A Beginner's Guide to Neuroanatomy

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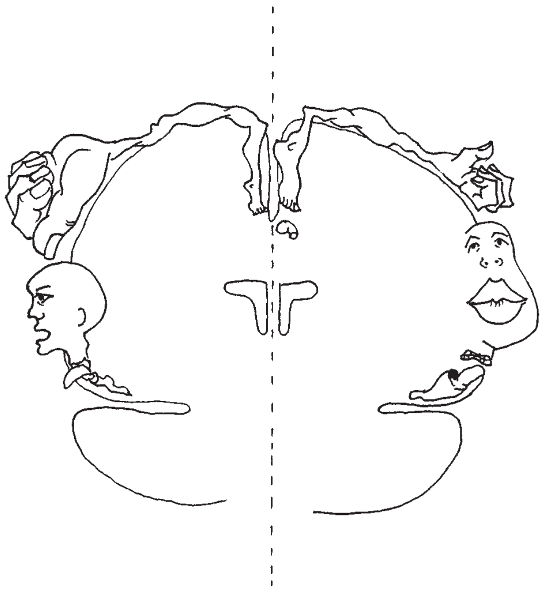

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Introduction

The teaching of Anatomy in general, and of neuroanatomy in particular, has declined during the last fifty years.

Students are expected to search out relevant anatomical explanations when confronted in their clinical years with pathology affecting the nervous system. This could be time-consuming, particularly in the earlier stages of their studies, as some knowledge of neuroanatomy is essential, if only to limit the search to an area likely to be relevant.

This beginner's guide builds on a prior basic knowledge of the gross anatomy of the nervous system. To assist in remembering the descriptive anatomical names, the Latin is translated into English and added in parentheses when each term in introduced.

Alexander Gonski
Neurosurgeon

Sydney, July 2006

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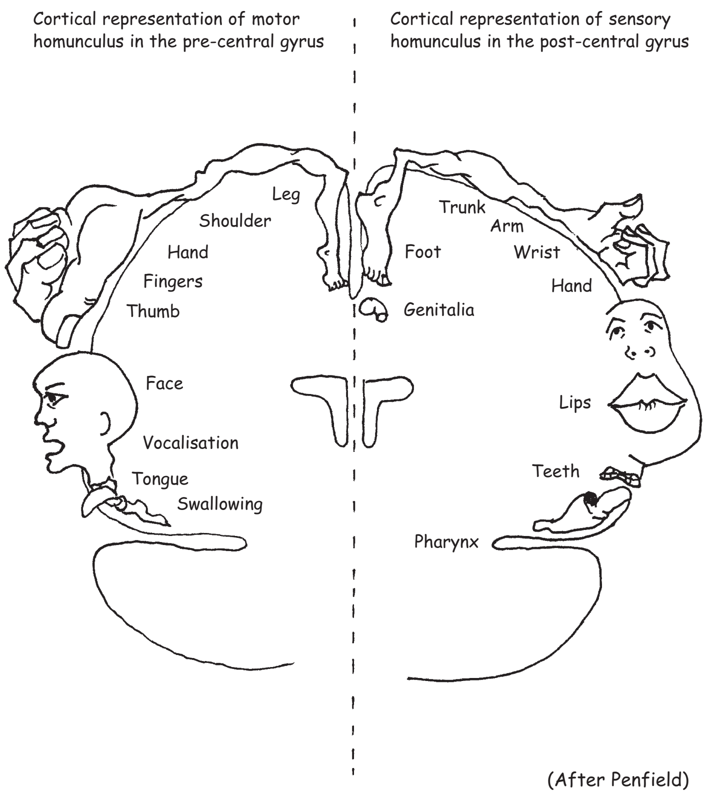


(After Penfield)

1. The brain

The structure of the cerebrum (*brain*) and the configurations of its component parts are easily found in standard books, but the associations between different areas (the fibres connecting one part of the brain with the other parts) need to be understood.

The main association fibres

The corpus callosum (*thick-skinned body*) is the major bundle of association fibres connecting the two cerebral hemispheres. It consists inferiorly of a rostrum (*head*) attached to the lamina terminalis (*terminal plate*), a genu (*knee*), a body and it then expands posteriorly into the splenium (*bandage*). The anterior fibres, the forceps minor (*small tongs*), project into the frontal lobes, whilst posteriorly the fibres of the splenium spread out into the occipital lobes as the forceps major (*large tongs*).

The frontal, temporal and occipital cerebral lobes on each side are connected by a superior longitudinal fasciculus (*little bundle*), whilst the temporal and occipital lobes of each side are connected by an inferior longitudinal fasciculus. Short association, arcuate (*bow-like*) fibres connect neighbouring cerebral areas, whilst intermediate-sized uncinate (*hook-like*) fibres associate the frontal and temporal lobes.

Other connections between the left and right sides of the cerebrum are made by the anterior commissure (*joining seam*), joining the two olfactory bulbs, and by the posterior commissure, a part of the rhinencephalon (*nose brain*), which processes smell sensation.

Cortical representation

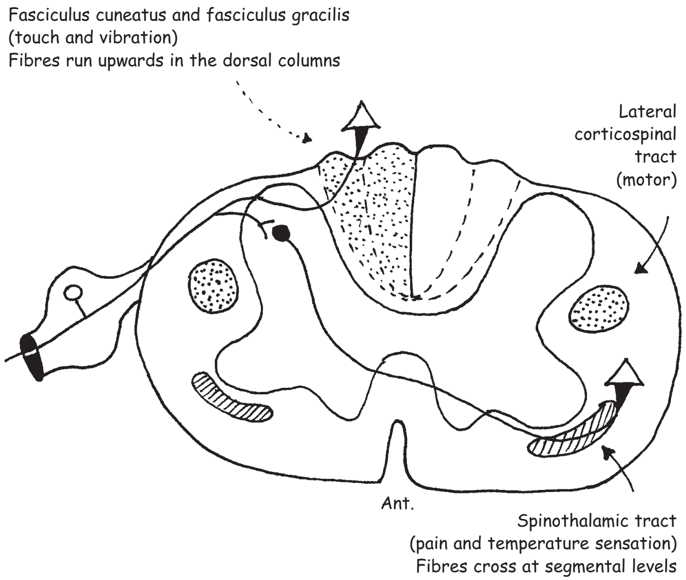
It would be worthwhile looking at pictures of the motor and sensory homunculi (imaginary caricatures of the human body superimposed on the surface of the cerebrum), noting that the lower limb representation is to be found on the medial (internal) aspect of each hemisphere. Note how hugely the hand and face are represented on the lateral aspects of the cortex (*bark*).

2. The spinal cord

This is a compact packaging of white bundles of fibres around a roughly H-shaped core of grey masses of cells. You need to familiarize yourself with the transverse sections of the cord (at cervical, thoracic, lumbar and sacral levels) as well as with the anatomy of simple spinal reflexes. The bundles are called funiculi (*little umbilical cords)*, within which lie the fibre tracts, the fasciculi.

The size of each funiculus depends on the number of fibres it contains; thus, in the posterior columns distally, there is only a fasciculus gracilis (*slender*), which, running cranially, enlarges into a further fasciculus, the fasciculus cuneatus (*wedge-shaped*). This enlargement is due to the inclusion of the extensive sensory fibres from the arm. By contrast, motor bundles are bigger proximally and diminish progressively in size distally. If fasciculi are *bruised* in a spinal cord injury, they have the potential, like peripheral nerves, to recover. However, if the axons within the fasciculi are *severed*, they cannot regenerate.

Cross Section of Lower Cervical Cord

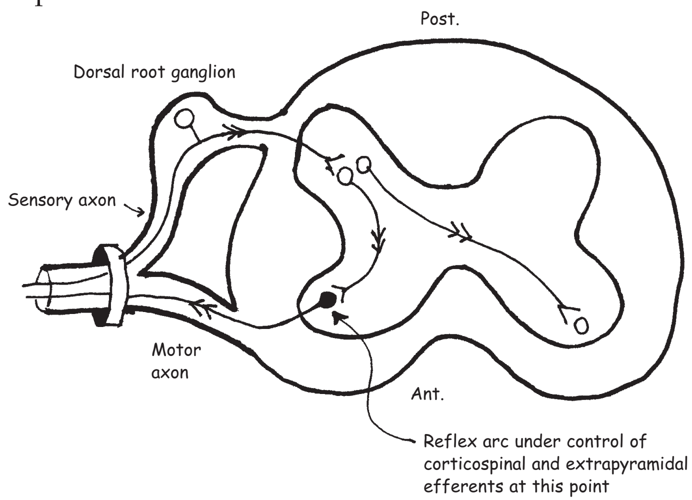


The spinal cord reflex (for instance, the knee-jerk) originates with a stimulus moving along a sensory nerve, entering the body of that nerve cell in the dorsal root ganglion and continuing into the spinal cord. This stimulates neuronal cells in the posterior horn to trigger, through a single synapse, motor cells to emit a stimulus which will activate the relevant muscles. The spinal cord reflex may involve just two or three neurones, but usually many more are involved.

The stimulus can also cross over to the anterior horn cells on the opposite side. Normally these cells are under the control of the cortico-spinal and extrapyramidal efferents, so that a simple, fluid, smooth contraction is produced by a suitable sensory stimulus. Without this controlling input from the cortex, the reflex is exaggerated and repetitive (spastic). These extrapyramidal connections are extensive. They can be followed down from the cerebral cortex to the basal ganglia (p. 18) and the thalamus (*inner chamber* or *bedroom*, p.16): there are cortico-thalamic projection fibres to the globus pallidus (*pale globe*), the caudate (*tail-like*) nuclueus, the corpus striatum (*striped body*) and the substantia nigra (*black substance*).

From the basal ganglia, efferent fibres—a host of descriptively named fibres—associate various nuclear masses, then connect to the anterior horn cells, affecting tone and repetitive movements and fulfilling other facilitatory functions, including inhibition of movement.

Spinal Cord Reflex Arc

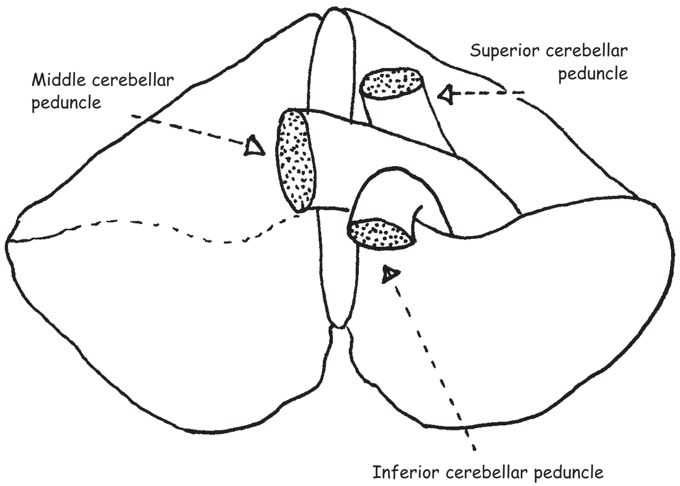


3. The cerebellum

The primary function of the cerebellum (*little brain*) is the synergy (co-ordination) of repetitive movement. Such movement requires proprioceptive information (messages about internal sensations, such as movements of muscles and joints) from the entire body, in order for exteroceptive, indirect influences to be correlated and then forwarded to both the cognitive and motor areas of the brain.

For this complex correlation to be effective, communication is needed between the cerebellum, the cord and the rest of the body (via the brainstem and spinal cord), as well as from cells of the spinal cord themselves. This communication is the function of the three cerebellar peduncles (*little feet*).

Ventral aspect of the Cerebellum



4. The cerebellar peduncles

The middle peduncles are the most prominent of the three, consisting of fibres uniting the cerebrum and the cerebellum. They originate from the pyramidal cells of the frontal and temporal cerebral lobes and end in the nuclei ponti (*nuclei of the bridge*). From here, most of the connecting axons cross the midline and aggregate to form the middle cerebellar peduncle entering the cerebellum and the cerebellar cortex; from here, efferent fibres pass to the deep cerebellar nuclei.

The superior cerebellar peduncles originate from fibres arising in the dentate (*tooth-like*) nucleus of the cerebellum and run mainly to the red nucleus of the mesencephalon (*midbrain*). Some fibres can be identified again in the reticular (*net-like*) formation, where they cross over to the other side, in the superior cerebellar decussation (*crossing over*). From the red nucleus, fibres descend down the rubro(*red*)-spinal tract to the spinal cord. The fibres within the reticular formation re-form and proceed distally as the reticulo-spinal tract.

The inferior cerebellar peduncles are composed of ascending fibres from the spinal cord, fibres from the medulla, fibres from the olivary (*olive-shaped*) nucleus, and fibres from the arcuate reticular nuclei, together with the vestibulo-cerebellar fasciculus passing into the cerebellum.

The peduncles form the junction of the cerebrum, cerebellum and brain stem. Fibres cross twice or more often as they progress through the peduncles.

5. The motor system: pyramidal pathways

We do not know how the wish to move a muscle initiates the movement. What we do know is that the earliest motor signal begins in large cells in the cerebral cortex. These cells are found mostly in the prefrontal motor cortex, but they do exist elsewhere in the cerebral cortex.

They induce a flow down their axons which course through the white matter (fibres) to the internal capsule—a boomerang-shaped area bounded anteriorly by the caudate nucleus, posteriorly on its medial aspect by the thalamus and postero-laterally by the lentiform (*lens-shaped*) nucleus.

This bundle of fibres, recognisable as the cortico-spinal (or pyramidal) tract, passes through the midbrain (in the pes pedunculi - *foot of the little feet*) into the pons (*bridge*) and then into the medulla (*marrow*). Here the tracts cross over to the opposite side in the pyramidal decussation (previously called the pyramids). They then pass into the postero-lateral compartment of the spinal cord until, in turn, they reach the level of the relevant muscle, where the axons synapse with another cell or, more probably, with a group of cells, known as the anterior horn cells, in the grey matter of the cord.

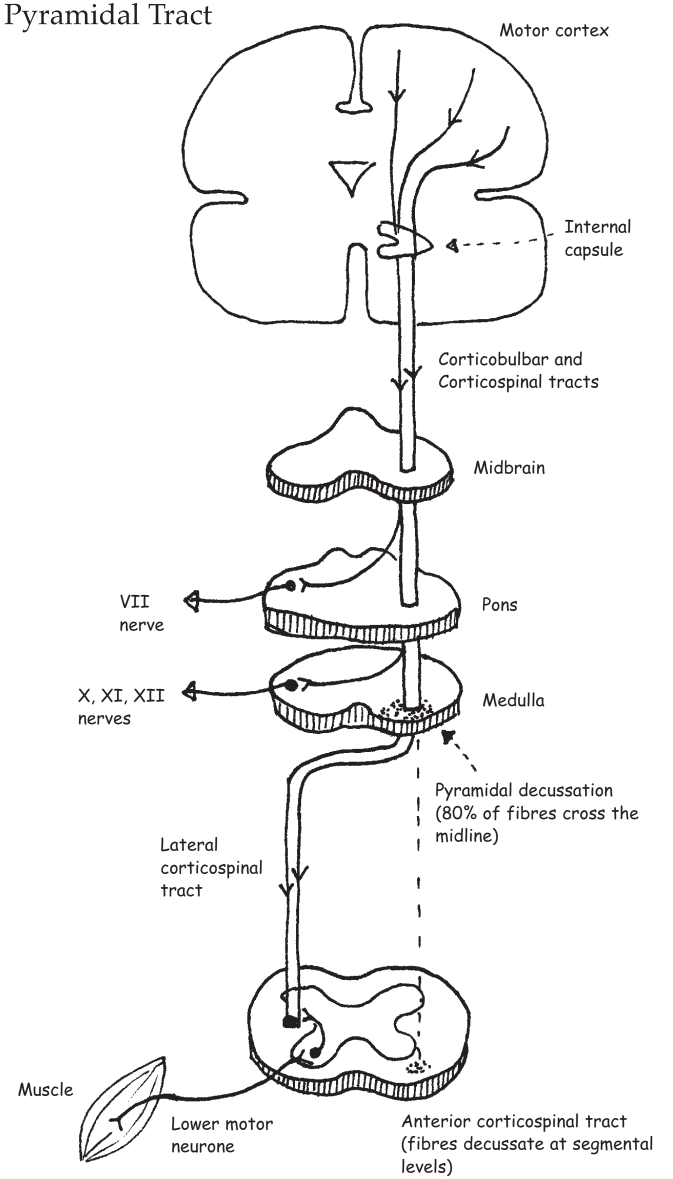
The synapse is not a discrete, one-to-one stimulation, as the anterior horn cells are also bombarded by impulses from other cortico-spinal units and from cells of the extra-pyramidal system.

6. The motor system: extra-pyramidal pathways

All fibres originating in the cerebral or cerebellar tissues and coursing down to synapse with the anterior horn cells, *other than* the pyramidal (ie cortico-spinal) tracts, are called extra-pyramidal. Their origins are varied, some from the cerebral cortex and others from the cerebellum or its nuclei.

Their names, such as vestibulo-spinal or more complex names, such as cerebello-ponto-spinal, generally indicate their origins and destinations. These pathways modify the effects of the pyramidal pathways on the anterior horn cell by inhibiting, facilitating and overall, by regulating, the stimulated anterior horn cells. Major cell areas such as the basal ganglia and the reticular formation are described later.

Pyramidal Tract



(After Collander)

7. The lower motor neurones

The bodies of these cells lie in the anterior part of the spinal cord, grey in colour because of the abundance of cells with comparatively few fibres. We noted above how these cells are stimulated or affected by synapsing with the upper motor neurone system and the extrapyramidal system.

The axons of these cells then leave the cord, some joining with others of the posterior nerve root to constitute the spinal cord reflex, whilst the majority exit as the motor (anterior) nerve root. They then join with the sensory fibres to form the peripheral nerve or plexus coursing on to the appropriate muscle endings at the motor nerve end-plate.

8. The sensory system

This is more complicated than the motor pathways. It is the way sensations are transmitted to the sensorium, that part of the cerebral cortex in which sensation is represented.

Whereas the motor pathways are a 'two-neurone' system, with the upper motor neurone connecting the cortex to the anterior horn cell and the lower motor neurone connecting the anterior horn cell to the motor end-plate, sensation is a three-neurone system.

Sensation from the skin, joints, muscles and organs, and the special senses are discussed. The following points are general.

Different sensations are perceived and transmitted differently: touch, pain, temperature (hot and cold) and vibration. Sensations from the joints travel with sensations from the skin, but joint and vibration modes course up primarily in the dorsal columns.

i. **Touch** is perceived by tactile receptors (Meissner's corpuscles) which transmit impulses along the nerve fibres of the peripheral nerves to the cell bodies of those nerves clustered in the dorsal root ganglia (singular: ganglion), adjacent to, but outside, the spinal cord. This is the first sensory neurone. Its branches enter the dorsal funiculus of the spinal cord. Here, fibres carrying touch sensation divide into two groups. One group crosses the midline to enter the spino-thalamic tract; the other does not yet cross, but continues cranially in the dorsal funiculus (the fasciculus gracilis and lateral to it, in the fasciculus cuneatus).

   The fibres which crossed over into the spino-thalamic tract lie in the antero-lateral aspect of the spinal cord, and course cranially through the medulla, pons and midbrain (where they are also called the medial fasciculus), into the thalamus, where they synapse onto neurones. These are the second sensory neurones.

   The next and last relay of crossed fibres now pass through the internal capsule to the sensory area of the cortex.

   The uncrossed fibres in the gracilis and cuneatus fasciculi synapse onto cells in the gracilis and cuneatus nuclei at the uppermost part of the spinal cord. These cells are the second sensory neurones in the previously uncrossed pathway.

   From these synapses, new axons cross over to the other side in the sensory decussation of the medulla and enter the medial lemniscus (*ribbon*; plural: lemnisci) where they join up with the spino-thalamic tract which is already in this lemniscus, and all end together in the thalamus. They then course together into the cerebral cortex adjacent to other sensory fibres.

ii. **Pain Sensation** follows the same route map outlined above for touch, into the spino-thalamic tract. Unlike the Meissner's corpuscles sensitive to touch, there are no known nerve endings subserving pain as such. Pain stimuli, to be appreciated, must be directed to the simple nerve endings themselves. Pain tracts follow the peripheral nerves to the lateral root ganglia, then course via the crossed spino-thalamic tract to the thalamus and finally, via the posterior part of the internal capsule, to the sensory cortex.

iii. **Temperature sensation (both hot & cold)** takes the same route as pain. Once again, there are no specialised nerve endings for temperature.

iv. **Vibration sensation** accompanies the fibres of touch, via the dorsal gracilis and cuneatus columns, to the thalamus and so onto the sensorium.

9. The thalamus

The thalamus is the rostral portion of the brainstem; the diencephalon, (*between brain*); it relays and integrates with the pathways from and to the cerebrum and from and to the lower motor centres. It is divided anatomically into the thalamus proper, the hypothalamus, the subthalamus and the epithalamus.

There is one thalamic complex on each side, united minimally across the midline by the massa intermedia (*intermediate mass*). Each is a well-defined mass of grey matter (nuclei) on either side of the third ventricle, is bounded laterally by the internal capsule, and is adjacent anteriorly to the caudate nucleus.

The thalamus functions mainly as an interchange of impulses from other centres, including:

auditory impulses from the inferior colliculus (*little hill*) nucleus via the inferior quadrigeminal (*quadruplets*) brachium (*arm*) onto the auditory cortex in the temporal lobe;

visual impulses from the lateral geniculate (*knee-like*) body of the superior quadrigeminal brachium to the visual cortex in the calcarine (*like a cock's spur*) area of the occipital lobe;

visceral impulses from the bladder and bowel, and their correlation with the higher centres of emotion and cultural inhibition;

arousal impulses from the reticular formation to the cerebral cortex;

pain sensation, perceived in the thalamus and transmitted to the cortex;

balance (cerebellar information) from the dentate nucleus crosses to the red nucleus and thence, via the rubro-spinal and rubro-reticular tracts, to the brain stem and reticular formation; and

cortical information, which passes through the thalamus to the caudate nucleus and globus pallidus and back to the cortex.

The hypothalamus, ie. the optic chiasma, tuber cinereum (*ashy swelling*) and mammillary (*breast-like*) bodies including the infundibulum (*funnel*), has many separate nuclei not discussed

here because of their complexity, and because of uncertainty as to their function.

It should be recalled that this is the 'flight or fight' centre and that autonomous responses originate here; for example, thermo-regulatory, glucose metabolism, fat metabolism factors, and a sleep challenge. This is a fundamental part of the limbic system, terminating via the fornix (*vault*) in the mammillary bodies.

The subthalamus is functionally related to the basal ganglia.

The epithalamus is situated posteriorly to the thalamus and includes the pineal body, whose function has not yet been clearly defined.

10. The basal ganglia

Basal ganglia is the name given to the mass of grey matter deep in the insula (*island*). Note that the thalamus is not included in the basal ganglia. The region is made up of clusters of neuronal cells with fibres passing through them and also integrating with them.

In the coronal section of the brain, starting from the cortical grey matter and working medially, one sees deep to the insula:

- the 'extreme' capsule of fibres;
- the claustrum (*barrier*)—a thin layer of cells;
- the external capsule of fibres;
- the lentiform nucleus continuous with the head of the caudate nucleus anteriorly;
- the internal capsule, described previously, largely composed of the cortico-spinal tract (motor) and also the spino-thalamic tract (sensory); and
- the caudate nucleus, its head anteriorly, body and tail 'wrapping' the above structures, its tail inferiorly, ending in the amygdaloid (*almond-shaped*) nucleus.

NB: More posterior to the head of the caudate nucleus and medial to the internal capsule is the thalamus, previously described.

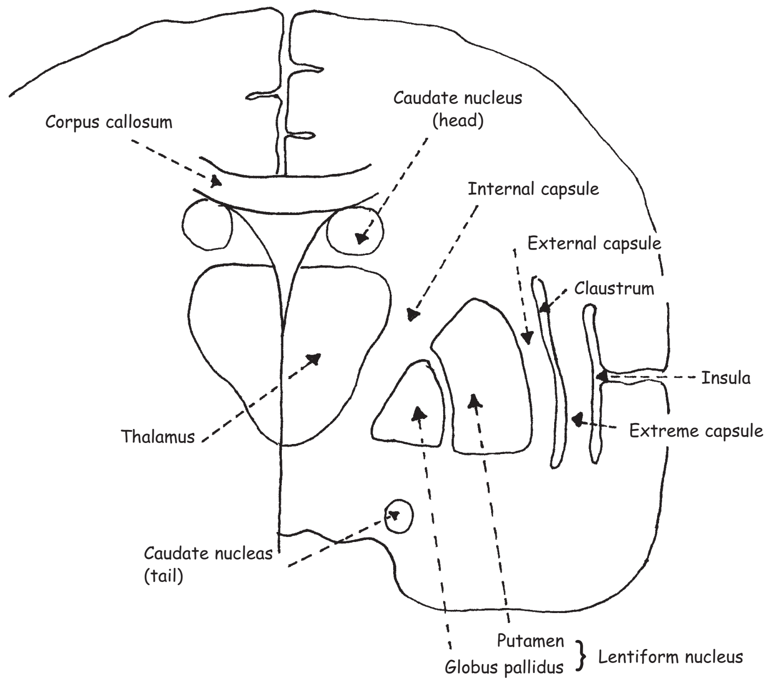
The body of the caudate nucleus surrounds the thalamus on its course around the basal ganglia.

The lentiform nucleus is a large lens-shaped area of cells, which can be readily subdivided into a lateral putamen (*something which falls off when pruning*) and a more medial globus pallidus.

Corpus striatum is an old name for an entity comprising the caudate nucleus, plus the putamen, plus the structures of the internal capsule .

The intricate functions of the basal ganglia are beyond the scope of this summary. Basically, they are involved with repetitive movements, co-ordinating and modulating function. They are under the control of the cerebral cortex, and are concerned with the initiation and cessation of functions which depend on awareness, and which occur independently of conscious volition.

Coronal Section of brain showing basal ganglia



(After Samson)

11. The special senses

11a. Smell

Suitable stimulation of the olfactory mucosa is transmitted to the olfactory nerves which pass through the cribriform (*sieve-like*) plate of the skull, entering the olfactory bulb. From each bulb, a tract passes distally, dividing into three (the trigone, *triangle*). The two main divisions, the lateral and the medial, end in the olfactory cortex, known as the cuneus, and in the deeper hippocampus (*sea-horse*). The few remaining central fibres enter the anterior perforate substance, anterior to the optic chiasma (*crossing*).

The hippocampus originates as a gyrus (*circle*) on the medial aspect of the brain; it continues as the fimbria (*fringes*) and then curves around anteriorly to form the fornix, crus (*cross*) and body of the hippocampus. The left and right fornices are joined by the hippocampal commissure, finally becoming columns of fornix and ending in the mammillary bodies, which protrude on the base of the brain.

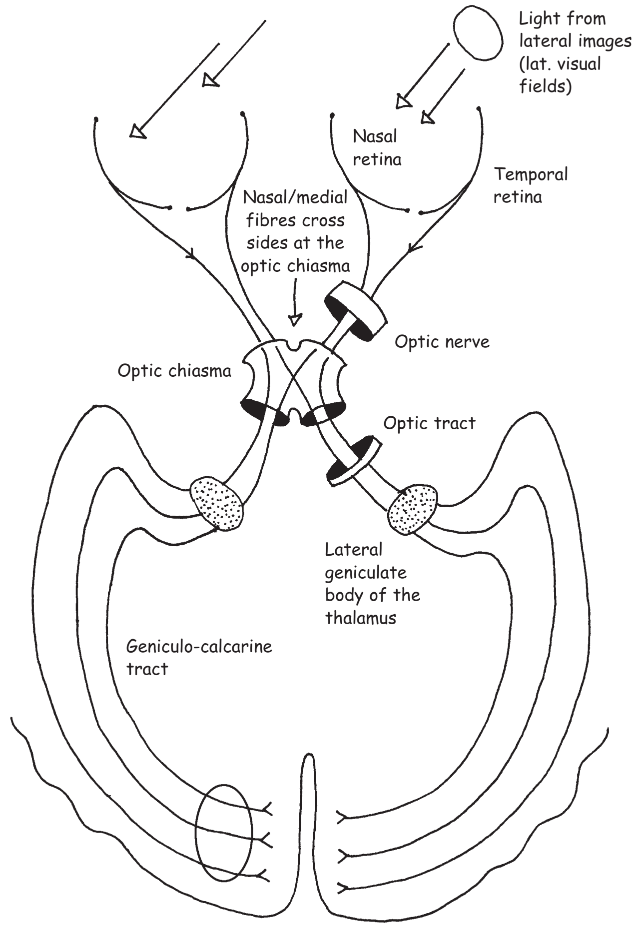
From these mammillary bodies, tracts relay impulses to the thalamus, caudate nucleus, tegmentum (*covering*) and globus pallidus, whilst further fibres descend to connect with anterior horn cells (this is important in extrapyramidal dysfunction, and therefore, in the treatment of Parkinsonism).

11b. The visual system

These anatomical pathways are more direct. Stimuli traverse the optic lens onto the retina (note the blind spot, where the retina is deficient due to the exit there of the fibres which constitute the optic nerve). The stimuli are then separated as the two optic nerves join to form the chiasma. The portion of the optic nerve conveying fibres from the *medial* half of the retina crosses to the opposite side via the chiasma, whilst the portion of the fibres from the *lateral* half of the retina do not cross, but join with the crossed fibres from the opposite side, to form the optic tract on each side. This ends by synapsing with cells of the lateral geniculate body, then forms a well defined geniculo-calcarine tract which terminates in the calcarine visual cortex on the medio-posterior portion of the occipital lobe.

The corpora quadrigemina are four small colliculi (singular: colliculus) which are rounded prominences making up the tectum (*roof*) of the mid brain. The two rostral colliculi, one on each side (the superior quadrigeminal bodies) comprise some of the fibres from the optic tract and some from the cortex, synapsing with fibres from the cord and brainstem. These are responsible for those eye movements, such as following a moving object, which utilise exteroceptive stimuli. They are not involved with pupillary reactions, which depend on sympathetic and parasympathetic influences. Note that the parasympathetic input, *constricting* the pupil, arrives via pretectal nuclei to the oculomotor nerve, the ciliary ganglion and onto the iris. The sympathetic input, *dilating* the pupil, occurs via the superior sympathetic ganglion onto the internal carotid artery, the ophthalmic artery and so to the iris.

Optic pathway viewed from above



11c. The trigeminal system

This comprises four nuclei, three of which are sensory. Sensation from the face and dura enters branches of the trigeminal system, together with the ophthalmic, maxillary and mandibular nerves, each traversing the skull through its named foramen, then coming together to form the semilunar (*half-moon-shaped*) ganglion, entering the brainstem into three separate nuclei, the distal one being a nucleus of the spinal tract, and two proximal nuclei which are mesencephalic. Communication is then mainly to the thalamus and on to the sensory cortex.

The motor nucleus, which is likely to comprise three separate sub-entities, innervates the muscles of mastication. The motor nerve lies clearly separate from the semilunar ganglion and exits the skull via the foramen ovale.

11d. The acoustic system

The eighth nerve consists of a cochlear (hearing) and a vestibular (balance) portion. Stimuli enter the cochlear nuclei via the spiral organ of Corti. Fibres from these nuclei form a conspicuous bundle (the trapezoid body). They then form the lateral lemniscus extending to the inferior colliculus on each side (part of the quadrigeminal body), and then pass on to the cortex.

The vestibular portion is derived from the three semicircular canals. The sacculus (*little sac*) and utriculus (*small bag*) detect head movements, sending information along the vestibular nerve, which has its nerve bodies in the vestibular ganglion, then to the medulla and on to the pons. Some branches pass onto the cerebellum, others to the motor nuclei of the eye (the cells of cranial nerves III, IV and VI) and some run distally, as the vestibulo-spinal tracts, to the anterior horn cells of the spinal cord.

12. The autonomic nervous system

This effector system is only occasionally influenced voluntarily. It supplies smooth muscle, glands and blood vessels. Although conscious perceptions can alter bowel motility, raise hairs, speed up the heart rate or increase sweating, the system mostly functions in a regular, routine, involuntary way.

There are no special autonomic *sensory* routes; these are served by the peripheral sensory system. Cerebral origins of the autonomic system are observed in many cranial areas at most levels: frontal and temporal cortical, insular (in the midbrain) and specifically, hypothalamic. These connections are difficult to observe and to identify.

The system is divided into the sympathetic and the parasympathetic (names which do *not* help our understanding of their course or function). Both are two-neurone systems. The secondary neurones of the sympathetic system lie in the sympathetic ganglia, whilst those of the parasympathetic are in distal ganglia, intimately related to the target organs.

The *sympathetic system* is anatomically evident, consisting of two substantial chains lying antero-lateral to the vertebral bodies, one on each side. There are about 23 interconnected ganglia on each side, joined by a long chain of nervous tissue. Each chain starts at the T1 level and extends distally to the sacral region. Above the level of T1 are inferior (stellate, *star-like*), the middle and the superior cervical ganglia, with the inferior joined to the T1 ganglion. The middle cervical ganglion supplies the heart, lungs and stomach. The superior supplies the pupils, secretory glands of the head and the heart.

Fibres run from their cranial origins down the medulla into the lateral fasciculus of the spinal cord. Entry from the cord to the sympathetic chain is via the white fibres. Synapses occur in the ganglia of the chains, but not necessarily at specific cord levels; the fibres may course up and down, and then synapse; the next relay of neurones exit via the grey fibres into the sympathetic chains, then form the greater and lesser splanchnic (*viscus*) nerves, the coeliac ganglion, and the mesenteric ganglion. Together, these innervate the gall bladder, upper intestine, kidneys, adrenal glands, and, via the hypogastric plexus, the large intestine.

The distal large intestine is innervated by fibres from the S2, S3 and S4 segments.

The *parasympathetic system* originates cranially and is represented in various cortical areas. Impulses flow via cortico-hypothalamic fibres to exit via cranial nerves III, VII, IX and particularly X, targeting the spheno-palatine and coeliac ganglia, where they synapse. The vagus (*wanderer*) nerve is the most prominent carrier distally, synapsing in the visceral ganglia for the respective viscera. Vagal stimuli do not go further than the proximal colon.

More distally, information exits via the parasympathetic sacral outflow of the spinal cord at S2, S3 and S4. This outflow forms the pelvic plexus (plural: plexi) and the hypogastric ganglia and terminates in the distal colon, bladder and genitals.

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(main reference in **bold** type)