Neurological Systems Update

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SUMMARY

- Normal movement –motor control
- Motor Control within sensory systems
- Visual system
- Vestibular system
- Somatosensory system
- Muscle spindles
- Afferents
- Ascending pathways
- Brain Stem
- Reticular Formation
- Processing
- Cerebellum
- Basal Ganglia
- Motor cortex/Premotor cortex
- Corticospinal Tract
- Vestibulospinal Tract
- Reticulospinal Tract

Normal movement/Motor control

- Motor control – the study of nature of movement and how it is controlled
- Rehabilitation often involves the development, progression and/or refinement of motor control – both when dysfunction stems from the nervous system, and when other body systems are primarily affected.

Normal movement/Motor control

- Analysis of a task described in 3 stages:
- Perception- integration of sensory information to allow interaction of task within the environment.
- Cognition- attention/ motivational/ emotional aspects of movement.
- Action- the specific components of the action, taking into account the different degrees of freedom involved.

Normal movement/Motor control

- Movement can be both responsive/reactive/reflexive [feedforward] and/or
- priming implicit/predictive [feedback].

Functional Anatomy of the CNS

- 6 principals proposed by Frey et al [2011]
- -anatomical gradients in the parietal and premotor cortices
- Anterior-to-posterior gradient in the frontal lobe [goal to action]
- Parallel parieto-frontal circuits [sensory-motor loop]

-superior parietal lobe to dorsal premotor cortex

-inferior parietal lobe to ventral premotor cortex

Medial-to-lateral gradient in premotor areas [internal v externally cued movts]

-overlapping synergies in the primary motor cortex

-critical role of the cerebellum in motor and cognitive prediction

-basal ganglia- mvt selection and reward

-parallel pathways from the cortex to the spinal cord

-the complex roles of the spinal cord

Motor Control- Sensory Systems

- The idea/stimulus for mvt may be driven by the receipt of sensory information but is not necessarily reliant on it
- -many activities are undertaken automatically although they may be brought under conscious control
- - a number of automatic rhythmical activities are generated at the level of the brain stem or spinal cord [central pattern generators for locomotion, respiratory system
- Sensory information is necessary for both the control/modulation/refining of movement and for updating/learning new mvts
- -transforms inputs into sensory signals that enter and travel through the CNS

Motor Control- Sensory Systems

- For movt and function, the 3 main systems that are NB for providing sensory information are the :
- -**Somatosensory System-** both cutaneous and proprioception input.
- Reference to the supporting surface and of one body segment in relation to another

-**Visual System**

Reference to objects and the environment [especially vertically]

-**Vestibular System**

Reference to head position/motion/gravity

Each system provides a different frame of reference for mvt and postural control, and are used/prioritised differently for different tasks and stages of learning.

Sensory Systems- Visual

- **Visual system** – provide information on both:
- -the position of the head/body in relation to its body parts and in respect to objects and the environment [esp in relation to vertically]
- -object identification itself and the determination of their movt in respect to self.
- -the process of receiving light and converting this light energy into a recognised entity of a visual image of the world
- For motor control need the ability to rapidly discriminate subtle differences in contrast, spatial position and colour.

Microscopic anatomy of the retina

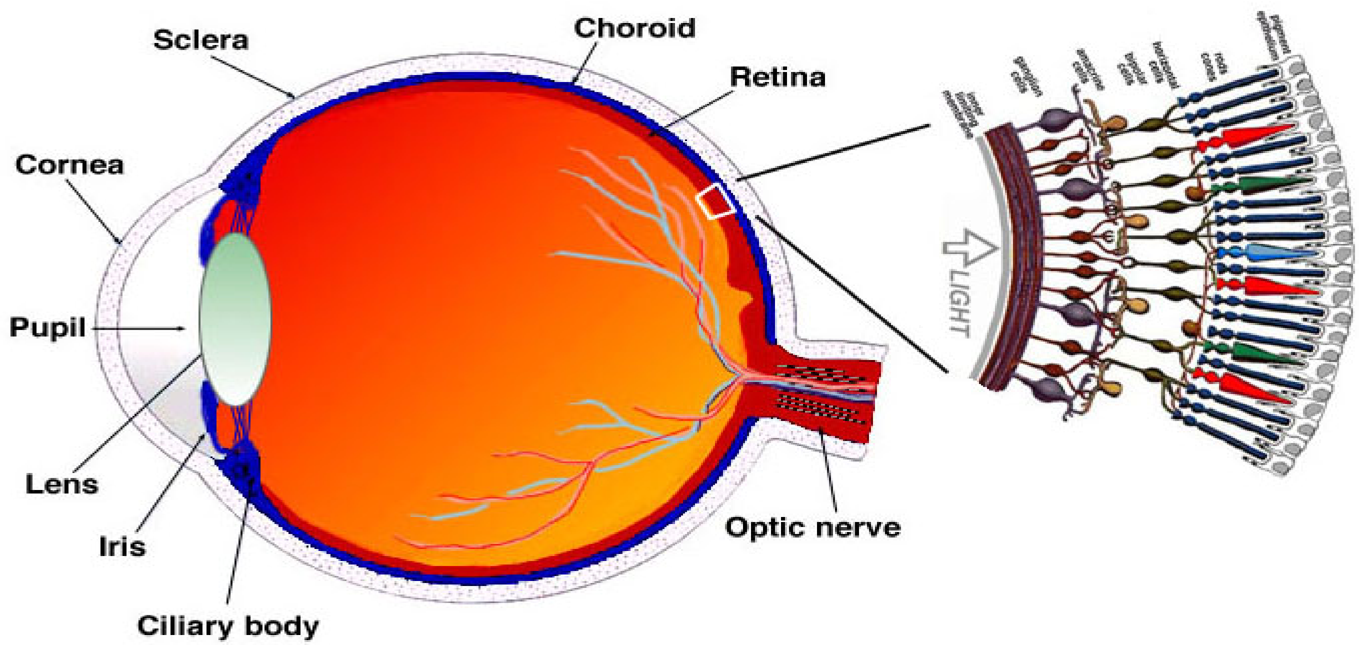
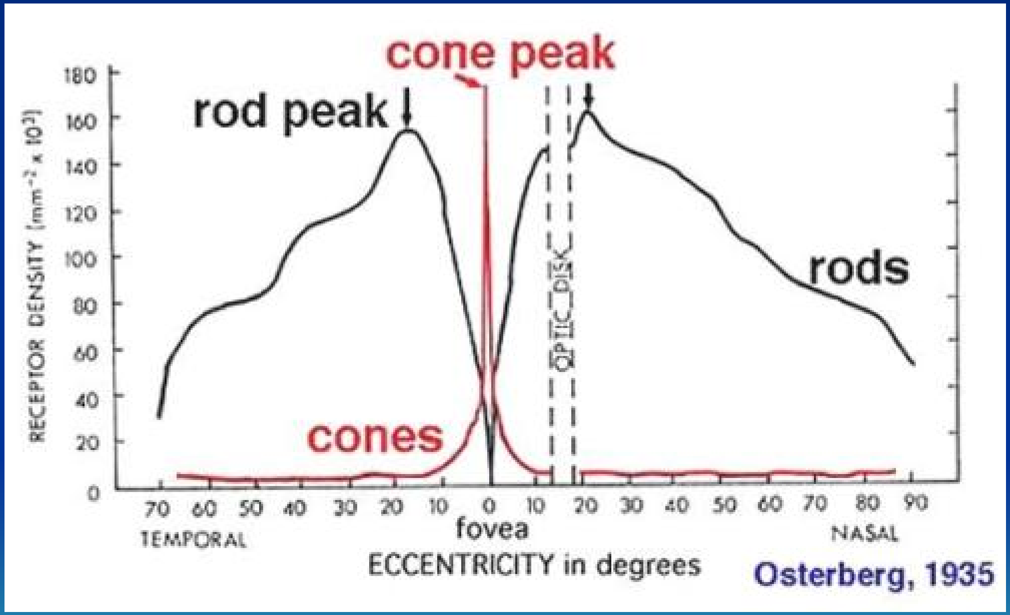


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Rods and cones in the retina

- The central **retina** is rich in cones, and in the peripheral **retina** the rods



Complexity of vision

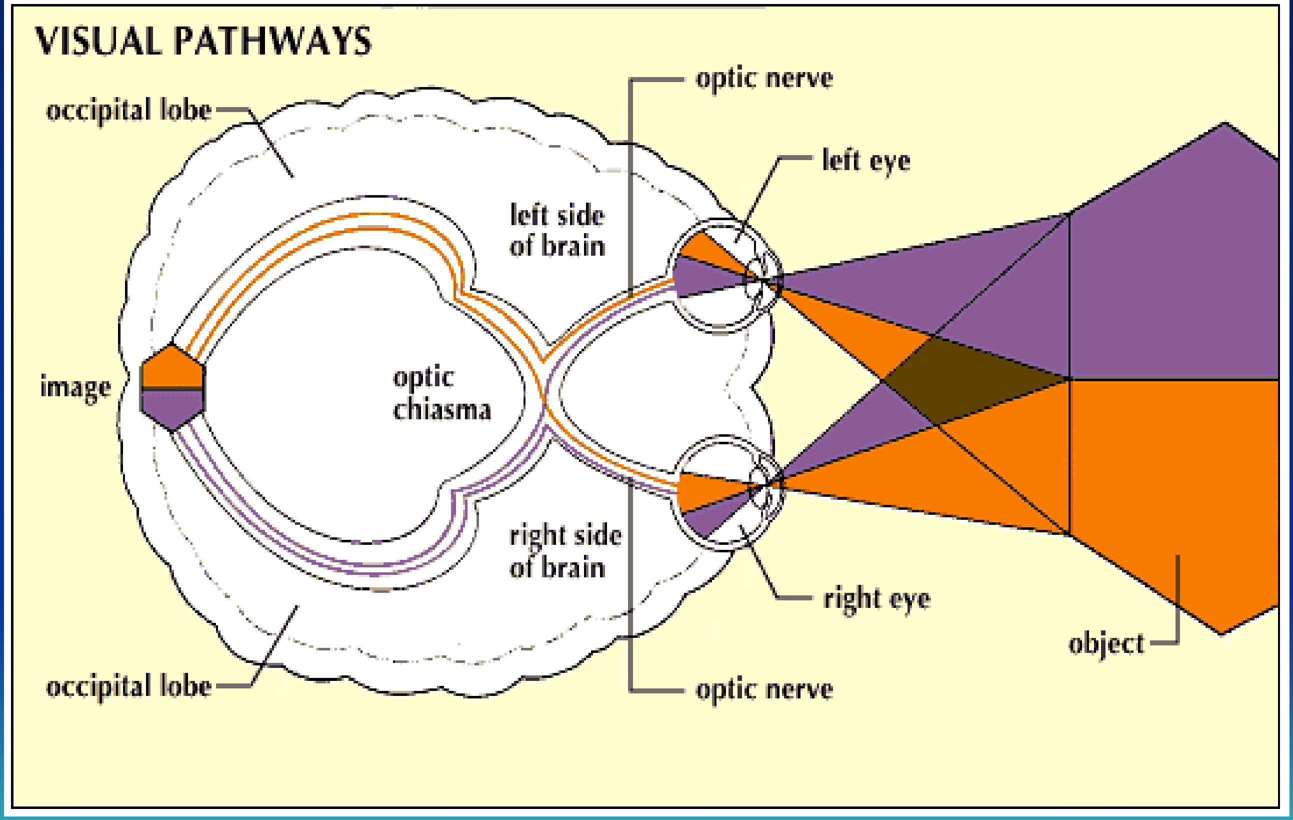
- Not as simple as the eye seeing and the brain interpreting this message.
- A complex construction takes place by the brain of what it thinks it is seeing rather than a literal interpretation of the light that is actually falling onto the eye
- -this interpretation can be seen with optical/visual illusions where the brain struggles to work out the correct interpretation
- To support this complex process, there are about 10 different pathways taking information received in the eye to different brain regions.- the pathway to VI via the lateral geniculate nucleus gives the greatest contribution to our visual awareness.
- Despite the pathways and the complexity of the system, we have a limited capacity in the amount of information that we can be aware of at any one time →inattentional blindness.

Optic nerve

- Unlike most of the other cranial nerves
- The optic nerve is a projection of the CNS and does not have its cell bodies in the brain stem [offactory nerve is similar]

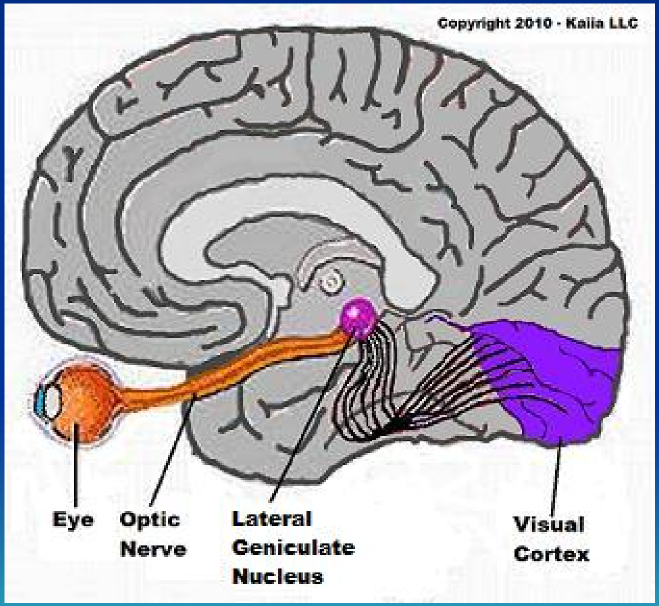
Optic nerve

- Visual pathway



Visual system

- Any problem that impairs or interrupts this pathway leads to loss of vision



Visual system

- Able to move and maintain postural control without visual input- however, we lose information about self within the environment.

-increased postural sway during quiet stance with eyes closed compared with eyes open [Romberg Quotient]

-More difficult balance tasks are associated with increased dependence on vision

-greater reliance on vision during learning.

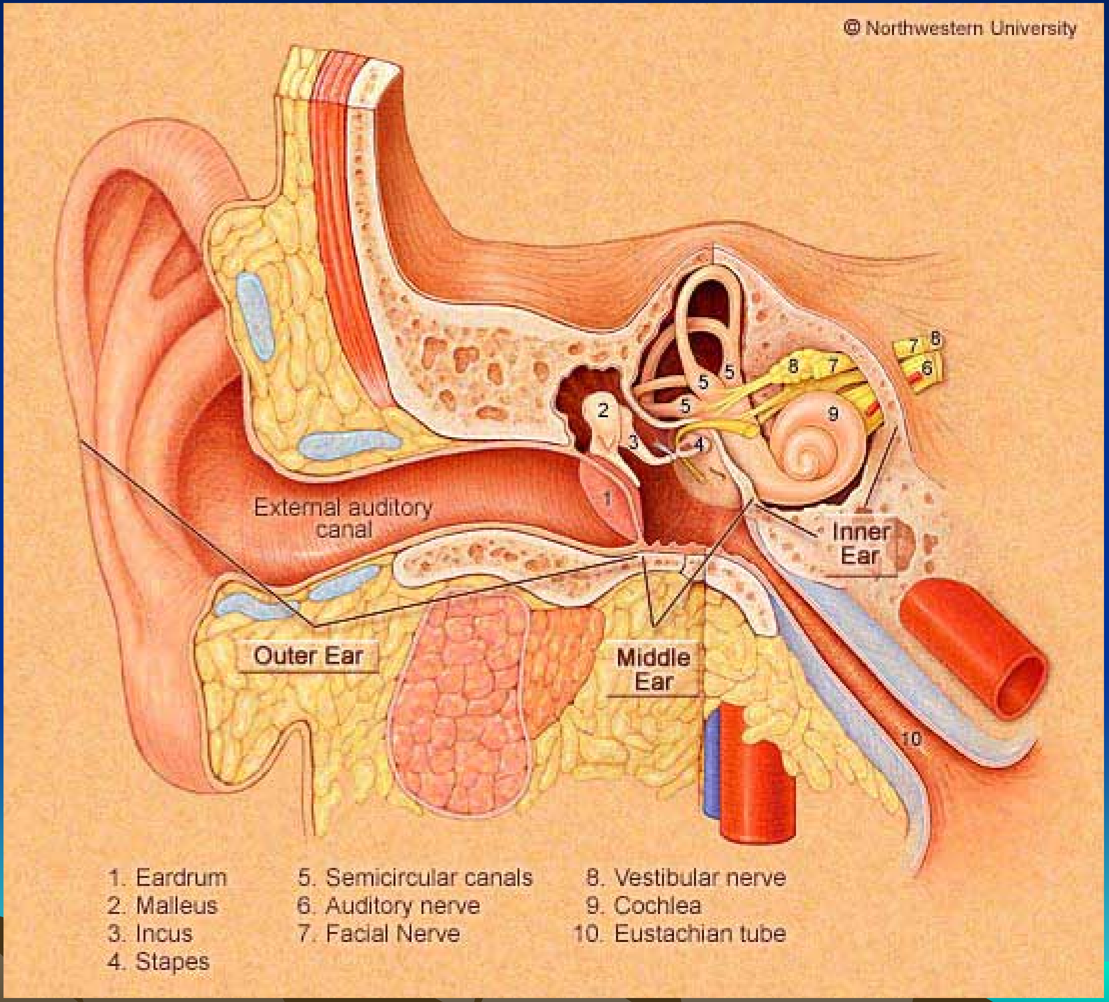
System can become confused between mvt of self and mvt of objects- unable to distinguish inappropriate motor response

-difficult to distinguishing between exocentric and egocentric motion.

Vestibular input

- Provides info regarding the position of head in space [with particular respect to gravity] and sudden changes in direction [acceleration]
- - gives a gravito-inertial frame of reference
- Involved in the control of mvt/balance through:
- - the direction and perception of head in relation to neck movement/position
- The initiation of compensatory eye mvts during head mvts to keep images in the visual field still [gaze stabilisation]
- - vestibulo-ocular reflex
- - the initiation of compensatory postural adjustments of the trunk and limbs.

Vestibular system



Function of Vestibular system

- -to detect the mvts of the body in all 3 planes
- - detects the position of the head and its relationship to the rest of the body [gravitational vector]
- -weight of the otoconia crystals within the maculae creates a gravitational pull on the otoconial membrane and then on to the surrounding stereocilia
- -when combined with other sensory inputs contributes to:
- -stabilising the gaze when the head moves
- Maintenance of balance
- Maintaining activity of the autonomic nervous system

Output from vestibular system

- Information from the VIII CN is received centrally in one of 4 vestibular nuclei within the medulla of the brainstem- processing occurs to make sense of the info received from all 5 components of the peripheral vestibular apparatus from both ears.
- Output from the vestibular system go to:
- - spinal cord [VST]
- - contralateral vestibular nuclei
- - cerebellum
- - cranial nerves supplying the muscles that move the eyes
- - reticular formation
- - thalamus to higher cortical regions
- - autonomic nervous system
- Vestibular nuclei also receives inputs from the cerebellum and reticular formation

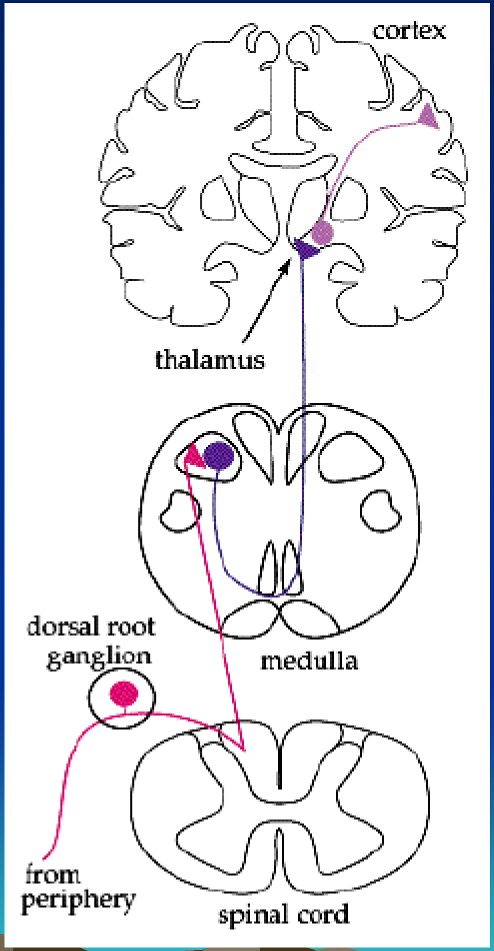
Vestibular reflexes

- Vestibular Ocular Reflex [VOR]- stabilise the visual axis to minimise retinal image motion [gaze stabilisation]
- Vestibulospinal Reflex [VSR]- stabilise head in space through activation of neck muscles [brain stem]
- All extremely short latency responses with second order sensory neurones also acting as premotor neurones synapsing directly with motor neurones

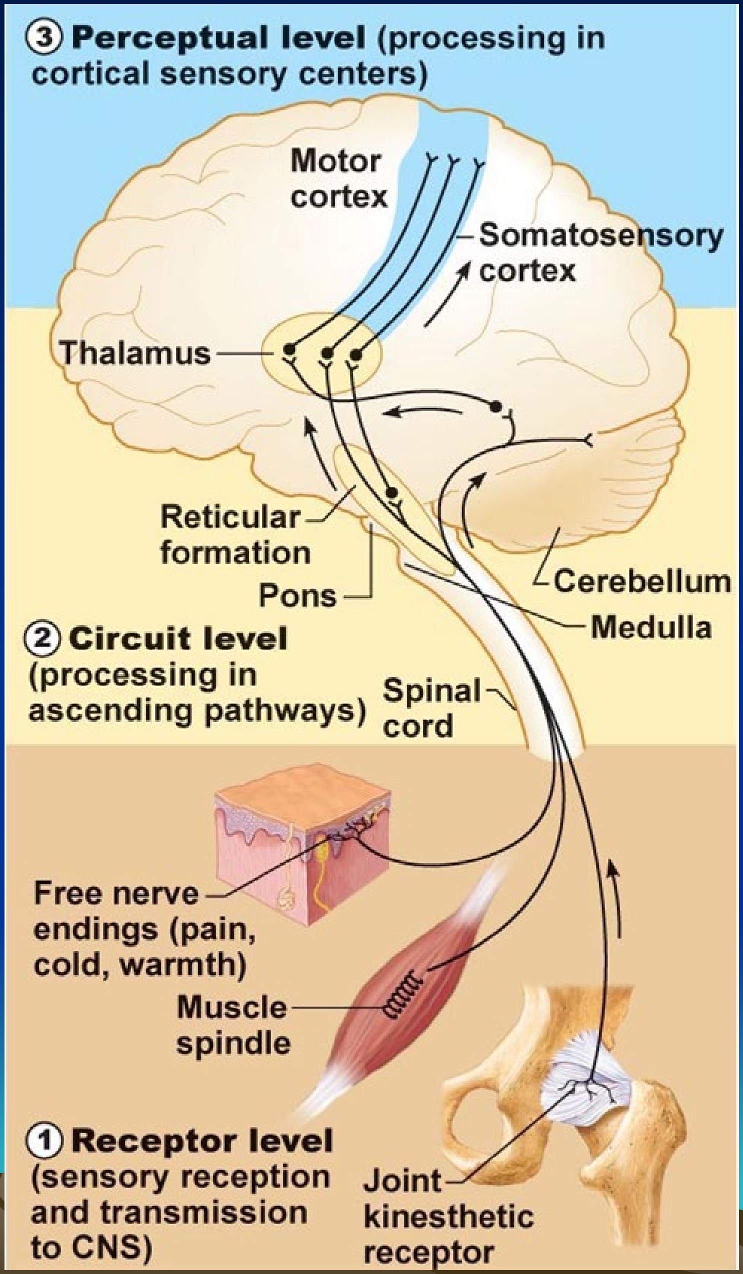
Somatosensory input

- Provides info re the position of the body with respect to the supporting surface [in respect to horizontal] and/or one body part in relation to another.
- Muscle spindles – signal change in length and speed of change, but significantly influenced by the muscle history
- Golgi tendon organs [change in tension]
- Cutaneous and pressure receptors in the skin
- Joint receptors
- Provide information for perception of proprioception, touch, pressure, pain and temperature.

Basic Somatosensory pathway



Three basic levels of neural integration in sensory systems

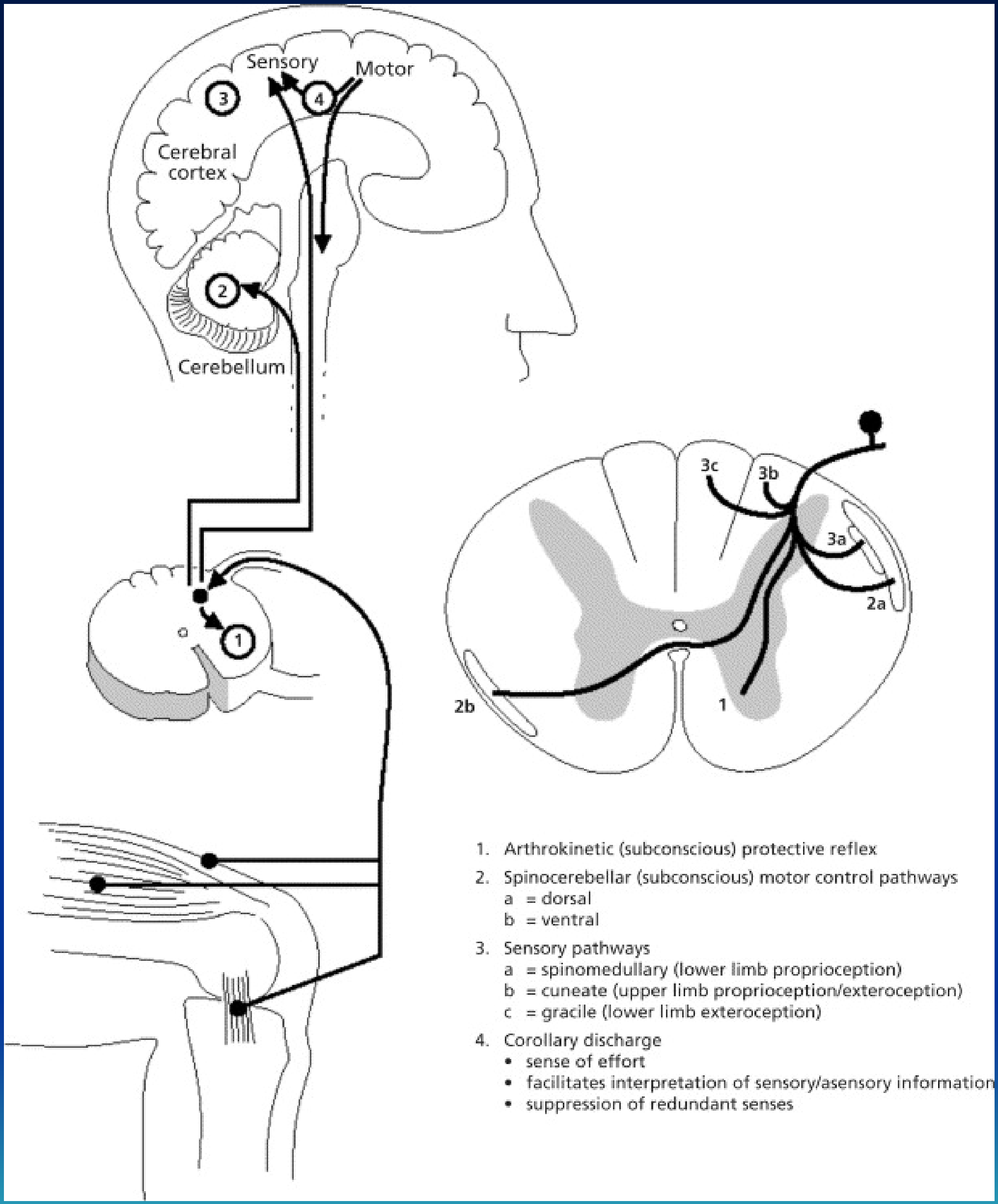


Muscle spindles

- Information from muscle spindles provides priopriоceptive /kinaesthetic information
- Muscle history in relation to previous activity [eg slack or on stretch] confers kinaesthetic awareness
- Cutaneous receptors also provide kinaesthetic awareness
- It is thought that joint receptor information is relatively minor

Afferent Pathway

- the nerve structures through which an impulse, especially a sensory impression, is conducted to the cerebral cortex



Majority of afferents that arrive in the spinal cord terminate at interneurones.

Interneurones receive both inhibitory and excitatory impulses from both a multitude of peripheral receptors and descending pathways.

Combined effect of these will direct the output from these interneurones.

Afferents

- Afferents may:
- - be processed and acted upon at same level of the spinal cord- either ipsilaterally and/or contralaterally
- - this processing may be either through linear summation or non linear mechanisms eg inhibition/excitation

-the processing/integration that occurs is open to neuroplastic change

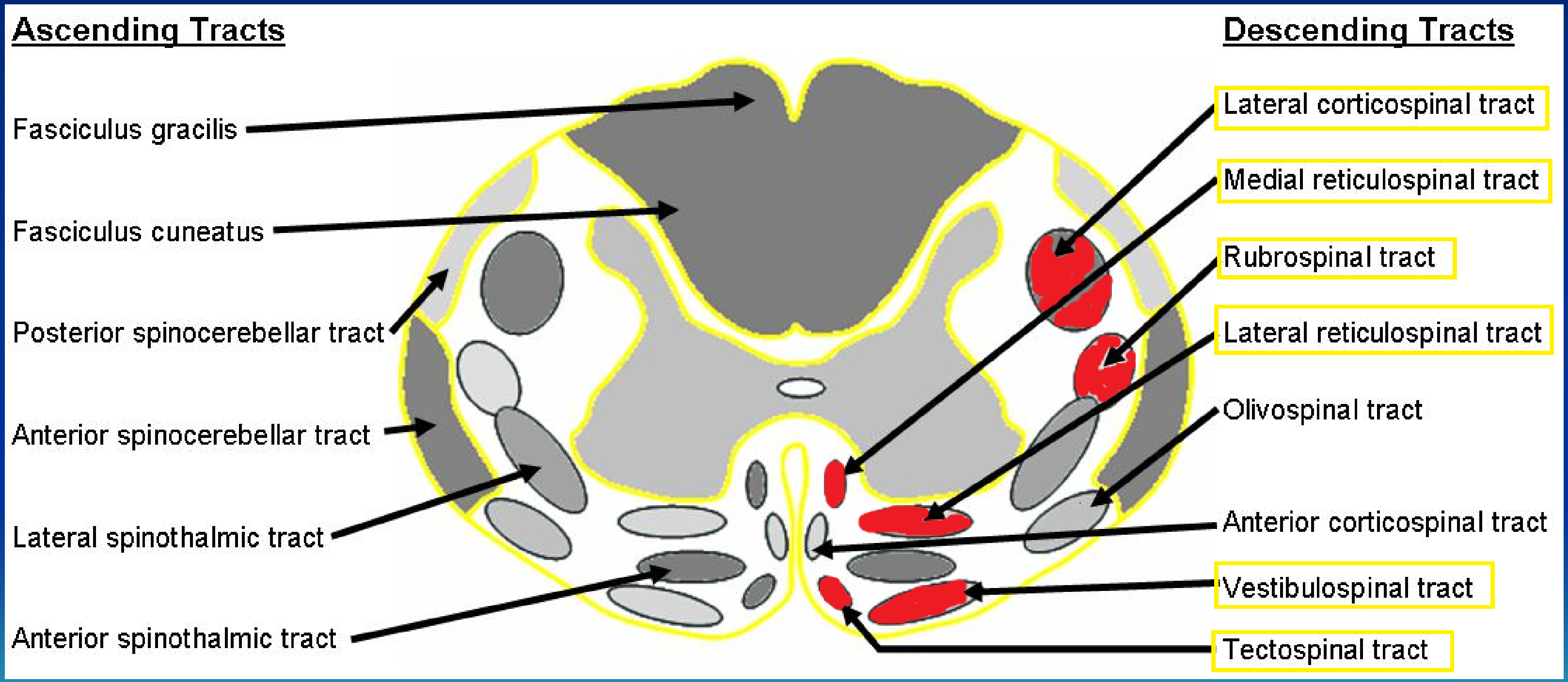
Travels up or down within one or two spinal cord levels

Ascends centrally to higher cortical regions

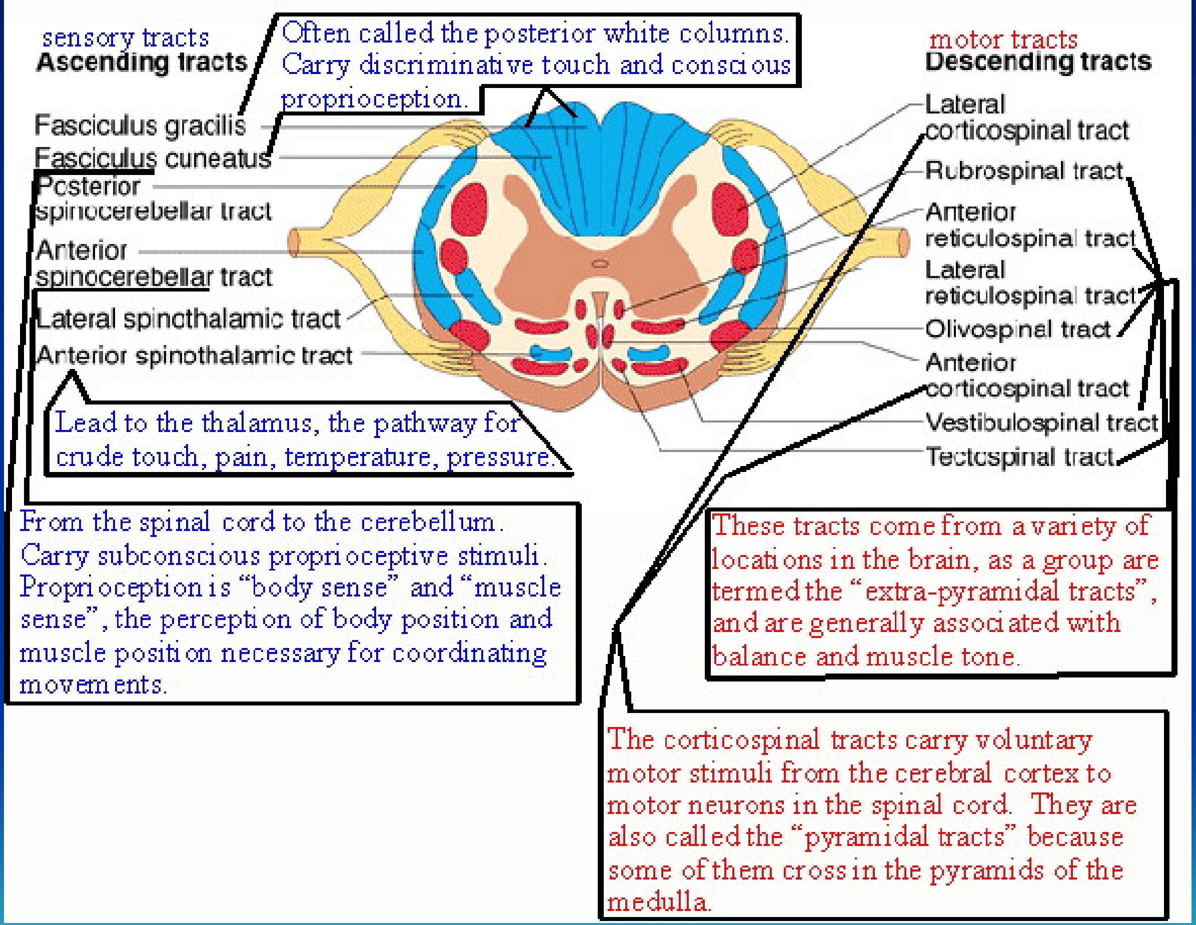
Ascending pathways

- Topographically organised within the cord and somatotopically organised within each tract
- Anterolateral system [eg spinothalamic tract] – main temperature and pain, also crude touch/proprioception
- Dorsal-column medial lemniscal system –main discriminative fine touch/proprioception, lower limb proprioceptive afferents ascend in a separate lateral column from cervical/thoracic inputs- come together as the medical lemniscus within the medulla
- Spinocerebellar –main project afferents from muscle spindles, GTO and skin, providing subconscious proprioceptive information
- Dorsal and ventral pathways comprising large diameter, myelinated fibres - allow for fast transmission.

Major ascending (sensory) and descending (motor) tracts of the spinal cord – cross section view



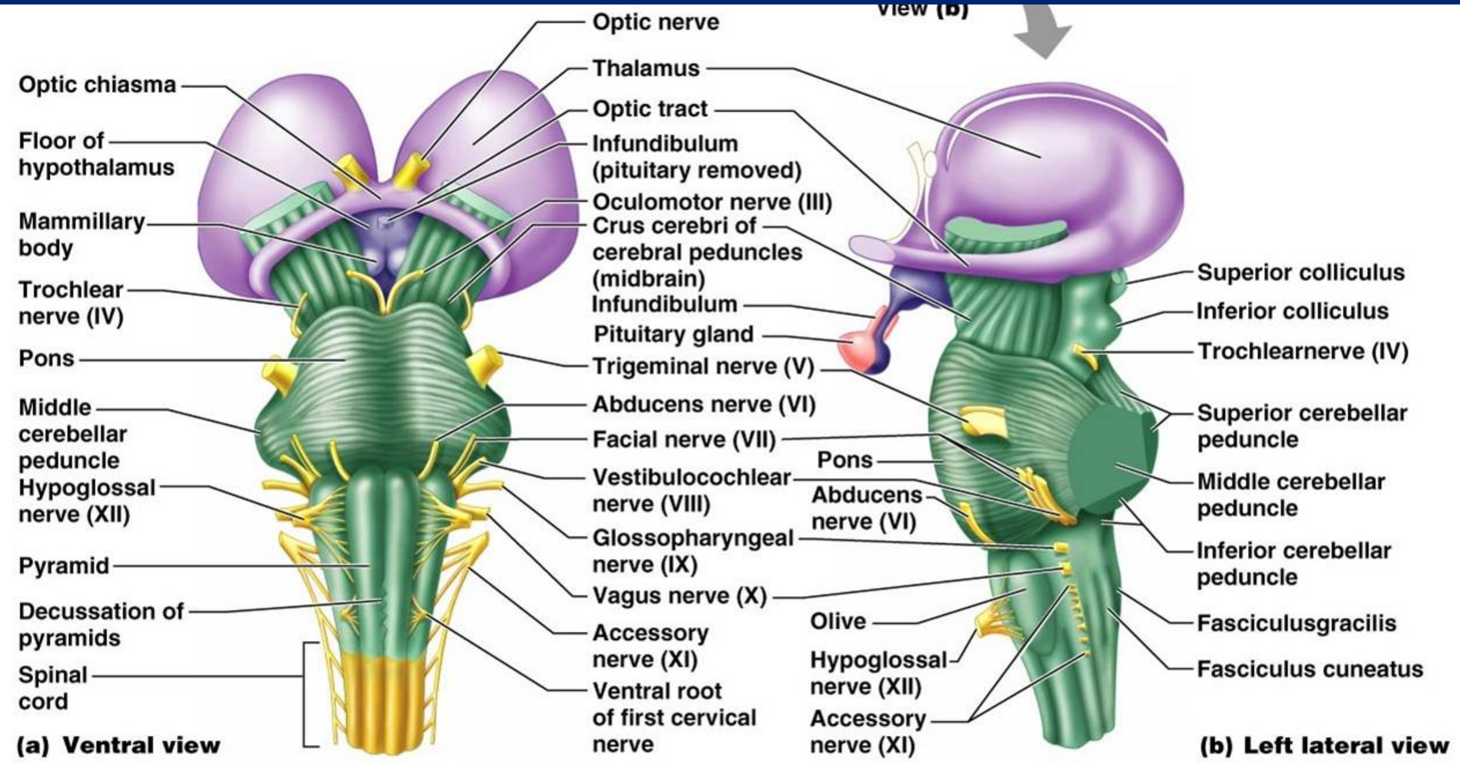
The Spinal Tracts



Brain Stem

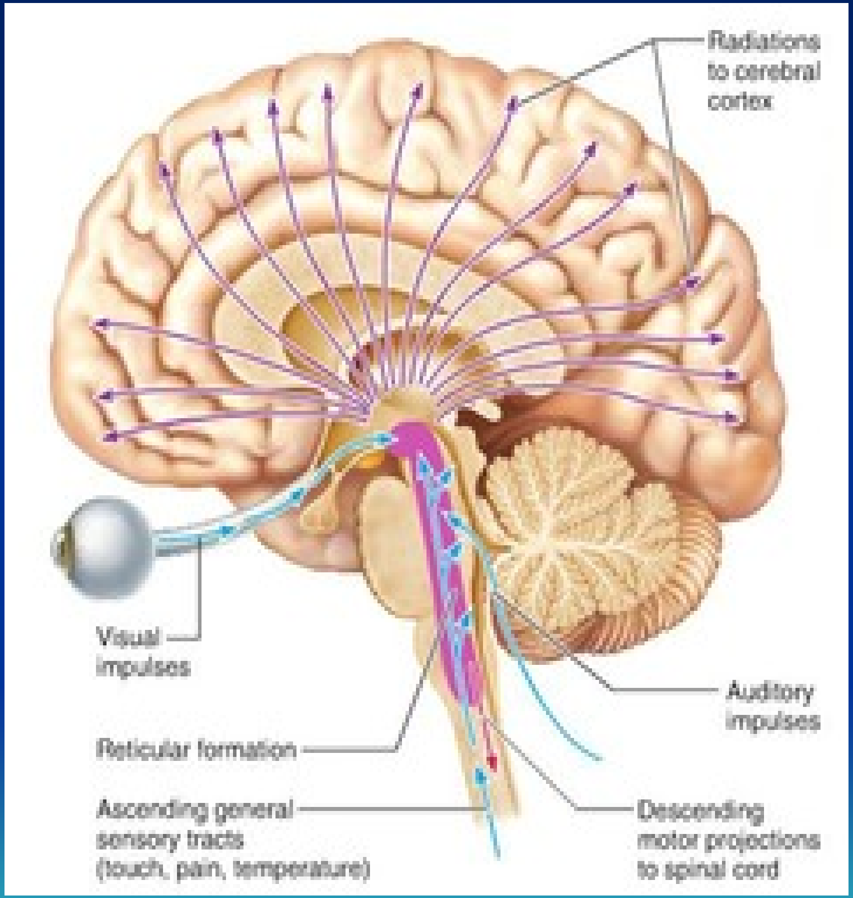
- Consists of the medulla, pons and midbrain
- - contains numerous ascending and descending pathways
- - communicates with the cerebellum – via cerebellar peduncles
- -contains cranial nerve nuclei
- -contains reticular formation [NB for levels of consciousness, pain, perception etc and connects with range of cranial nerve nuclei, cerebellum, limbic systems]
- -mediates various parasympathetic reflexes eg cardiac output, BP, pupillary response

Anatomy of the Brain Stem



Reticular Formation

- 4 key functions:
- 1. mediation of behavioural responses (arousal, alertness)
- 2. modulation of pain perception
- 3. modulation of spinal and cranial motor function (muscle tone, reflexes, body posture)
- 4.Co-ordination of motor survival centres



Thalamus

- Part of the diencephalon containing over 50 nuclei- almost all have reciprocal connections with different regions of the cortex and basal ganglia
- – transmits sensory information except smell
- -receives impulses from the cerebellum and basal ganglia and which are transmitted to regions of the frontal lobe
- -nuclei that have connections with associative and limbic areas of the cortex
- Not just a relay centre but also modulates and processes information

Hypothalamus

- Also part of the diencephalon- consists of a variety of nuclei that control body temp, hunger, thirst
- Influences behaviour through its extensive connections with most other regions of the CNS
- Essential for motivational aspect of mvt- initiating and maintaining behaviours
- Amygdala – part of limbic system
- - receives input from major sensory systems
- -projects to the neocortex, hippocampus, basal ganglia and brainstem
- - involved in emotional/ motivational aspect of mvt and behaviour
- -

Processing

- **Association areas-** found mainly in the prefrontal, parietal and temporal cortices and project to the motor and limbic systems.
- - Do not have a primary motor or sensory role but one of processing
- Three main areas of importance:
- -Anterior association area [three regions within the prefrontal cortex]- involved the purposive aspect and planning of mvt
- - holds, weighs up and organises events from memory for prospective actions – determines consequences of actions
- -posterior association area- integrates information from different sensory systems for perception
- -limbic association area- involved with the emotional aspects of mvt
- Integration between the association areas provides comprehension, cognition and consciousness

Pre-frontal Cortex

- Large area at the front of the frontal lobe [greatest size in humans compared to any other species]
- Main role:
- Motivation and planning purposeful mvt in response to incoming stimuli- judgement, foresight, prediction, responsibility

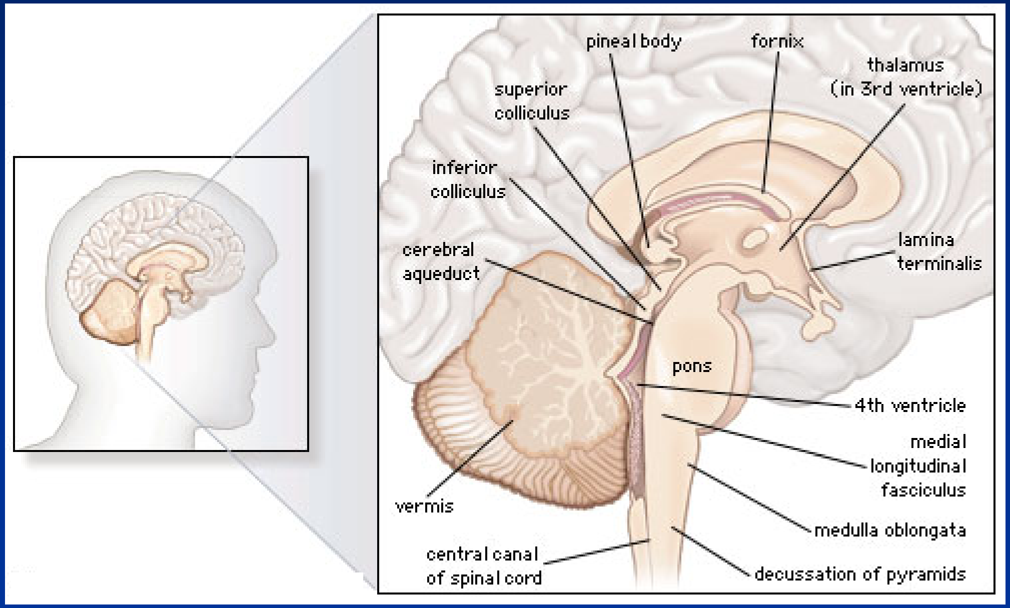
Association areas- Processing

- Link between the sensory and motor systems.
- -interpretation of sensory information, association of perceptions and previous experience, focusing of attention and exploration/understanding the environment
- -ability to carry out skills mvts whilst performing cognitive tasks
- - the degree of attention that needs to be given to a task, including balance will depend on the context and the environment which changes with aging and pathology.

Cerebellum

- Located within the posterior fossa under the occipital lobe.
- - plays a major role in the co-ordination of mvt [esp complex mvts]
- - like the basal ganglia the cerebellum plays this important role without any direct motor output to the motor neurons of the brainstem.
- -plays a large role in the generation of smooth mvt and predictive motor learning- achieved through learning
- - role in cognition, learning, language, speech, attention, visual motion perception and higher executive function

Cerebellum



pineal body
fornix
thalamus
(in 3rd ventricle)
superior
colliculus
inferior
colliculus
cerebral
aqueduct
lamina
terminalis
pons
4th ventricle
medial
longitudinal
fasciculus
vermis
medulla oblongata
central canal
of spinal cord
decussation of pyramids

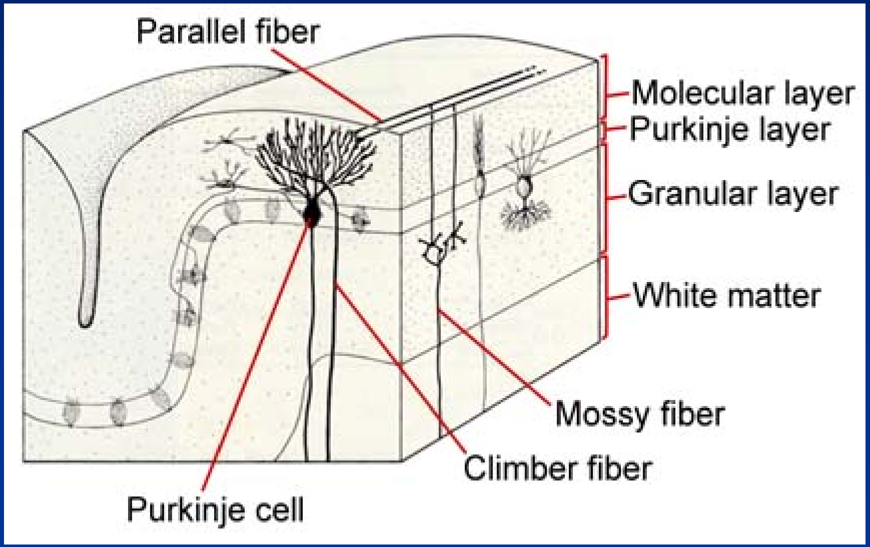
Cerebellum processing

- Receives afferent information from almost all sensory systems as well the motor cortices- receives 40 times more inputs than leave it
- - primary input from:
- - peripheral receptors via the spinocerebellar tract
- -brainstem nuclei
- -vestibular system
- -the cerebral cortex [motor and somatosensory areas, including pre-frontal, premotor areas and posterior parietal lobe]
- -inferior olive from contralateral brainstem

Purkinje cells

- Project to and inhibit the deep cerebellar and vestibular nuclei; neurons then travel out of the cerebellum along the superior cerebellar peduncle to both the brainstem and higher cortical regions
- - seem to bridge the temporal gap between the start of mvt and the availability of proprioceptive/ feedback information
- -provide the underpinning framework for motor learning

Purkinje cell diagram



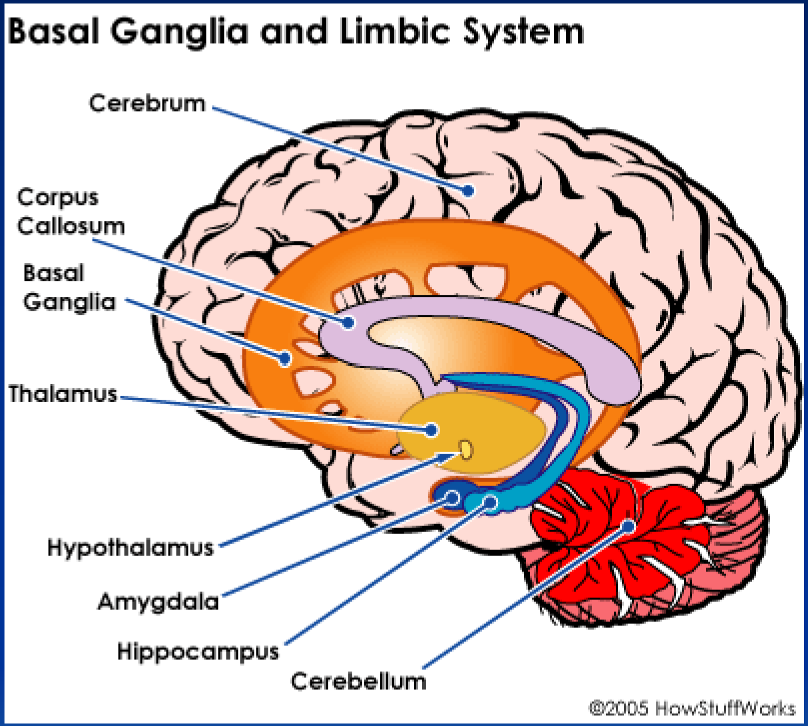
Cerebellum lesions

- Lesions in different regions cause:
- - Floculonodular lobe- ataxia
- - Vermis-reduced posture and balance/ataxia
- -Intermediate zone- tremor
- -lateral hemisphere- poor sequencing of mvt, ataxia

Basal Ganglia

- Essential for mvt but receives no direct sensory input from peripheral receptors and no direct connections to the spinal cord - inputs come from most cortical regions
- - involved in automatic, internally generated mvts- preparation of upcoming mvt

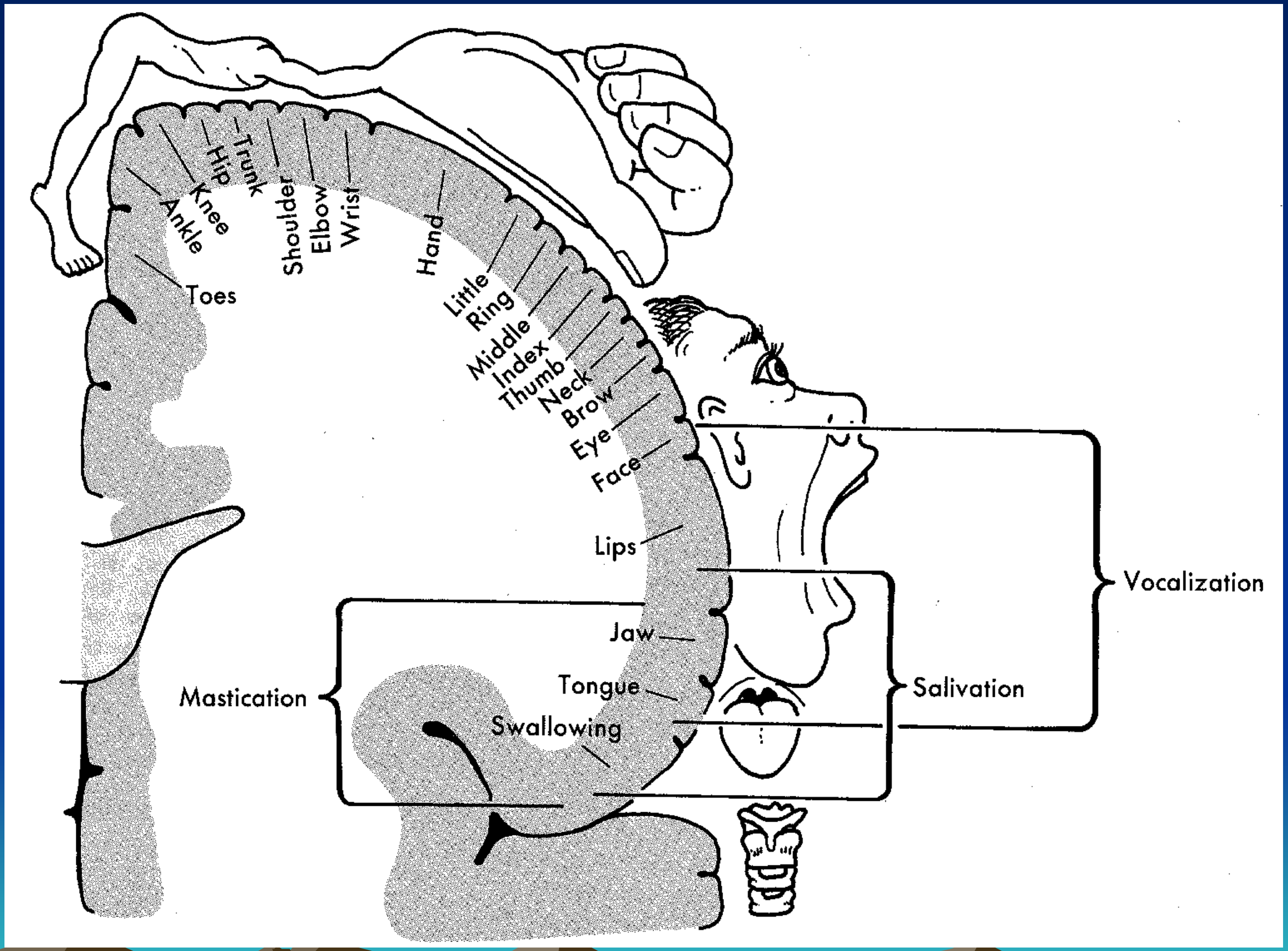
Basal Ganglia



Motor Cortex

- Within the Frontal lobe, there are a number of distinct but interconnected motor cortices [primary motor cortex, supplementary motor area, premotor cortices and the cingulate motor cortex]
- Broadly speaking the primary motor cortex is responsible for the execution of voluntary mvt whereas other regions are concerned with the planning for mvt.

Primary Motor Cortex



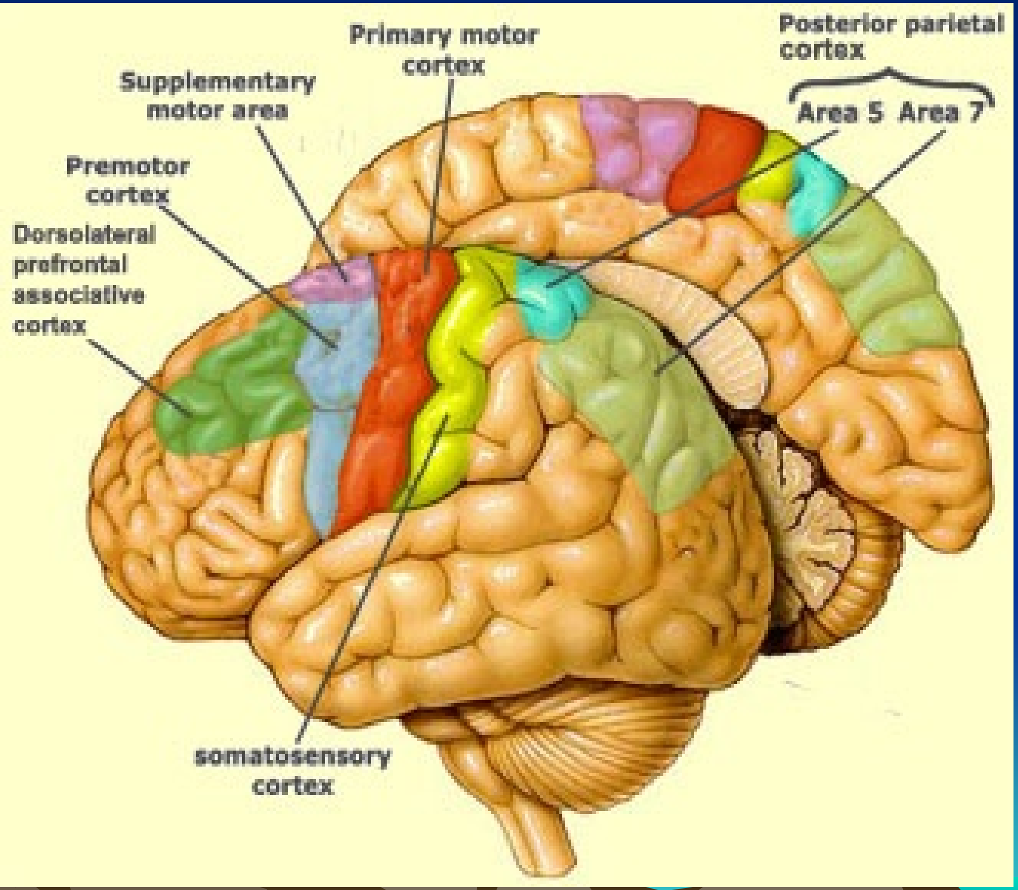
Motor Outputting

- Voluntary mvt is purposeful and organised around performance- activity from one neuron may therefore lead to the firing of a number of muscles and, depending on the activity being undertaken, different neurons might activate centrally at different times to activate the same muscle.
- Firing of neurons is refined/improved by experience and learning with the pattern remaining in the same but the amplitude and timing altering with changes in sensory input.

Motor Outputting

- Motor cortex particularly involved in the control of complex mvts [eg bilateral movts] that are internally generated [i.e from past experience/motor programmes of learnt experiences] and requiring temporal organisation
- Neurones activated more in preparation for mvt rather than during the execution of the mvt itself- specifying what is to come rather than what is happening.

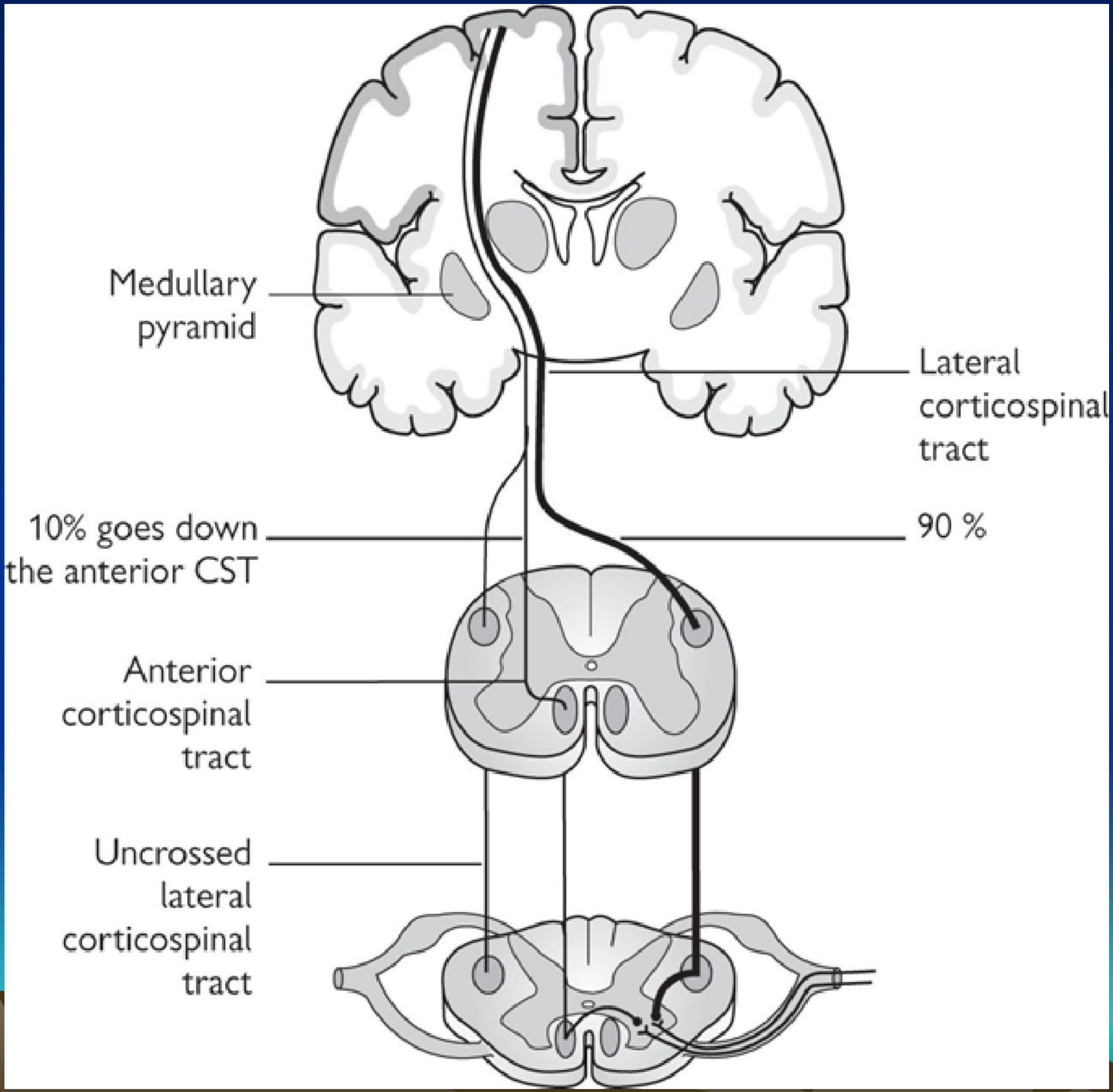
Premotor Cortex



Premotor Cortex

- Outputs to the primary motor cortex, brainstem regions and spinal cord.
- Involved in the generation of more complex mvts [eg of more than 1 body part] that are given by external cues esp those that are visually guided [esp more dorsal part of premotor region]
- Neurons are activated prior to mvt as well as during mvt itself.

Corticospinal Tract



Corticospinal Tract

- Fibres originate from widespread cortical regions
- Most fibres [approx 80-90%] decussate in the medulla
- Role in:
- -excitation of motor neurons
- -descending control of afferent inputs esp nocioceptive
- -gating and gain in control of spinal reflexes
- -autonomic control
- - long term plasticity of spinal cord circuits
- Trophic functions [flight or fight]

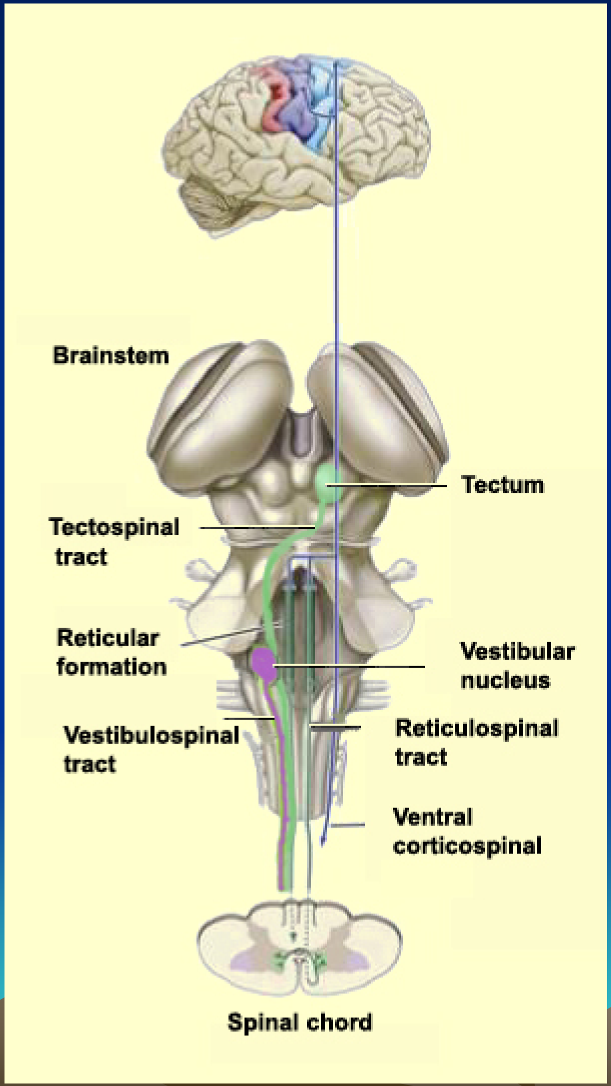
Motor outputting of CST

- CST develops with age- expands in density through childhood – in adulthood there are -1/2 million fibres in the CST
- Most descend in the lateral pathway, with fewer fibres travelling in the anterior column

Vestibulospinal Tract

- Descending motor output
- Largely bilateral postural/extensor activity of trunk and limbs- antigravity, also disynaptic flexor inhibition
- Output may be either anticipatory [feedforward] or reactive [feedback]- primarily in control of posture and balance
- VST acts as a bilateral postural control system [alongside other pathways]

Vestibulospinal, Reticulospinal



Reticulospinal Tract

- Originates in the reticular formation and projects to interneurones of the spinal cord
- Innervates all levels of the spinal cord often bilaterally
- Another important system for balance and postural control.
- Assists in regulation of tone

Reticulospinal Motor Outputting

- RST should allow the recruitment of the correct combination of muscles, with the right levels or activation, sequencing, timing and grading/scaling of activity= smooth ,efficient mvt.
- Deficits that are commonly seen with poor recruitment:
- -inappropriate coactivation and sequencing
- -timing dysfunction- NB for starting, maintaining and stopping mvts
- -scaling/grading dysfunction

The End Part 1