nuclei to habenular nuclei)
  - Medial forebrain bundle (from basal forebrain/hypothalamus to brainstem reticular formation and tegmentum)
  - Dorsal longitudinal fasiculus (to brainstem reticular formation and tegmentum)
- Brainstem nuclei (autonomic and behavioural responses)
  - Periaqueductal gray (PAG – pain modulation)
  - Solitary nucleus
  - Dorsal motor nucleus of vagus (CN X)
  - Various reticular formation nuclei (just note general location)

N-98 Limbic System

Hippocampus □ Dentate gyrus (of hippocampus) □ Lateral ventricle □ Pes hippocampus □ Amygdala □ Uncus □ Parahippocampal gyrus □ Alveus □ Mammallary bodies □ Fornix □ Fimbria □

N-100
N-101
N-102
N-103
N-104
N-105

Cerebral Hemispheres

The cerebral hemispheres (telencephalon) consist of the cerebral cortex, corpus striatum, hippocampus, lateral ventricles and associated white matter structures. Specific functions have been attributed to certain hemispheres although this can vary with dominance. Generally, the dominant hemisphere is responsible for language, sequential and analytical skills related to math and music, following a set of written directions and skilled motor formulation (praxis). The non-dominant hemisphere is generally responsible for prosody (emotion conveyed by tone of voice), visual-spatial analysis and attention, arithmetic ability by being able to line up numbers in a column, musical ability in untrained musicians or complex pieces for trained musicians, and sense of direction relating to finding ones way by spatial orientation sense. For more information see Blumenfeld p.826. Note, the left hemisphere is dominant for language in over 95 % of right-handers and 60-70% of left-handers. Using the specimens and models provided try and identify the following structures:

- Cerebral cortex
  - Primary sensory areas
    - Somatosensory
    - Visual

- Auditory
  - Vestibular
  - Gustatory
  - Insular cortex (under operculum, Latin for lid)
- Association cortex (everywhere else, almost)
- Limbic cortex
  - Cingulate (medial)
  - Parahippocampal (inferior)
  - Uncus (inferior)
- Sulci
  - Central
  - Parieto-occipital
  - Cingulate (medial)
  - Precentral
  - Postcentral
  - Intraparietal
  - Superior, inferior temporal
  - Superior, inferior frontal
  - Calcarine
- Gyri
  - Precentral
  - Postcentral
  - Cingulate (limbic)
  - Supramarginal
  - Superior, middle, inferior temporal
  - Superior, middle, inferior frontal
  - Parahippocampal (limbic – inferior)
  - Gyrus rectus (inferior)
  - Orbital (inferior)
  - Cuneus (Latin for wedge shape)
  - Precuneus
  - Angular
  - Supramarginal
- Fissures
  - Longitudinal
  - Lateral (Sylvian)
  - Calcarine
- Notches
  - Preoccipital
- Poles
  - Frontal
  - Temporal
  - Occipital
- Lobes
  - Frontal
  - Temporal

<u>Museum Specimens</u>

N-15 Lateral view:
Central sulcus □ Precentral sulcus □ Precentral gyrus □ Lateral (Sylvian) fissure □
N-15 Medial view: Cingulate sulcus □ Parieto- occipital sulcus □ Calcarine sulcus □ (dividing upper and lower portions of the primary visual cortex)
N-37 Lateral View:
Frontal lobe □ Parietal lobe □ Temporal lobe □ Cerebellum □ Central sulcus □ Precentral gyrus □ Postcentral gyrus □ Occipital lobe □
N-3:
Sagittal fissure □ Frontal lobes □ Temporal lobes □ Lateral (Sylvian) fissure □ Brainstem: midbrain, pons and medulla □ Cerebellum □
N-4:
Frontal lobes □ Temporal lobes □ Occipital lobes □ Sagittal fissure □
N-7 Medial view:
Cingulate sulcus □ Cingulate gyrus □ Corpus callosum: rostrum □, genu □ body □, splenium □ Septum pellucidum □ (a thin midline membrane between the two cerebral hemispheres) Parieto-occipital sulcus □ Calcarine sulcus □

* <u>Note</u>: The *corpus callosum*, a large C-shaped band of white matter, is the major connecting pathway between the right and left cerebral hemispheres. It consists of about 250 million axons crossing between the hemispheres.

Parietal
Occipital

- Corpus Striatum
  - Globus pallidus (part of lentiform nucleus)
  - Putamen (part of lentiform nucleus)
  - Caudate
- White Matter
  - Corpus callosum
  - Anterior commisure
  - Posterior commisure
  - Superior longitudinal fasiculus
  - Arcuate fasiculus
  - Uncinate fasiculus
  - Inferior longitudinal fasiculus
  - Internal capsule
  - Corona radiata
  - Optic radiation
  - Auditory radiation
  - External capsule (between putamen and claustrum)
  - Extreme capsule (between clausturm and insula)

Questions

- Which lobes of the brain does the Sylvian fissure separate?

- What are the key functions of the frontal lobe?

- What primary area of cortex lies in the precentral gyrus? What lobe is this part of?

- What primary area of cortex lies in the postcentral gyrus? What lobe is this part of?

- Which primary area of cortex lies in the Sylvian fissure?

- Which sensory modality does not relay through the thalamus?

- What kind of manifestation would develop if you had a stroke that damaged the lower lateral bank of your primary somatosensory cortex? What about the medial bank?

- What limbic structure is primarily responsible for autonomic functions? What about drive related behaviours?

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