Chapter 1

Neuroanatomy

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1.1 Overview

This chapter will provide a brief review of **basic neuroanatomy**, followed by a more detailed description of structures and pathways important for neuropsychiatric practice. The focus will be on the **limbic brain** and the functional anatomy of emotion, memory, cognition and behaviour. A more comprehensive review of **general neuroanatomy** can be found in standard textbooks such as Johns, *Clinical Neuroscience*.[1, 2]

1.2 Review of Basic Neuroanatomy

1.2.1 Overview of the Nervous System

The nervous system is divided into central and peripheral parts. The **central nervous system** (**CNS**) is made up of the brain and spinal cord, encased within the bones of the skull and vertebral column. It is surrounded by three protective membranes or **meninges** (dura, arachnoid, pia). The **subarachnoid space** lies between the inner two layers and is filled with **cerebrospinal fluid** (**CSF**). This contains dissolved oxygen and glucose that nourishes the cerebral surface and helps to cushion and protect the brain.

The **peripheral nervous system** (**PNS**) includes 31 pairs of **spinal nerves** which emerge between the vertebrae and 12 pairs of **cranial nerves** which arise from the base of the brain (Table 1.1, Figure 1.1). At the roots of the upper and lower limbs, sensory and motor fibres are redistributed in the **brachial** and **lumbosacral plexuses** to enter a number of named **peripheral nerves**. The motor component of the peripheral nervous system is further subdivided into **somatic** and **autonomic** parts. The **somatic nervous system** innervates skeletal muscles whilst the **autonomic nervous system** supplies smooth muscle, cardiac muscle and the contractile elements of glands.

1.2.2 Cells of the Nervous System

Neural tissue contains two specialised cell types: **neurons** and **glia**. Neurons are the main functional elements, whilst glial cells offer structural and metabolic support. Modern estimates suggest that the human brain contains approximately 86 billion neurons, with a similar number of glial cells.[3, 4]

Neurons occupy the **grey matter** of the brain and spinal cord. Their axons traverse the **white matter** to reach other parts of the central nervous system. The pale colour of white matter is due to the lipid-rich myelin sheath, which enhances nerve impulse conduction velocity. Discrete collections of neurons are called **nuclei** in the CNS and **ganglia** in the PNS.

1.2.2.1 Neurons

Neurons are **electrically excitable**, process-bearing cells. They are highly specialised for the receipt, integration and transmission of information via rapid electrochemical impulses (**action potentials**). The **cell body** contains the nucleus and biological machinery for protein synthesis and other housekeeping functions. It ranges from 5 to 100 μm in diameter.[5]

Two types of process (or **neurite**) arise from the cell body. A profusely branching 'tree' of **dendrites** (Greek: *dendron*, tree) is specialised to receive and integrate information, typically from many thousands of other neurons. Nerve impulses are triggered in the cell body and transmitted away from the neuron along the slender **nerve fibre** or **axon**. A typical neuron has a single axon which may be up to one metre long in humans.[6] Axons make contact with target cells at swellings called **axon terminals** and often give rise to collateral branches.

Types of Neuron

The cerebral cortex contains two major neuronal types: granular and pyramidal. **Granule cells** have

Table 1.1 The cranial nerves

Name (and fibre types)	**Main functions**
I: Olfactory (sensory)	**Special visceral afferent**: sense of smell
II: Optic (sensory)	**Special somatic afferent**: vision
III: Oculomotor (mixed)	**General somatic efferent**: superior rectus, inferior rectus, medial rectus, inferior oblique (four out of the six extraocular muscles); levator palpabrae superioris (eyelid elevator) **General visceral efferent (parasympathetic)**: sphincter pupillae (pupil constriction), ciliary muscle (accommodation)
IV: Trochlear (motor)	**General somatic efferent**: superior oblique only (depression of the adducted eye)
V: Trigeminal (mixed) V1: Ophthalmic V2: Maxillary V3: Mandibular	**General somatic afferent (V1, V2, V3)**: sensation to facial skin, cornea, nasal mucosa, paranasal sinuses, supratentorial dura; periodontal tissues, teeth, temporomandibular joint (proprioception); buccal cavity, anterior two-thirds of tongue (general sensation) **Special visceral efferent (branchiomotor, V3 only)**: muscles of mastication (masseter, temporalis, medial and lateral pterygoid), anterior belly of digastric, mylohyoid, tensor veli palatini (palate), tensor tympani (middle ear)
VI: Abducens (motor)	**General somatic efferent**: lateral rectus only (abduction of eye)
VII: Facial (mixed)	**General somatic afferent**: sensation to part of the external ear (*) **Special visceral afferent**: taste from anterior two-thirds of tongue (*) **General visceral efferent (parasympathetic)**: submandibular and sublingual salivary glands, lacrimal gland* **Special visceral efferent (branchiomotor)**: muscles of facial expression, stapedius (middle ear), stylohyoid, posterior belly of digastric
VIII: Vestibulocochlear (sensory)	**Special somatic afferent**: vestibular sensation, hearing
IX: Glossopharyngeal (mixed)	**General somatic afferent**: cutaneous sensation from the external ear, tympanic membrane, upper pharynx, and posterior one-third of the tongue **General visceral afferent**: carotid body and sinus (for baroreceptor reflexes) **Special visceral afferent**: taste from posterior third of the tongue **General visceral efferent (parasympathetic)**: parotid salivary gland **Special visceral efferent (branchiomotor)**: stylopharyngeus only
X: Vagus (mixed)	**General somatic afferent**: cutaneous sensation from auricle, external auditory meatus, larynx, pharynx and infratentorial dura **General visceral afferent**: main sensory innervation to thoraco-abdominal viscera **Special visceral afferent**: taste from the epiglottis and soft palate **General visceral efferent (parasympathetic)**: main parasympathetic innervation to heart, lungs and majority of gastrointestinal tract, as far as the splenic flexure **Special visceral efferent (branchiomotor)**: pharyngeal constrictors, intrinsic laryngeal muscles, muscles of the palate (apart from tensor veli palatini), upper two thirds of the oesophagus, therefore important for speech and swallowing
XI: Accessory (motor) XIc: cranial accessory XIs: spinal accessory	**General somatic efferent**: sternocleidomastoid, trapezius (spinal accessory nerve) **Special visceral efferent (branchiomotor)**: muscles of pharynx and larynx (cranial accessory nerve; fibres distributed via the vagus nerve)
XII: Hypoglossal (motor)	**General somatic efferent**: all intrinsic and extrinsic tongue muscles, apart from palatoglossus (the latter is supplied by the vagus nerve)

* Carried in the slender *nervus intermedius*, which joins the main nerve trunk.

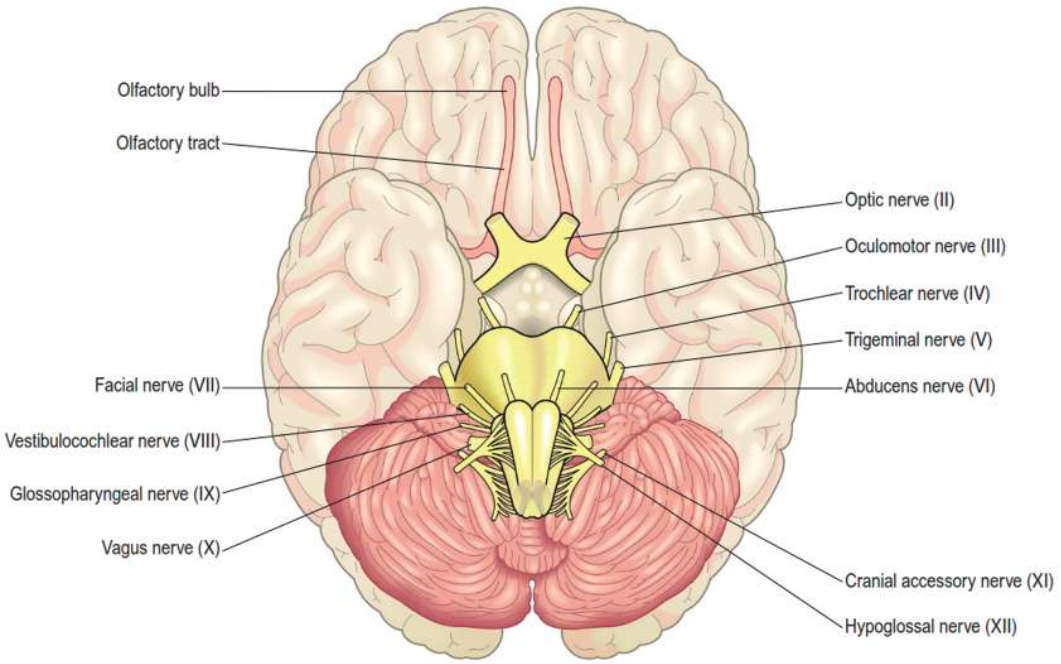

Figure 1.1 Ventral surface of the brain showing the 12 cranial nerves. The olfactory nerve (cranial nerve I) is not seen here; it consists of up to 5 million axonal filaments that arise from the nasal mucosa and synapse in the olfactory bulb. From Johns, *Clinical Neuroscience: An Illustrated Colour Text* (Elsevier, 2014).

small, spherical cell bodies and short axons. They are particularly numerous in areas that receive incoming projections (e.g. the granule cell layers of the hippocampus and cerebellum). Due to the predominance of granule cells, sensory cortices are thinner (e.g. 2 mm in the **primary visual cortex**).

Pyramidal cells have large, pyramid-shaped cell bodies. They predominate in areas that give rise to efferent projections, such as the **motor cortex**. Pyramidal cells require a larger cell body to support their long axons. Motor cortex is therefore thicker (up to 5 mm in the **primary motor cortex**). The largest neurons in the brain are the **giant cells of Betz**, found in the 'leg area' of the primary motor cortex in the medial frontal lobe. They are up to 100 μm in diameter.[7, 8]

The **medium spiny neuron** is the characteristic cell type of the **basal ganglia**. The 'ganglia' part of the term is a misnomer traditionally used to refer to a collection of **basal hemispheric nuclei** which contribute to the control of voluntary movement, cognition and behaviour.

Medium spiny neurons use the inhibitory neurotransmitter **gamma-amino butyric acid** (**GABA**). They have processes with microscopic **dendritic spines** which receive incoming axonal projections. In contrast, the granular and pyramidal cells of the cerebral cortex are excitatory neurons, many of which use **glutamate** as a neurotransmitter. Pyramidal cells also have dendritic spines, whereas granule cells may be spiny or aspinous.

Interneurons influence the activity of nerve cells in the cerebral cortex, subcortical nuclei and cerebellum. The cerebral cortex contains a significant population of **inhibitory interneurons** that use GABA as a neurotransmitter. A modest but functionally important group of cholinergic interneurons is found within the basal ganglia.

Neurons make contact at **synapses** (Greek: *sunapsis*, point of contact) and influence effector structures such as muscle fibres and glands at **neuroeffector junctions**. The point of contact between a somatic motor neuron and a skeletal muscle fibre is the **neuromuscular junction** (**NMJ**).

Neurogenesis

Mature neurons are **post-mitotic** cells, meaning that they are unable to divide and cannot be replaced. The

only location in the human brain that is capable of **neurogenesis** (production of new neurons from **stem cells**) is the dentate gyrus of the **hippocampus**.[9] In other species, a stem cell population in the **subventricular zone** of the lateral ventricle continuously gives rise to new neurons which migrate to the olfactory bulbs. However, this is minimal or absent in humans.[10]

Neurogenesis in the granule cell layer of the dentate gyrus is found in some patients with **temporal lobe epilepsy** (**TLE**) in association with **hippocampal sclerosis**.[11] This is presumably an attempt to replace neurons that have been lost due to seizure activity. It is unclear whether neurogenesis in hippocampal sclerosis is protective or if it exacerbates seizures.[12]

1.2.2.2 Neuroglial Cells

Five main types of **glial cell** provide metabolic and structural support to neurons (Greek: *glia*, glue):

- **Astrocytes**, which are involved in glucose metabolism, neurotransmission, response to injury and induction of the blood–brain barrier
- **Oligodendrocytes**, which invest axons with a myelin sheath in the brain and spinal cord
- **Schwann cells,** the peripheral counterparts of oligodendrocytes
- **Ependymal cells**, which line the cerebral ventricles and central canal of the spinal cord
- **Microglia**, the resident phagocytic and immunocompetent cells of the CNS

Glial cells have a mean diameter of 4–8 μm and are found in a 1:1 ratio with neurons.[13] Unlike neurons, glial cells are able to divide and may therefore give rise to cerebral tumours called **gliomas** (e.g. astrocytoma, oligodendroglioma).

1.2.3 Parts of the Brain

The human brain has a mass of around 1.3 kg and a very soft, gelatinous consistency. It consists of the cerebral hemispheres, diencephalon (thalamic region), brain stem and cerebellum (Figure 1.2).

1.2.3.1 Cerebral Hemispheres

The **cerebral hemispheres** (**cerebrum** or **telencephalon**) are responsible for sensorimotor functions, cognition, language, memory, emotion and behaviour. Sensory and motor pathways are **crossed** so that the left hemisphere is concerned with sensation and movement of the right side of the body. Cognitive functions are **lateralised** so that one hemisphere is said to be dominant for a particular mental faculty such as language or visuospatial ability (Box 1.1).

Cerebral Cortex

The **cerebral cortex** is a 2–5-mm-thick sheet of grey matter that forms the outermost layer of the cerebral hemisphere (Latin: *cortex*, bark). The brains of reptiles, birds and some mammals have a smooth or lissencephalic outer surface, whilst the human brain is thrown into convolutions. These consist of outfoldings (**gyri**) and furrows (**sulci**). The purpose of cortical folding (or **gyrification**) is to maximise the area of cerebral cortex that can be accommodated within the limited confines of the skull. It also enhances intracortical communication by bringing disparate areas into proximity.

Extent of gyrification varies greatly between species, depending on the size and complexity of the brain. It can be quantified as the **gyrification index**. The human brain has a high gyrification index, with approximately two-thirds of the cortical surface lying within sulci.

Two important sulcal landmarks on the surface of the brain are the **lateral sulcus** (**sylvian fissure**) and the **central sulcus** (**fissure of Rolando**). These help to divide the hemispheres into four main **lobes**. The key functional areas of each lobe are summarised in Table 1.2. The main gyri, sulci and functional areas are illustrated in Figure 1.3.

A separate **limbic lobe** is also recognised. This is a ring-shaped convolution that surrounds the corpus callosum and brain stem. It includes the **hippocampus**, a longitudinal roll of cortex in the medial temporal region. The limbic lobe is primarily concerned with emotion and memory and receives strong projections from the **central olfactory pathways**. This might explain why particular smells sometimes evoke vivid memories.

The brain contains two main **fissures** (deeper furrows that are not lined by cortex). These are the **longitudinal fissure** between the cerebral hemispheres and the **transverse fissure** which separates the cerebrum and cerebellum.

Hemispheric Grey Matter

Collections of subcortical grey matter in the base of the cerebral hemisphere are known as the **basal hemispheric nuclei**. These include the corpus striatum,

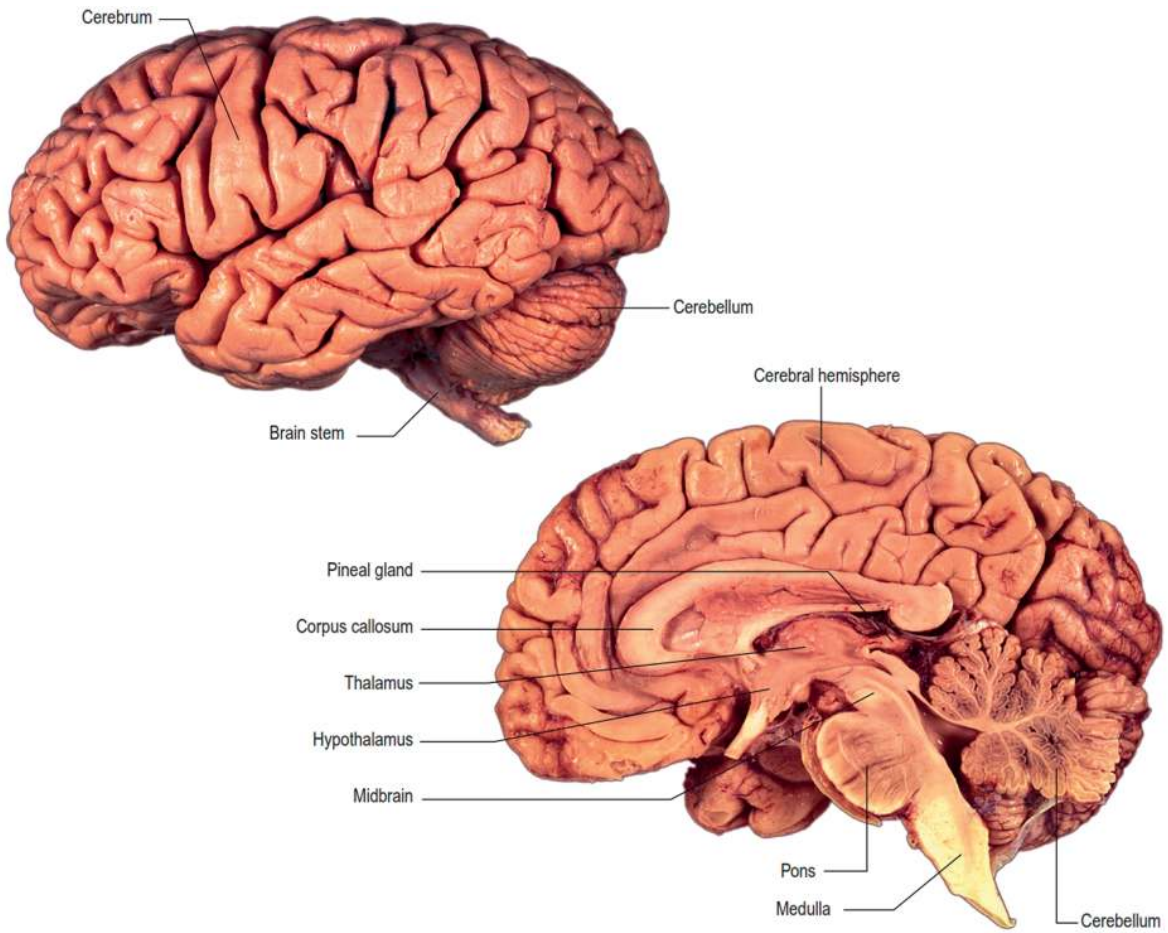

Figure 1.2 Lateral and medial views of a preserved human brain. The three main parts are the cerebrum, cerebellum and brain stem, together with the diencephalon (a small midline portion, which includes the thalamus and hypothalamus). From Johns, *Clinical Neuroscience: An Illustrated Colour Text* (Elsevier, 2014).

amygdala and claustrum, but not the thalamus, which belongs to the diencephalon (thalamic region).

The **corpus striatum** is the largest component of the basal ganglia and consists of the C-shaped **caudate nucleus** and cone-shaped **lentiform nucleus**, which are separated by white matter. The lentiform nucleus is further subdivided into the **putamen** laterally and **globus pallidus** medially.

The **amygdala** is an almond-shaped nuclear group in the medial temporal lobe that is concerned with emotional responses (particularly fear, anxiety and rage) (Box 1.2). The **claustrum** is a thin lamina of grey matter overlying the basal ganglia that is of uncertain function.

The basal nuclei are closely related to the **ventricular system** (Figure 1.4) which forms from the lumen of the embryonic **neural tube** and is filled with cerebrospinal fluid. CSF is as an ultrafiltrate of plasma that is secreted by the vascular **choroid plexuses**. Obstruction of CSF drainage or reabsorption pathways leads to **hydrocephalus** (Greek: *hydro*, water; *kephalē*, head).

Hemispheric White Matter

The subcortical white matter (Figure 1.5) is composed of interlacing **tracts**, defined as groups of axons with a common origin, destination and function. Two or more tracts running in company make up a **fasciculus** (plural: fasciculi).

Pathways linking areas within a hemisphere are called **association fibres**, which may be short or long. **Short association fibres** loop between neighbouring

Box 1.1 Hemispheric Lateralisation

In most individuals the left cerebral hemisphere has a **verbal bias** whilst the right hemisphere is superior for **visuospatial functions**. The hemisphere that controls the preferred hand is said to be **dominant**, and given that approximately 90% of people are right-handed, this is usually the left hemisphere.

Language is traditionally said to be left-lateralised in 95% of right-handed people and in 70% of those who are left-handed; right-hemisphere dominance occurs in just 2%, most of whom are left-handed.[14] This means that the majority of individuals are either **left-lateralised** for language or **co-dominant**. More generally, it has been shown that the strength of left-hemisphere language dominance is almost linearly correlated with the degree of right-hand preference.[15]

Language lateralisation can be assessed using **functional magnetic resonance imaging** (**fMRI**) and quantified as a **lateralisation index**. Another method is **Wada testing**, which was developed by the Japanese neurologist Dr Juhn Wada to assess language function prior to epilepsy surgery.[16] This involves injection of the barbiturate **sodium amobarbital** (**sodium amytal**) into the internal carotid artery to anaesthetise one cerebral hemisphere at a time. In most people, anaesthesia of the left hemisphere leads to transient loss of language function.

Selective left-hemisphere anaesthesia sometimes produces an agitated **acute dysphoric state** or 'catastrophic reaction'. In contrast, suppression of activity on the right-hand side may lead to **euphoria**.[17, 18] An affective lateralisation effect can also be seen following stroke. Left frontal lesions are strongly associated with **depression**, whilst right-sided lesions may lead to **pleasant indifference**, **elation** or **mania**.[19]

Box 1.2 Amygdala and Klüver-Bucy Syndrome

In the 1930s, the German experimental psychologist Heinrich Klüver and American neurosurgeon Paul Bucy reported the behavioural effects of **bilateral temporal lobectomy** in rhesus monkeys, some of which were attributed to ablation of the **amygdala.**[20–22] However, temporal lobectomy destroys many other cerebral structures, reflected in a constellation of neuropsychiatric symptoms.

The features included '**psychic blindness**' (visual agnosia), **emotional changes** (docility), altered **sexual behaviour** (hypersexuality, indiscriminate mating behaviour) and '**oral tendencies**' (excessive eating and oral exploration of objects, possibly due to visual agnosia). The obsolete term **hypermetamorphosis** is similar to what would now be called **utilisation behaviour** (compulsive grasping and utilisation of objects), but this is more typical of frontal lobe lesions.

In the 1950s, an analogous pattern of deficits was identified in humans with bilateral medial temporal lesions. This became known as the **Klüver-Bucy syndrome**, which was influential in the development of the 'limbic system' concept. Similar results had also been reported by Sanger Brown and Edward Albert Sharpey-Schafer in 1888.[23]

gyri, whilst **long association fibres** link more distant areas (e.g. the **superior longitudinal fasciculus**, connecting the frontal and parietal lobes). The **arcuate fasciculus** is a large, arc-shaped branch of the superior longitudinal fasciculus. It connects the inferior frontal and posterior temporal regions and is important for **language**.

Homologous cortical regions communicate across the midline via **commissural fibres** (Latin: *commissūra*, a joining together). The largest is the **corpus callosum**, consisting of 300 million myelinated axons.[24] The anteromedial temporal lobes are linked by the much smaller **anterior commissure**, whilst the **posterior commissure** connects the posterior hemispheres and rostral brain stem.

Axons passing to and from the cerebral cortex (e.g. sensory pathways, motor tracts) are called **projection fibres**. The majority are contained within the **internal capsule**, a massive white matter system composed of 20 million nerve fibres. The internal capsule passes through the corpus striatum, splitting it into the caudate and lentiform nuclei.[25]

1.2.3.2 Diencephalon (Thalamic Region)

The thalamus and hypothalamus belong to the **diencephalon**, which lies between the cerebral hemispheres (Greek: *dia-*, between; *enkephalos*, brain) surrounding the cavity of the **third ventricle**. The thalamic region is best appreciated on a midsagittal section of the brain (see Figure 1.2).

Table 1.2 Lobes of the cerebral hemispheres

Lobe	**Main functional areas** (clinical effects of focal lesions in parenthesis)
Frontal	• **Primary motor cortex**, precentral gyrus (contralateral paresis/paralysis with an upper motor neuron pattern: hypertonia, spasticity, clonus, hyperreflexia, positive Babinski sign) • **Premotor cortex,** lateral frontal lobe (contralateral weakness, apraxia) • **Supplementary motor area**, medial frontal lobe (transient contralateral weakness, akinesia, bradykinesia: 'SMA syndrome') • **Prefrontal cortex**: dorsolateral (dysexecutive syndrome), orbitomedial (behavioural disinhibition), medial prefrontal (apathy, abulia, amotivational state) • **Broca's area**, inferior frontal gyrus, usually left (expressive/non-fluent aphasia); non-dominant lesions may cause subtle deficits in speech comprehension and verbal working memory
Parietal	• **Primary somatosensory cortex**, postcentral gyrus (contralateral anaesthesia or paraesthesia, diminished ability to localise tactile sensations) • **Somatosensory association cortex**, anterior part of posterior parietal cortex (astereognosia) • **Visuospatial association cortex**, posterior parietal lobe (right: contralateral hemineglect; left: apraxia) • **Inferior parietal lobule**, angular and supramarginal gyri (Gerstmann syndrome: left/right confusion, agraphia, acalculia, finger agnosia; alterations in proprioception or body schema)
Occipital	• **Primary visual cortex**, calcarine sulcus (visual field defect: contralateral scotoma, quadrantanopia, hemianopia; cortical blindness with bilateral lesions) • **Visual association cortex** (visual field defect: contralateral quadrantanopia, hemianopia; category-specific visual agnosia, e.g. specific to faces; alexia without agraphia)
Temporal	• **Primary auditory cortex**, transverse temporal gyri (deafness, if bilateral; diminished sound localisation, speech recognition and pitch discrimination, when unilateral) • **Auditory-visual association cortex**, lateral temporal lobe (visual agnosia; semantic memory deficit; impaired verbal memory; word agnosia) • **Fusiform gyrus**, inferior occipito-temporal region (left: visual word-form area, alexia; right: fusiform face area, prosopagnosia) • **Wernicke's area,** posterior third of superior temporal gyrus/temporo-parietal junction, usually on the left (fluent aphasia; non-dominant lesions may cause amusia or aprosodia)

The **thalamus** is an egg-shaped structure containing numerous nuclei that project to different parts of the cerebral cortex. It acts as a relay station for cortical afferent pathways and is sometimes referred to as the 'gateway' to the cerebral cortex. The **hypothalamus** is a tiny, triangular-shaped part of the diencephalon that forms the floor of the third ventricle and the lower part of its side walls. It lies below and in front of the thalamus and is important for homeostasis.

The hypothalamus has ultimate control of the **endocrine system** by modulating hormone release from the underlying **pituitary gland**. It also controls the **autonomic nervous system** and influences behaviour. Other roles include the control of hunger, satiety, thirst and sexual function. Its contribution to **emotional behaviours** is illustrated by the clinical features of hypothalamic **seizures** (Box 1.3).

The **preoptic area** is just in front of the hypothalamus and is important for the regulation of sleep, feeding, body temperature and fever. The medial preoptic area contains the **sexually dimorphic nucleus,** which is significantly larger in heterosexual males and appears to influence sexual orientation and gender identity. Although sometimes said to belong to the hypothalamus, the preoptic area is in fact derived from the telencephalon (cerebral hemispheres).[26]

Two important white matter pathways pass through the hypothalamus. The **columns of the fornix** (part of the hippocampal memory system) traverse the lateral hypothalamus before terminating in the pea-like **mamillary bodies** in the floor of the third ventricle. The **medial forebrain bundle** is an important conduit for fibres passing between the brain stem and cerebral hemispheres, including diffuse neurochemical projections for serotonin, noradrenaline and dopamine.

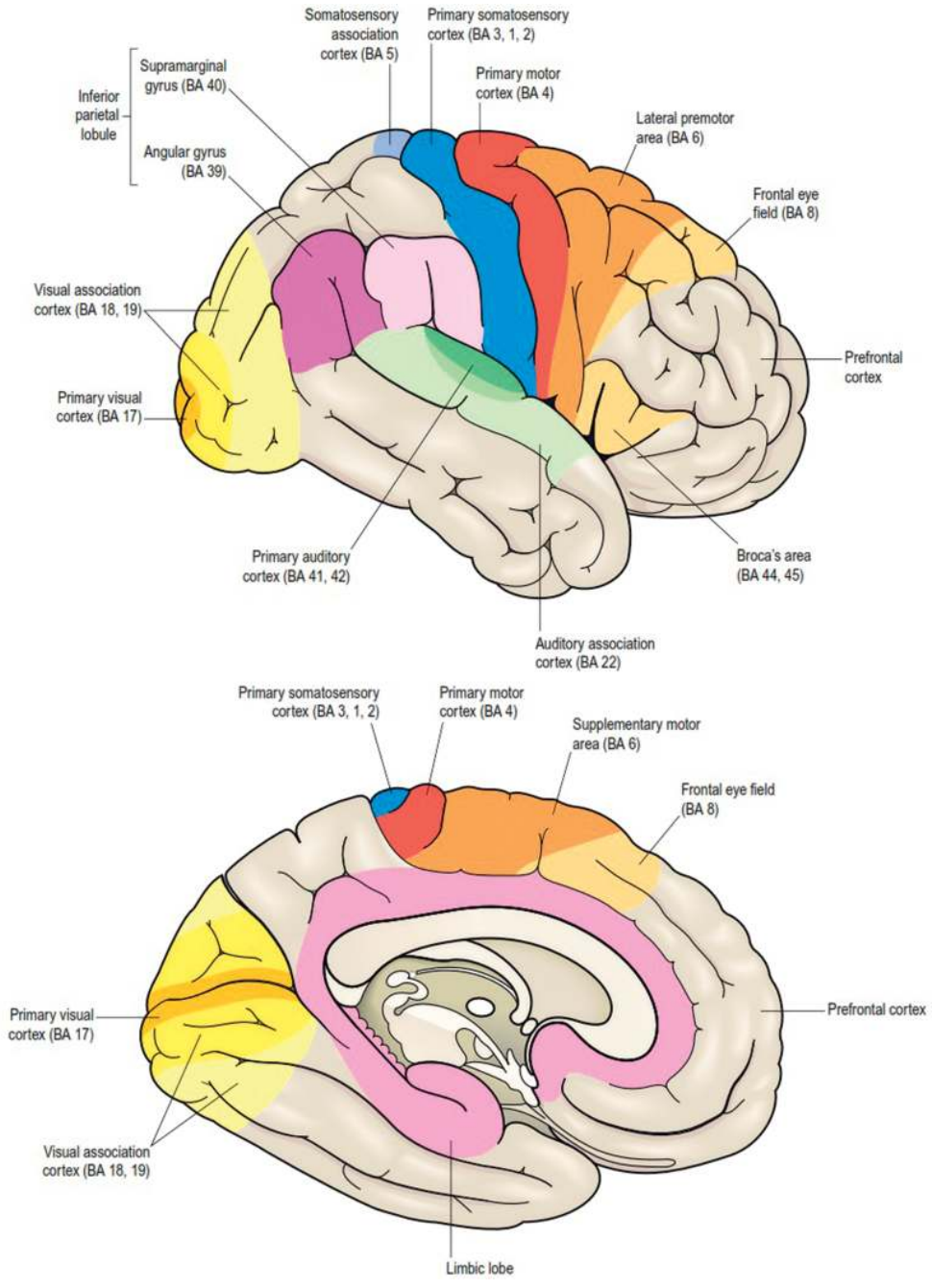

Figure 1.3 Lateral and medial views of the cerebral hemispheres. The main functional regions of the cerebral cortex are indicated; the numbers are Brodmann areas (BA), representing cortical zones with distinct microscopic structure and function. From Johns, *Clinical Neuroscience: An Illustrated Colour Text* (Elsevier, 2014).

1.2.3.3 Brain Stem

The **brain stem** as a whole can be divided longitudinally into basal and tegmental regions (Figure 1.6). The **base** of the brain stem is anterior and contains descending axons (e.g. the corticospinal motor tract). The **tegmentum** is the central core of the brain stem. It contains cranial nerve nuclei, the reticular formation and numerous long tracts passing between the

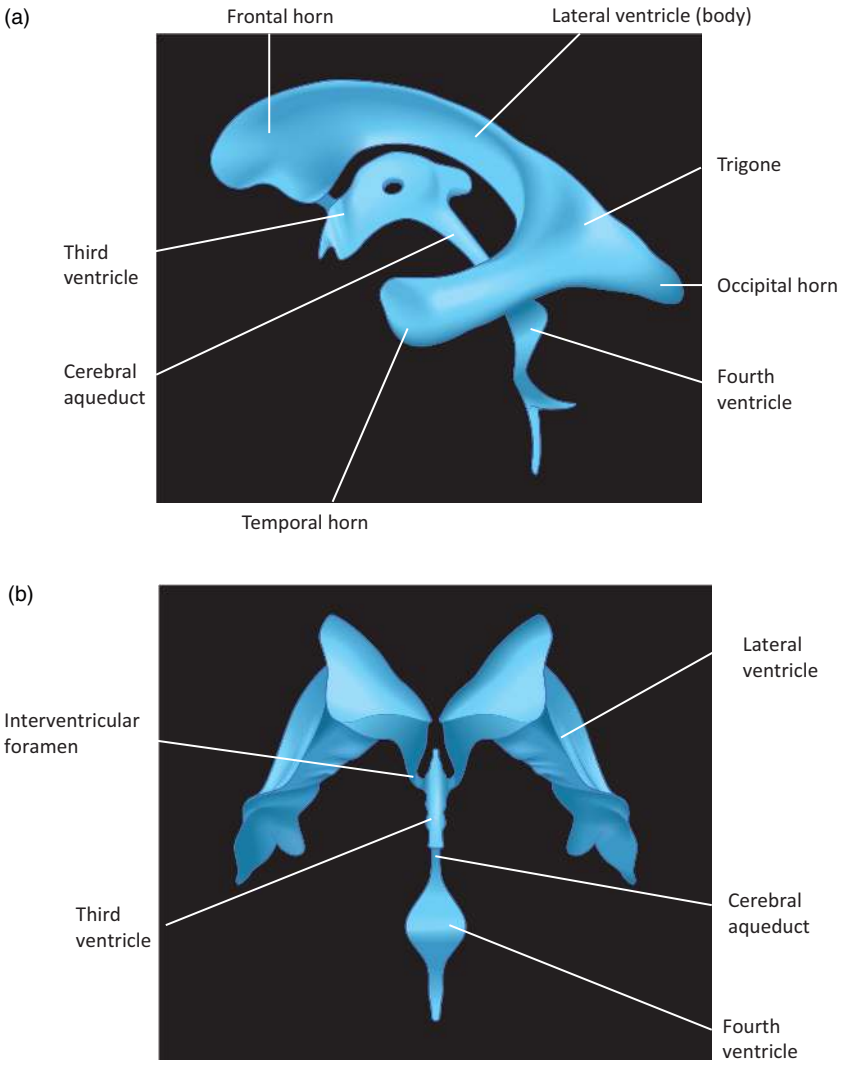

Figure 1.4 The ventricular system from (A) lateral and (B) anterior aspects. Note that the third ventricle appears large and impressive from the side, but when viewed from the anterior aspect, it can be seen to be a slit-like cavity that is only a few millimeters wide.

spinal cord and cerebral hemispheres. The brain stem consists of the midbrain, pons and medulla oblongata.

Midbrain

The **midbrain** is the most rostral part of the brain stem. It contains the **cerebral aqueduct**, which connects the third and fourth ventricles. The **tectum** or 'roof' of the midbrain (Latin: *tectum*, roof) is the small part that lies dorsal to the aqueduct. The remainder of the midbrain consists of the left and right **cerebral peduncles**. These resemble stout Roman pillars and make up almost half of the midbrain on each side. They are separated by the **interpeduncular fossa** (Latin: *fossa*, ditch or grave).

The term 'cerebral peduncle' is often used to describe the most anterior part of the midbrain, which contains the corticospinal tract. However, the proper name for this region is the **crus cerebri** (plural: crura) or base of the cerebral peduncle (**basis cerebri pedunculi**). The cerebral peduncle is a much larger region (almost half of the midbrain) that includes the tegmentum, substantia nigra and crus.

The tectum bears four smooth elevations called **colliculi** (Latin: *colliculus*, little hill). The **superior colliculi** (or **optic tectum**) give rise to the **tectospinal tracts** which co-ordinate head, neck and eye movements during orientation reflexes (e.g. involuntary turning to a novel stimulus). The **inferior colliculi**

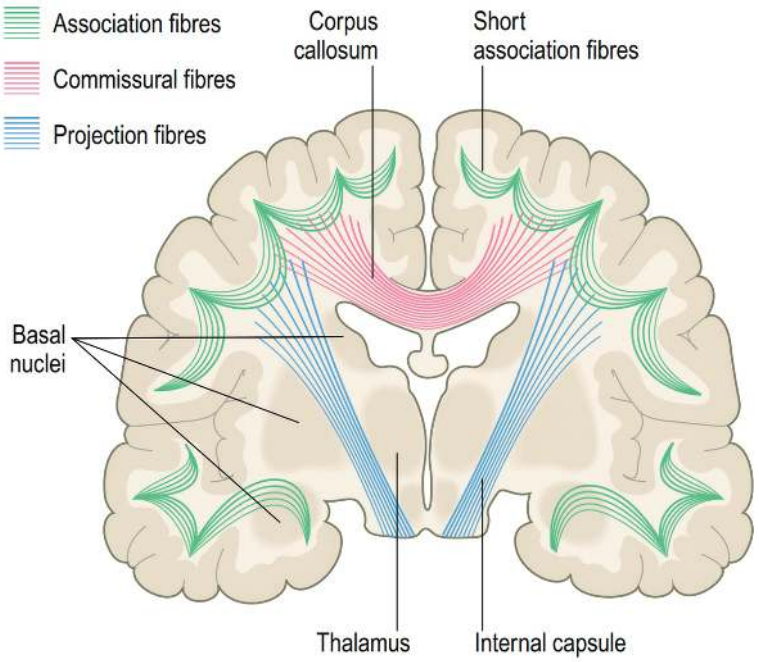

Figure 1.5 Types of subcortical white matter. The corpus callosum is the main commissural pathway linking the cerebral hemispheres. The internal capsule is a massive white matter bundle consisting of fibres passing to and from the cerebral cortex. From Johns, *Clinical Neuroscience: An Illustrated Colour Text* (Elsevier, 2014).

Box 1.3 Hypothalamic Seizures

Discrete lesions in the **hypothalamus** may be associated with **focal seizures** that have predominantly emotional manifestations such as laughter or crying.[27] The most common cause is a **hypothalamic hamartoma**. This is a benign, tumour-like congenital malformation with a prevalence of less than 1 in 100,000. It may be associated with **gelastic seizures**, characterised by paroxysms of uncontrolled laughter; or **dacrystic seizures**, in which there are episodes of uncontrolled weeping, with facial grimacing and lacrimation. The **emotional behaviours** in each type of seizure are divorced from the subjective mood state, and the patient (who remains conscious) typically experiences fear and panic rather than amusement or sadness. This underscores the dichotomy between emotional experiences (**feelings**) and their behavioural accompaniments (**emotional expression**), which are, respectively, cortical and hypothalamic in origin.[28, 29]

are part of the central auditory pathway from the cochlea to the **primary auditory cortex**.

A transverse slice through the midbrain reveals the deeply pigmented **substantia nigra** (Latin: black substance). It has **compact** and **reticular parts** (**SNc**, **SNr**), but only the compact portion is pigmented. The latter supplies dopamine to the basal ganglia via the **nigro-striatal tract**. The pars reticularis belongs to the globus pallidus and takes part in a basal ganglia loop involved in eye movement control. Just medial to the substantia nigra, but not visible with the naked eye, is the much smaller **ventral tegmental area**. This provides dopamine to the **ventral** (**limbic**) **striatum**.

The tegmentum of the midbrain is the large portion of the cerebral peduncle that is posterior to the substantia nigra, whilst the crus cerebri is the smaller portion in front of it. The tegmentum contains cranial nerve nuclei, long tracts and part of the reticular formation.

Pons

The **pons** is the middle portion of the brain stem. When viewed from the front, it appears to bridge the cerebellar hemispheres (Latin: *pons*, bridge). It is divided into basal and tegmental regions.

The anterior two-thirds of the pons is the **base** (or **basilar pons**). This transmits bundles of descending corticospinal tract fibres that have already passed through the internal capsule and crus cerebri on their way to the spinal cord. It also contains the **pontine**