Neuroanatomy Tutorial

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Learning Objectives:

1. Describe the general organization, orientation and function of the major components of the Central Nervous System (CNS).
2. Explain how the structures of the CNS are functionally linked and exchange information.
3. Describe the neuroanatomical structures underlying language
4. Describe the functions of the frontal cortex.
5. Describe the neuroanatomical structures involved in the experience and expression of emotion and reward.

Gross Anatomy of the Brain and Spinal Cord

Brain

A. Forebrain

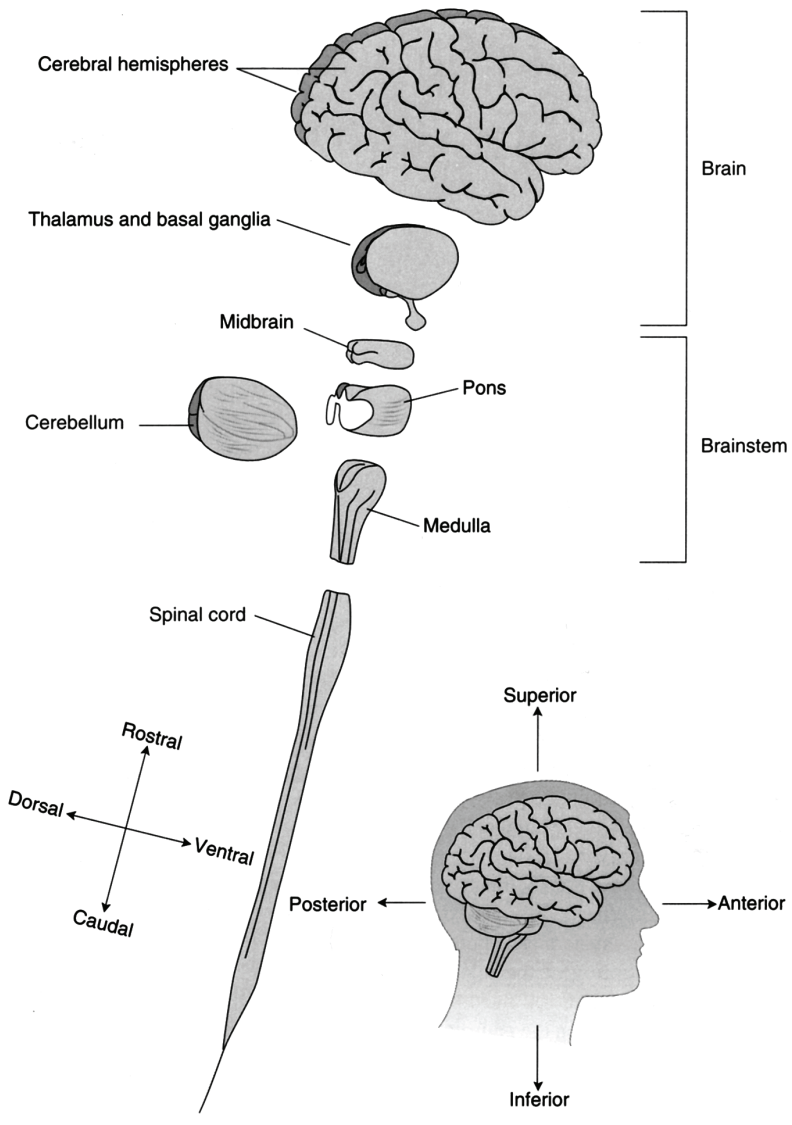
- telencephalon -cerebrum
  -basal ganglia
- diencephalon - thalamus
  - hypothalamus
  - subthalamus

B. Midbrain

C. Hindbrain - medulla
- pons
- cerebellum

Spinal cord

- cervical
- thoracic
- lumbar
- sacral divisions

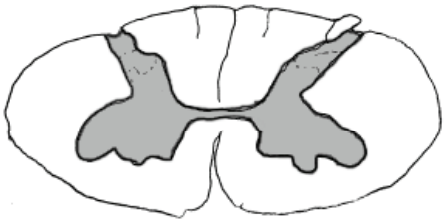


Gray matter - White matter

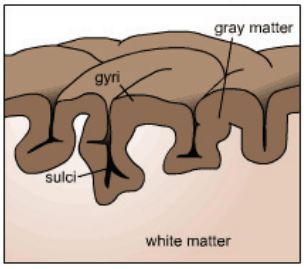
Gray matter – where neuronal somata (and dendrites) are located
- Cortex – gray matter forms a covering, cerebral and cerebellar cortex
- Nucleus – collection of neurons, functionally related (ganglion in PNS)

White matter – axons, fibre tracts
- Mostly myelinated (lipid accounts for white appearance)
- Tract – collection, group of axons (similar to nerve in PNS)
- (also called fasciculus, funiculus, column, lemniscus, peduncle, brachium, stria)

CNS: covering of gray (cortex), white matter deep – tracts running to and from cortex
Spinal cord: central gray (butterfly-shaped), surrounded by white matter fibre tracts



spinal cord



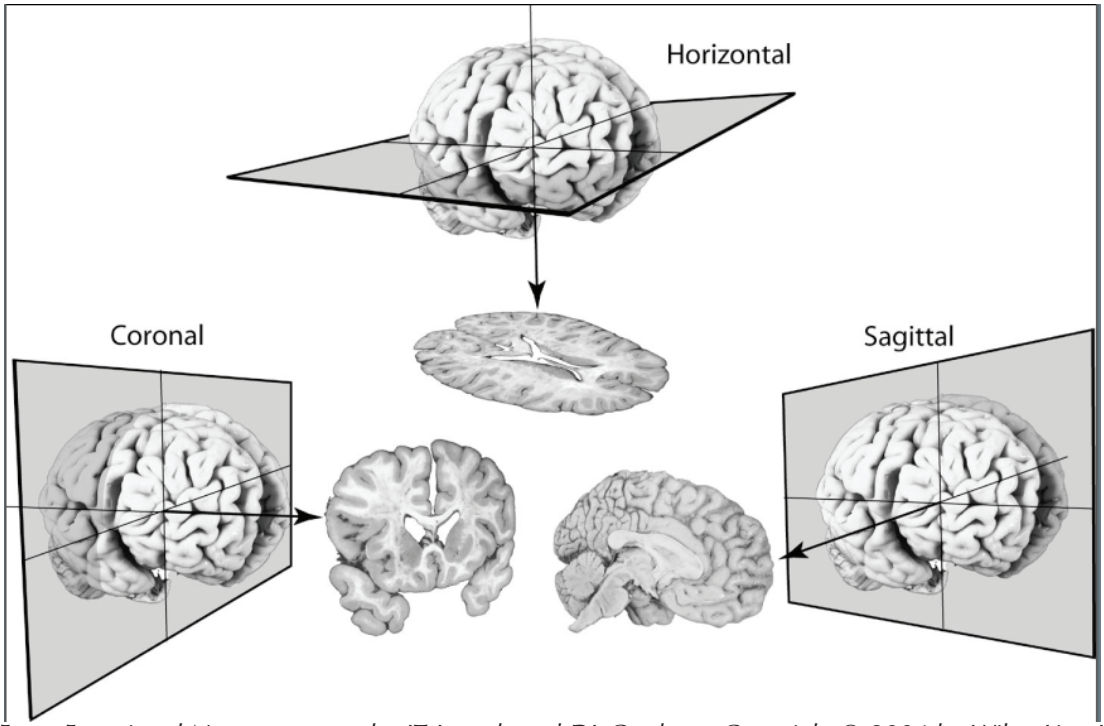
cortex

Flow of Information

- Ascending : sensory (dorsal in spinal cord)
- Descending : motor (ventral in spinal cord)

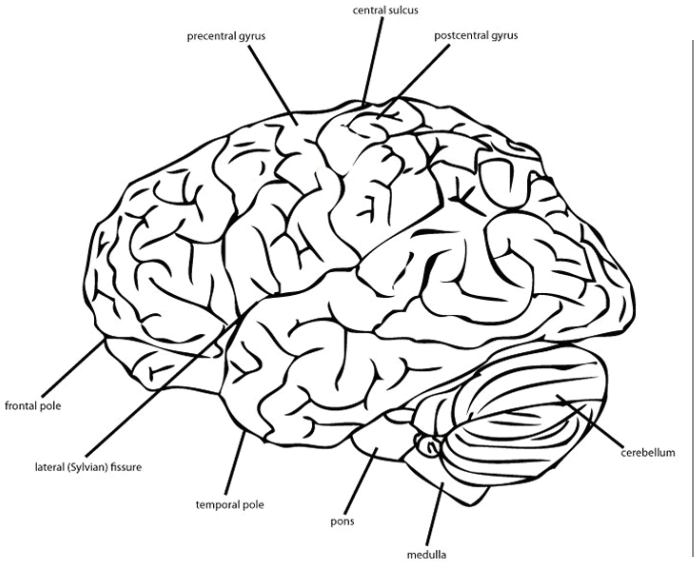
right side of the brain controls left side of body, so fibres must cross (almost all do), at different levels though

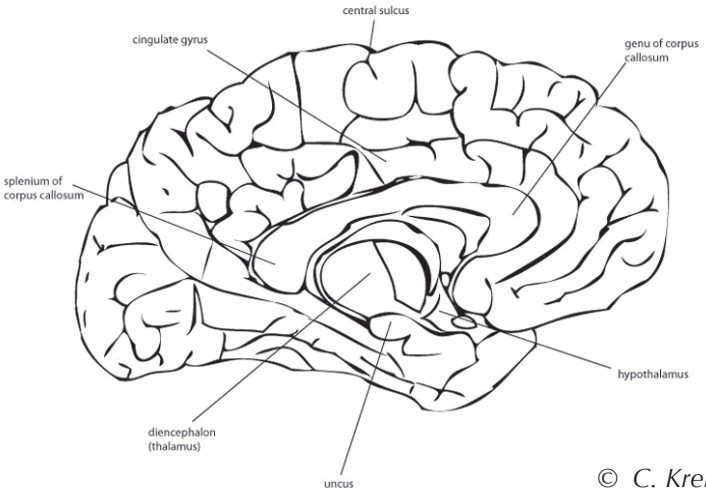
Orientation



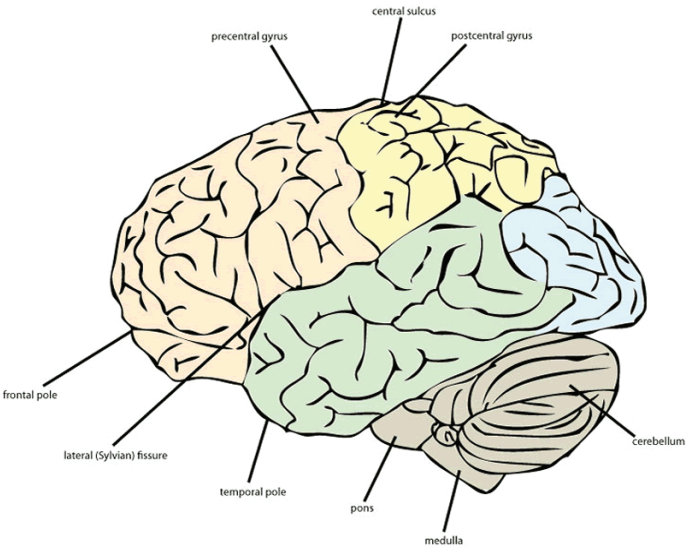
The surface of the brain is the cortex, where the neurons for higher order processing are located. Sensory information from the environment is interpreted, motor commands are given to the muscles, cognitive functions are located in the cortex, and there are areas responsible for behaviour. The two cerebral hemispheres are not symmetrical in function, some functions show more representation in one hemisphere than the other (language).

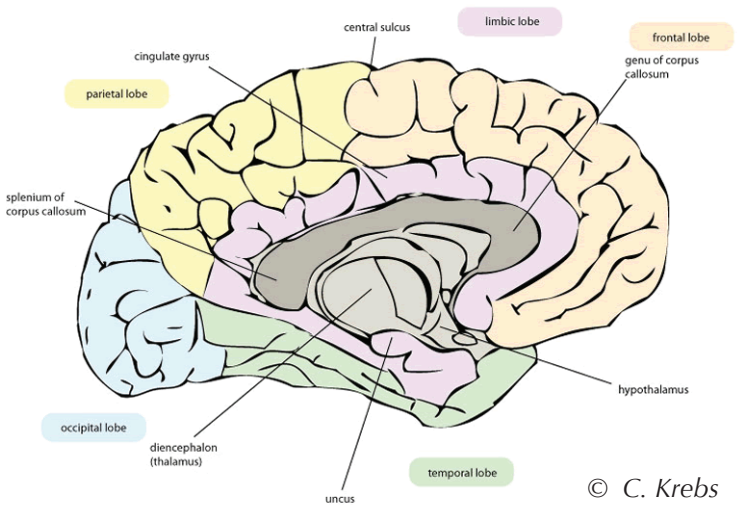
Surface Markings of the Cortex



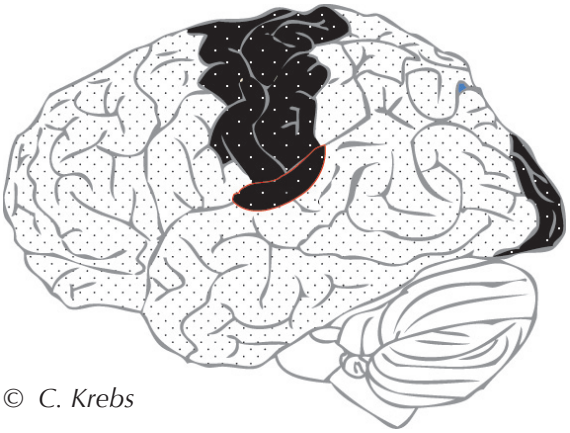


Lobes of the Cortex





Functional areas of the Cortex



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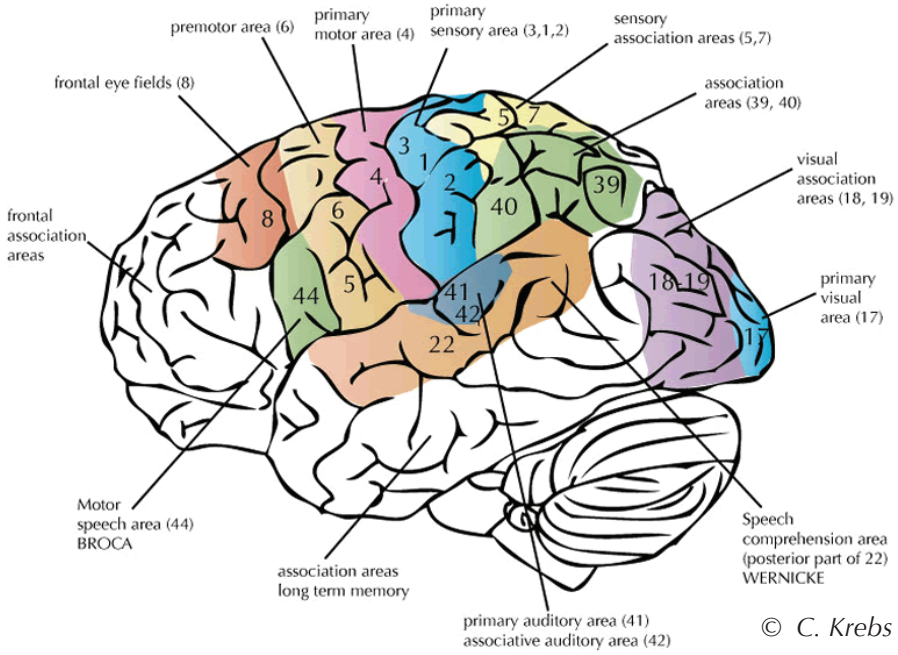
- **Primary cortices** occupy a relatively small area of the cortical mantle
- **Association cortices** make up the bulk of the area; this is where human cognition happens. These areas integrate the information of several brain areas.



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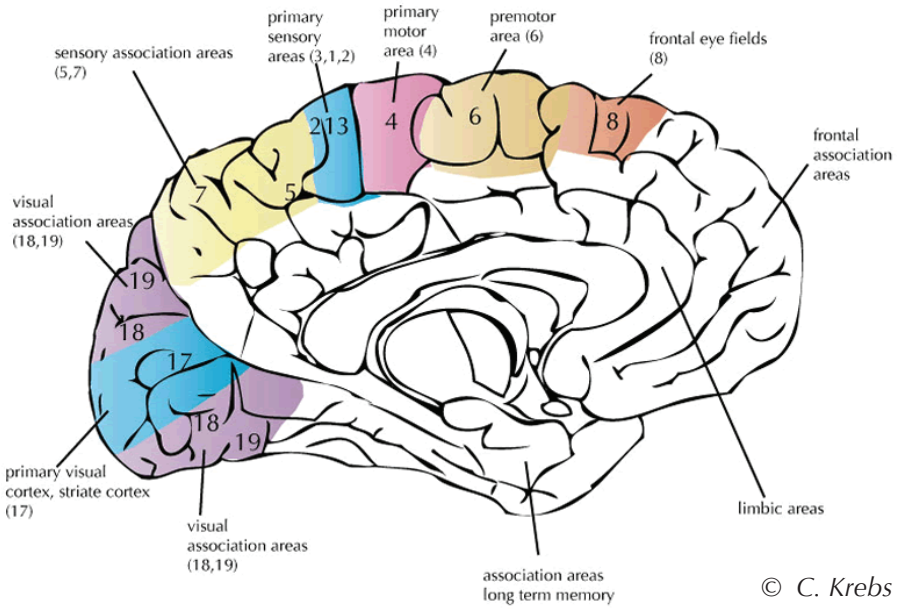

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Deep structures of the brain

Basal Ganglia & Cerebellum - for the coordination of movement

Limbic system - coordinates drives, emotions and memory

Thalamus - gateway to the cortex

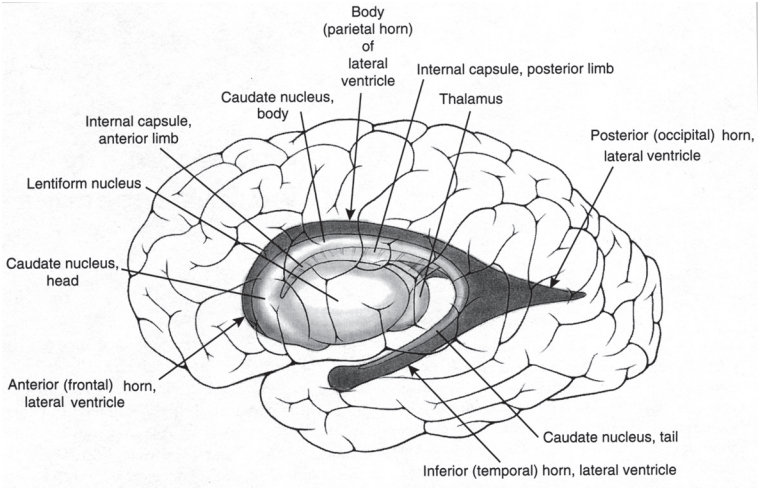


FIGURE 8–1. Lateral view of the position of the corpus striatum and its relations in the left cerebral hemisphere.

From Basic Clinical Neuroanatomy by PA Young and PH Young. Copyright © 1997 by Lippincott Williams & Wilkins.

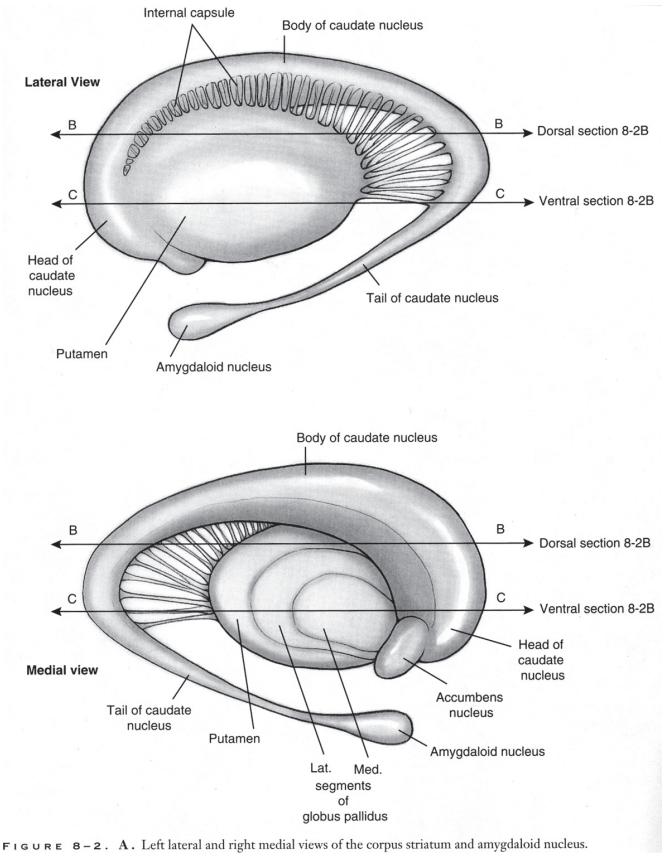
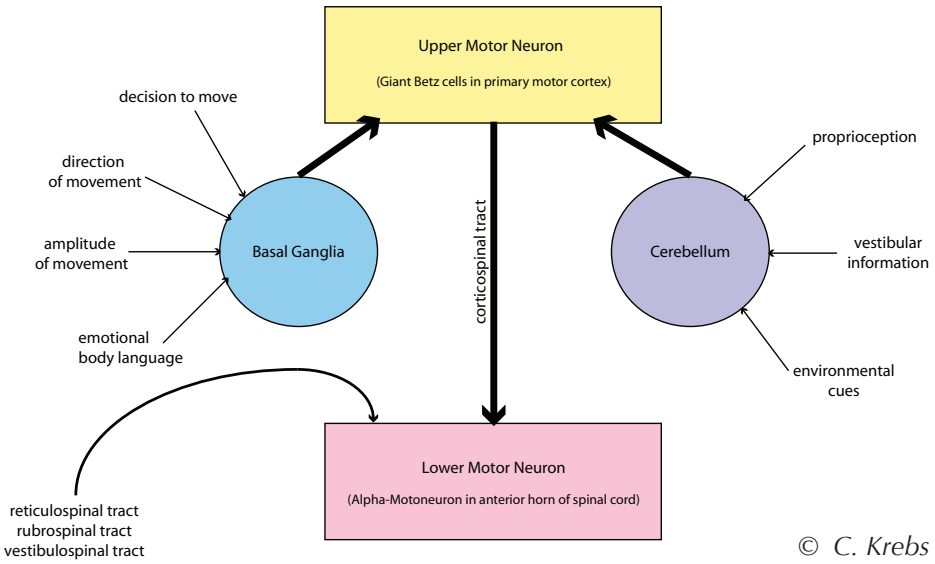


FIGURE 8–2. A. Left lateral and right medial views of the corpus striatum and amygdaloid nucleus.



The influence of the deep structures on a simple motor command.

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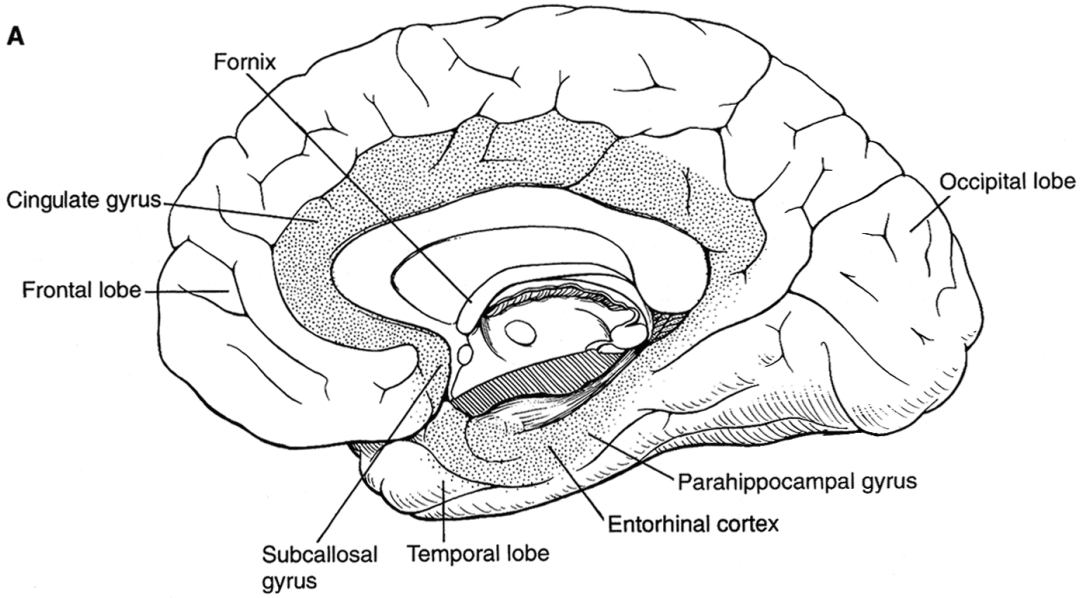
The Limbic System

General comments:

Structures include:

- **hypothalamus** – anatomically part of diencephalon, but functionally, part of limbic system
- subcortical structures (**hippocampus, amygdala**) that are interconnected with each other and with the hypothalamus
- **cortical areas** ('limbic lobe')



From The Principles of Neural Science by Kandel et al.

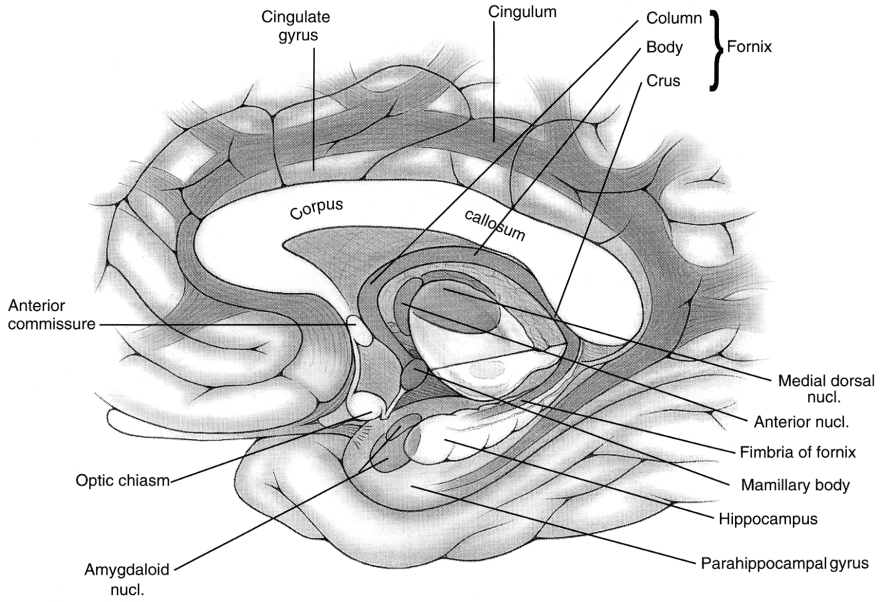


FIGURE 16–3. Three-dimensional view of cerebral hemisphere showing relations of hippocampal formation, fornix, and cingulum. (Young & Young, Basic Clinical Neuroanatomy)

From Basic Clinical Neuroanatomy by PA Young and PH Young. Copyright © 1997 by Lippincott Williams & Wilkins.

Hypothalamus

The diagram below is a simplified view of some of the major anatomical and functional interconnections of the hypothalamus and limbic system structures with each other and with other parts of the brain.

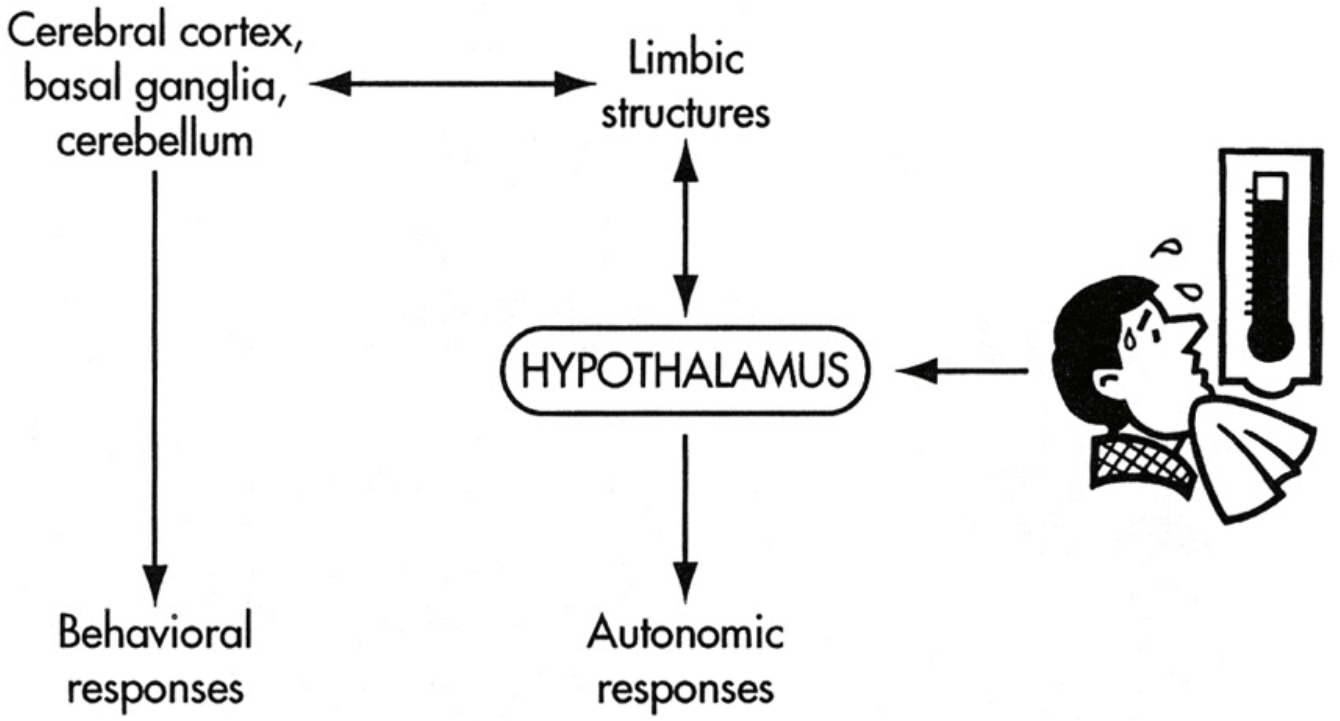
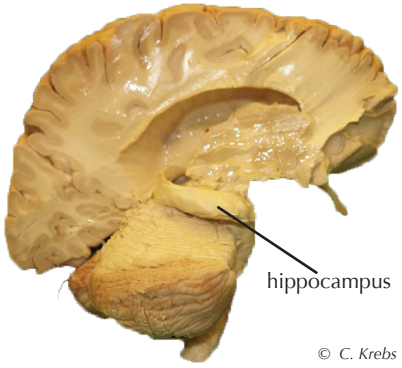


Figure 23-1. Overview of limbic/hypothalamic roles. (Nolte, The Human Brain - Study Guide)

- The hypothalamus has 2-way communication with limbic system structures.
- Limbic structures have 2-way communication with cortex, basal ganglia, cerebellum
- (Note: The cerebellum is involved in more than motor function. Research suggests it is involved in planning, judging time, mental activities [e.g., cognitive processing of words], and in emotional and cognitive disorders [e.g., autism]).
- Connections of basal ganglia to limbic structures are important. Emotions, affective state can influence motor function; conversely, see affective component in basal ganglia diseases

Major Limbic Structures



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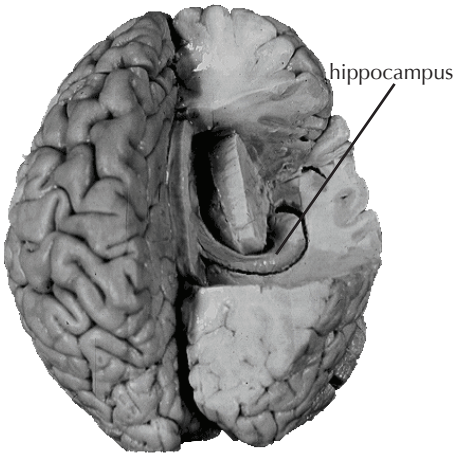
lateral view of the brain, right hemisphere removed and lateral ventricle opened to reveal the hippocampus



superior view of the brain, right hemisphere and lateral ventricle opened to reveal the hippocampus

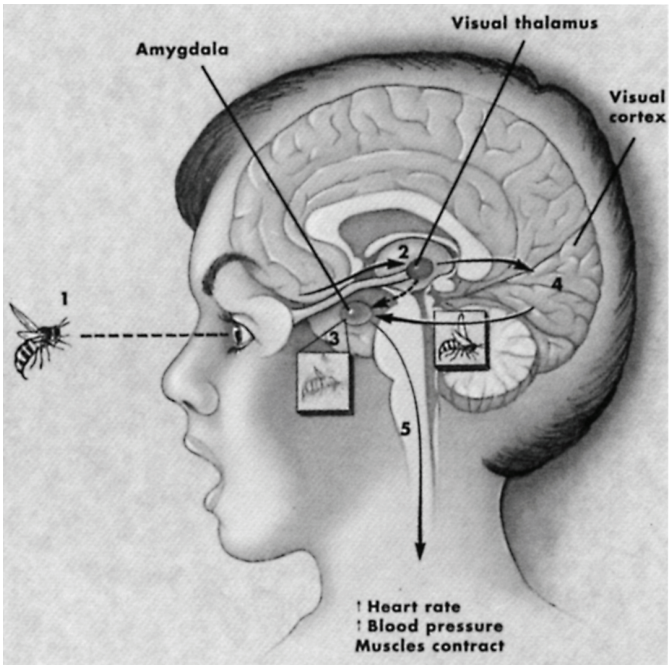
from the Digital Anatomist

The hippocampus and memory:

- Important role in learning & formation of new memories
  - Hippocampus acts as “encoding area” for translating short-term memories into long-term memories. Important for declarative memory.
  - May be the initial storage site for memory. As process of consolidation occurs, more permanent memories laid down (probably diffusely) in cortex.
  - Overlying cortex (uncus, entorhinal cortex) also plays important role in memory.
  - Bilateral removal of hippocampi results in inability of form new memories of facts and events. Deficits less severe if overlying cortex not involved.
  - The hippocampus and amygdala are linked to two independent memory systems. They act in concert when ‘emotion meets memory’.

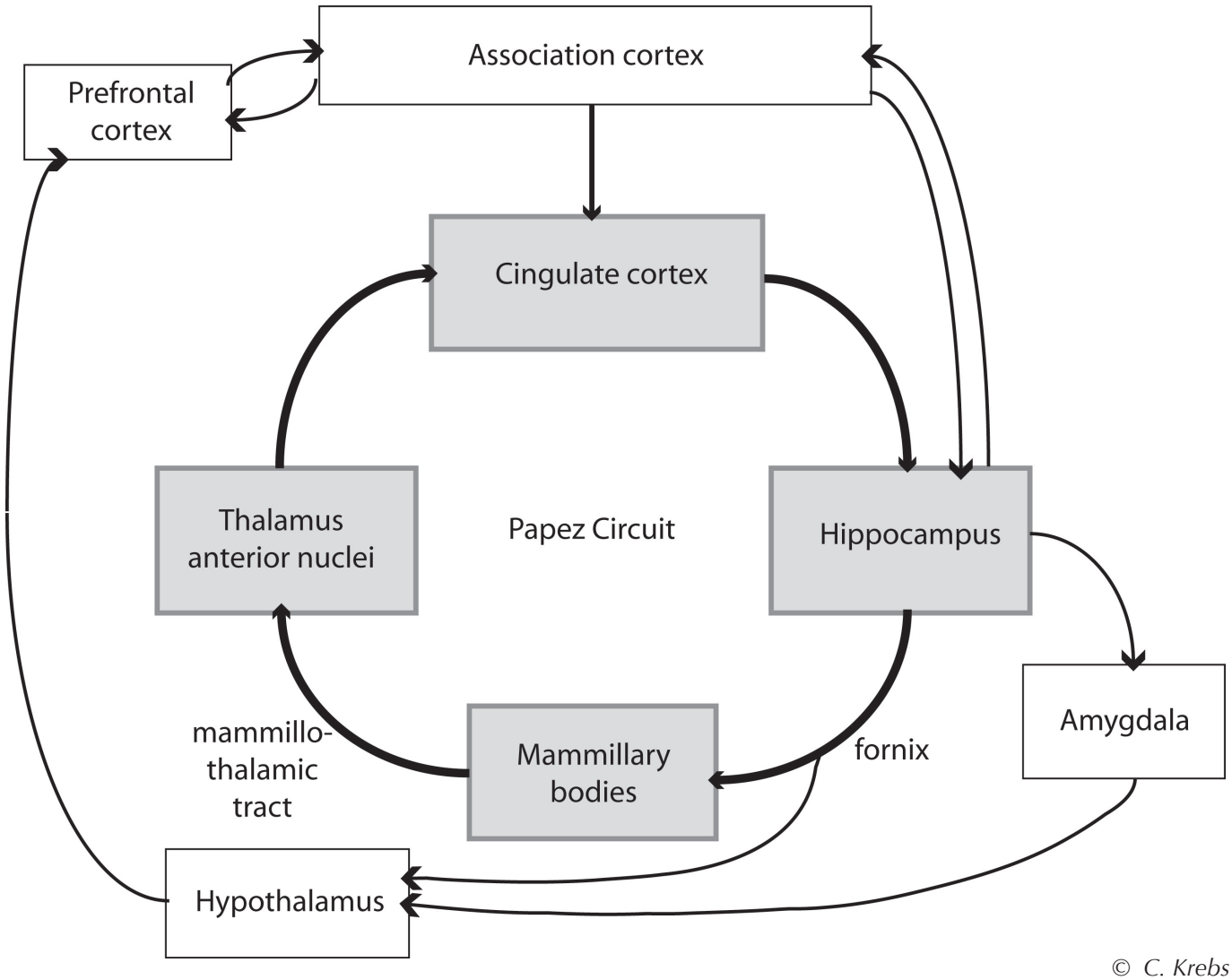
The amygdala and emotion:

- The amygdala associates experiences with consequences and then programs the appropriate behavioral response to the experience. Specifically, the amygdala plays a role in emotional learning and emotional processing, with a particular role in the expression of fear and anger.
- Input to the amygdala comes mainly from the cerebral cortex
- After assessing the nature of the input, i.e., friendly, unfriendly, frightening, dangerous, etc., the amygdala sends signals to centers in the hypothalamus that elicit the appropriate autonomic and motor responses. Signals are also sent from the basolateral amygdala via the dorsomedial nucleus of the thalamus to the orbitofrontal cortex.
  - The orbitofrontal cortex provides the perception of emotions, whereas the hypothalamus provides the expression of emotions.



Visual stimulus sent to thalamus and from there to the visual cortex. Information from visual cortex sent to amygdala activates autonomic and behavioral responses.

Interconnections between hypothalamus and limbic system structures



How do we express ourselves in movement, language and thought?

Cortical Association areas:

- Parietal association cortex - attention and awareness
- Temporal association cortex - recognition and identification of information
- Frontal association cortex - planning responses to ongoing stimuli, matching these behaviours to the demands of a particular situation, social planning

Language function: the integration of primary cortical areas with association areas.

Emotional Body Language: the connection between the basal ganglia / cerebellum and the limbic system.

Phineas Gage - a case study of a lesion to the frontal cortex

Harlow described the pre-accident Gage as having been hard-working, responsible, and popular with the men in his charge, but the post-accident Gage as:

"fitful, irreverent, indulging at times in the grossest profanity (which was not previously his custom), manifesting but little deference for his fellows, impatient of restraint or advice when it conflicts with his desires, at times pertinaciously obstinate, yet capricious and vacillating, devising many plans of future operations, which are no sooner arranged than they are abandoned in turn for others appearing more feasible. A child in his intellectual capacity and manifestations, he has the animal passions of a strong man. Previous to his injury, although untrained in the schools, he possessed a well-balanced mind, and was looked upon by those who knew him as a shrewd, smart businessman, very energetic and persistent in executing all his plans of operation. In this regard his mind was radically changed, so decidedly that his friends and acquaintances said he was 'no longer Gage."

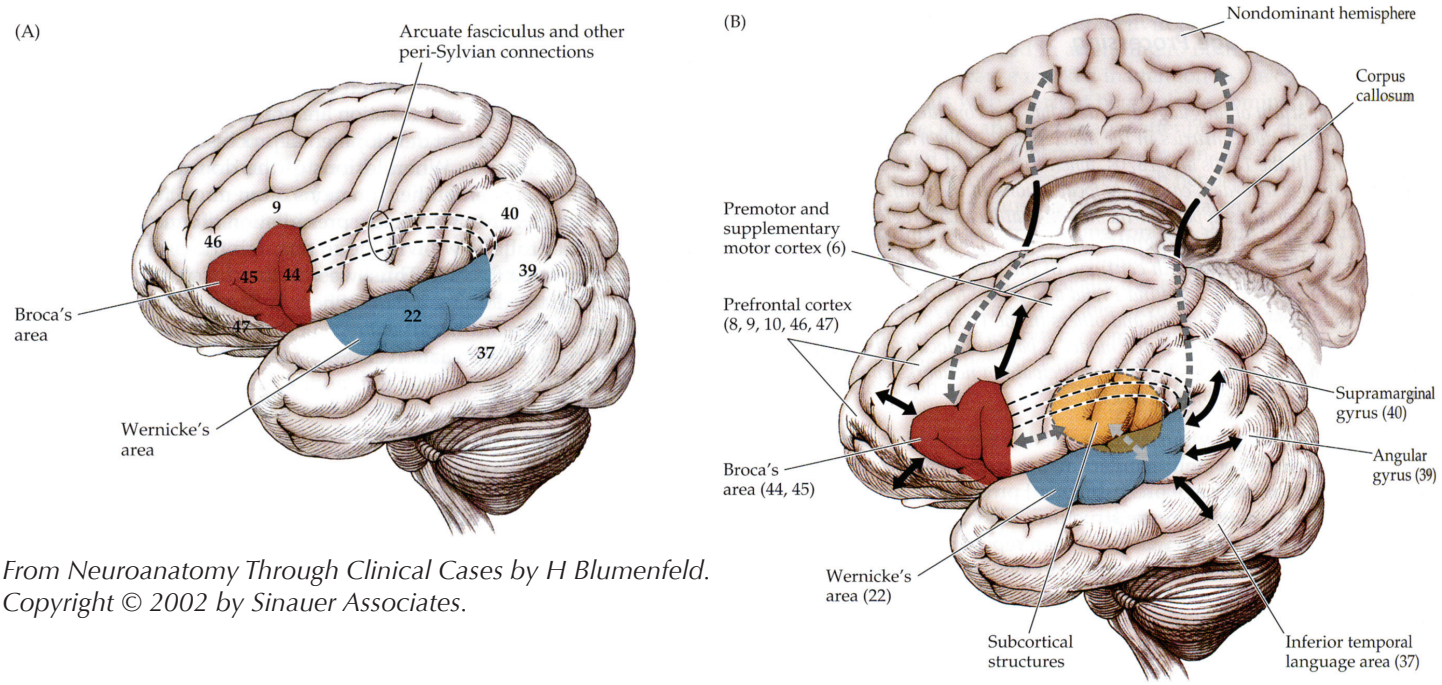
reference from Wikipedia

Lesion of the frontal cortex results in:

- impaired restraint
- disordered thought
- perseveration
- inability to plan appropriate action
- impaired working memory

Images in Public Domain

Language function



Language function is primarily located in the dominant (left) hemisphere.

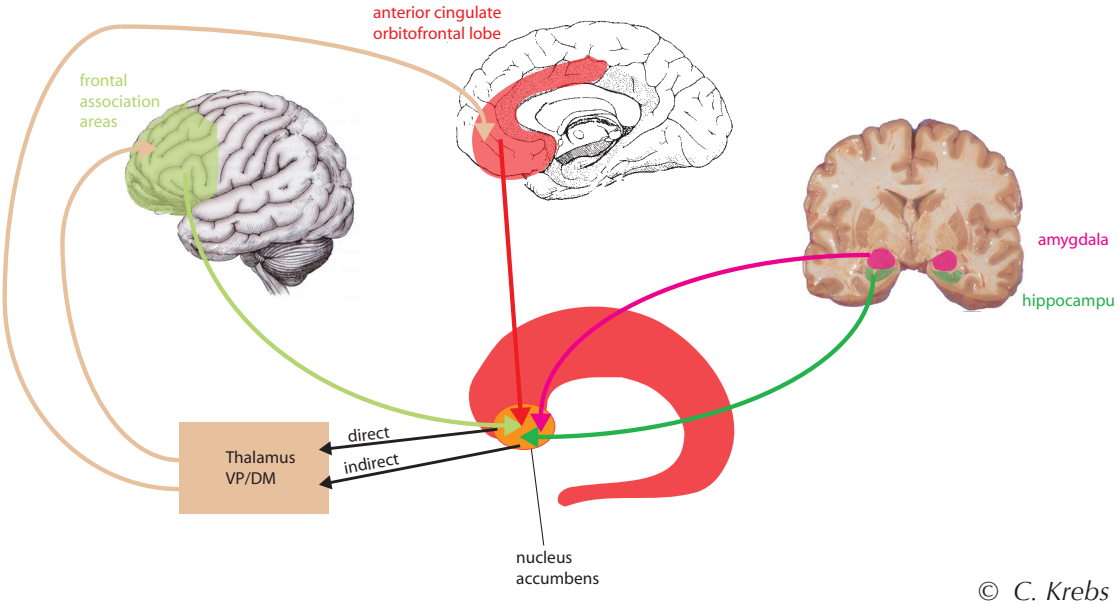
A motor or expressive speech area (Broca's) is responsible for the production of language.
A sensory or receptive speech area (Wernicke's) is responsible for the understanding of language.

The two areas need to be linked together so that the production of language makes sense.

The non-dominant (right) hemisphere adds additional aspects to language such as the expression and interpretation of emotion in language and the melody of language.

Emotional Body Language

- motor expression of emotions
- postures, gestures and facial expressions related to emotion
- rich in dopminergic neurons (“mask face” in PD)
- projections from frontal association cortex, cingulate gyrus, hippocampus and amygdala to mainly nucleus accumbens
- from there projections to thalamus



Not only can we express emotions through movement, but we can also interpret the emotional body language of others. The reflex-like EBL goes through the limbic circuit of the basal ganglia, other more conscious interpretations of EBL go through distinct cortical areas.

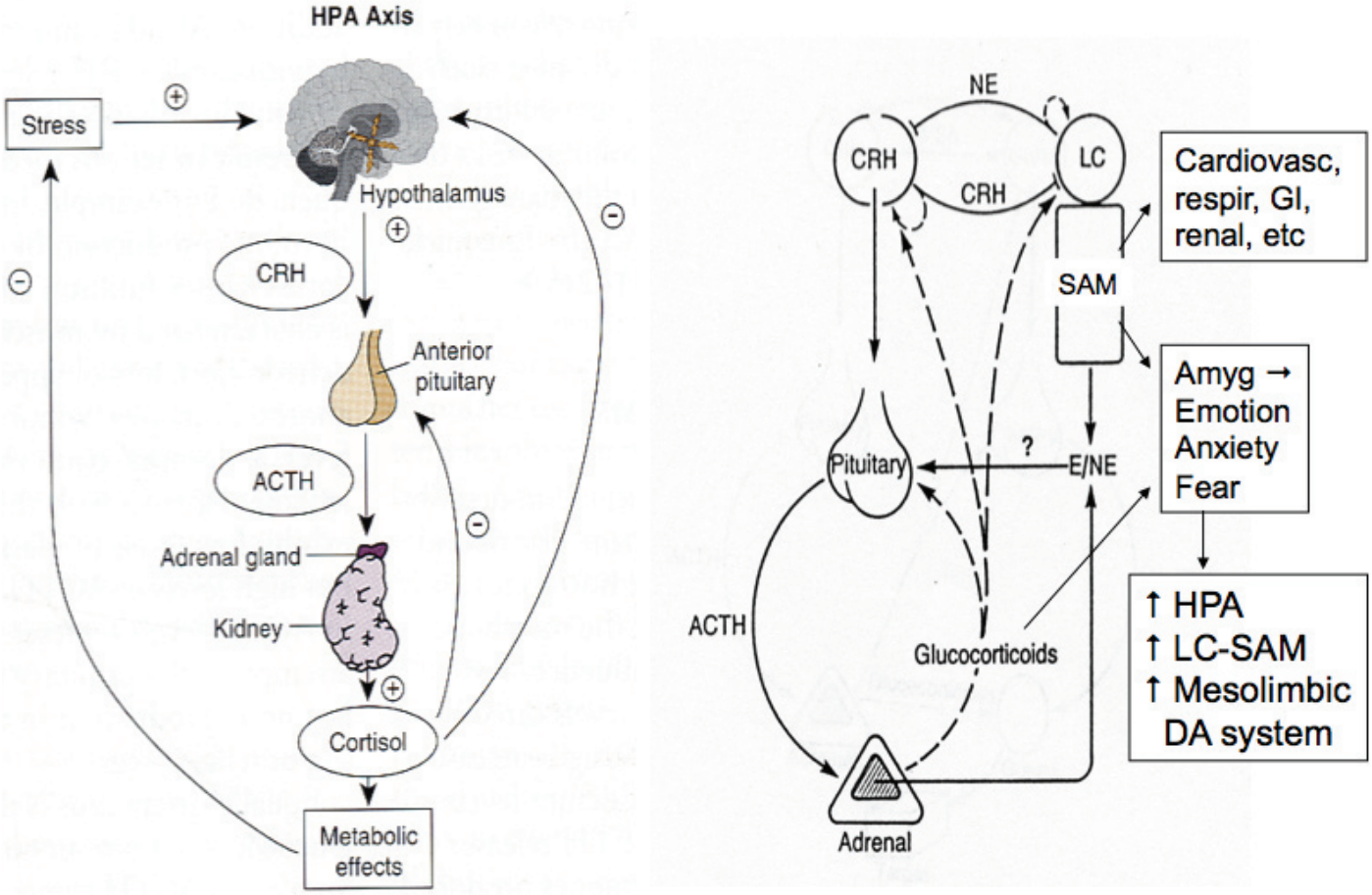
In this picture by Rubens (1577-1640) we see and interpret the turbulence of movement, the distress of the contorted bodies, this evokes an emotional response and interpretation, only then as a second order process do we put this into context. “The Fall of the Damned”

Towards the neurobiology of emotional body language. Nat. Rev. Neurosci. 2006 Mar; 7(3): 242-9

The stress system

The stress system has two major components:

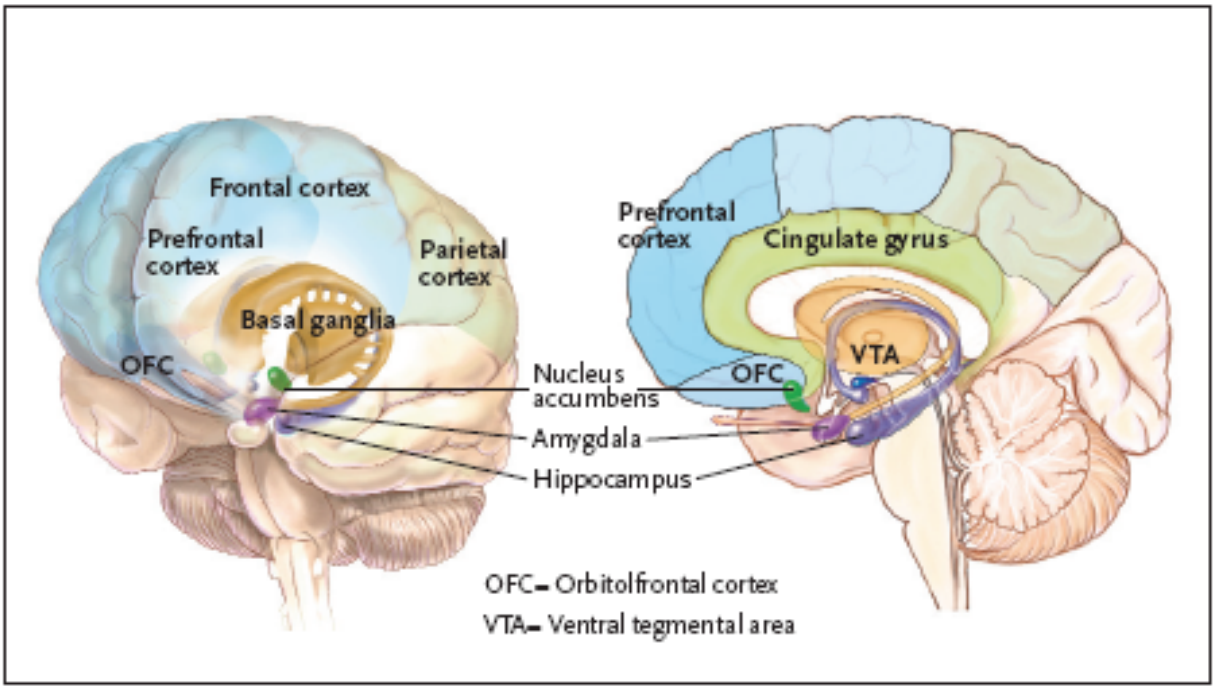
1. an autonomic component, the locus coeruleus - adrenal medullary system, which releases adrenalin and noradrenalin, and is responsible for a rapid 'fight or flight' response; and
2. the Hypothalamic-Pituitary-Adrenal (HPA) axis, which releases glucocorticoids such as cortisol, and provides a slower response which mobilizes resources to enable the body to respond to the stressor.



The HPA response is coordinated with that of the LC-SAM system. Together, these form the "stress system"

Neuroanatomical areas involved in cognition, emotion and reward overlap

(Fowler et al., Science & Practical Perspectives, April 2007)



The prefrontal cortex is the focal area for cognition and planning. The ventral tegmental area (VTA) and nucleus accumbens (NAc) are key components of the brain's reward system. The VTA, NAc, amygdala, and hippocampus are major components of the limbic system, which coordinates drives, emotions, and memories.

The stress system interacts with the dopamine system

- The mesolimbic pathway is one of the neural pathways in the brain that links the ventral tegmentum in the midbrain to the nucleus accumbens, which is located in the striatum and is a part of the limbic system. It is one of the four major pathways where the neurotransmitter dopamine is found. The mesolimbic pathway is thought to be involved in producing pleasurable feeling, and is often associated with feelings of reward and desire, particularly because of the connection to the nucleus accumbens, which is also associated with these states. Because of this, this pathway is heavily implicated in neurobiological theories of addiction.
- The ventral tegmentum also sends a dopaminergic projection to the cerebral cortex, particularly the frontal lobes. This mesocortical pathway is a second dopamine pathway in the brain. It is essential to the normal cognitive function of the dorsolateral prefrontal cortex (part of the frontal lobe), and is thought to be involved in motivation and emotional response. This pathway may be the brain system that is abnormal or functioning abnormally in psychoses, such as schizophrenia
- The mesocorticolimbic dopamine system is activated by the HPA and LC-SAM systems, and by glucocorticoids during stress. Increased glucocorticoids secretion or higher sensitivity to the central effects of the glucocorticoids can increase vulnerability to drug taking behavior, increase activity of the midbrain dopamine neurons, and feed back to inhibit the HPA axis but sensitive the CRH system in the amygdala, thus further increasing responsiveness and vulnerabity to stress.