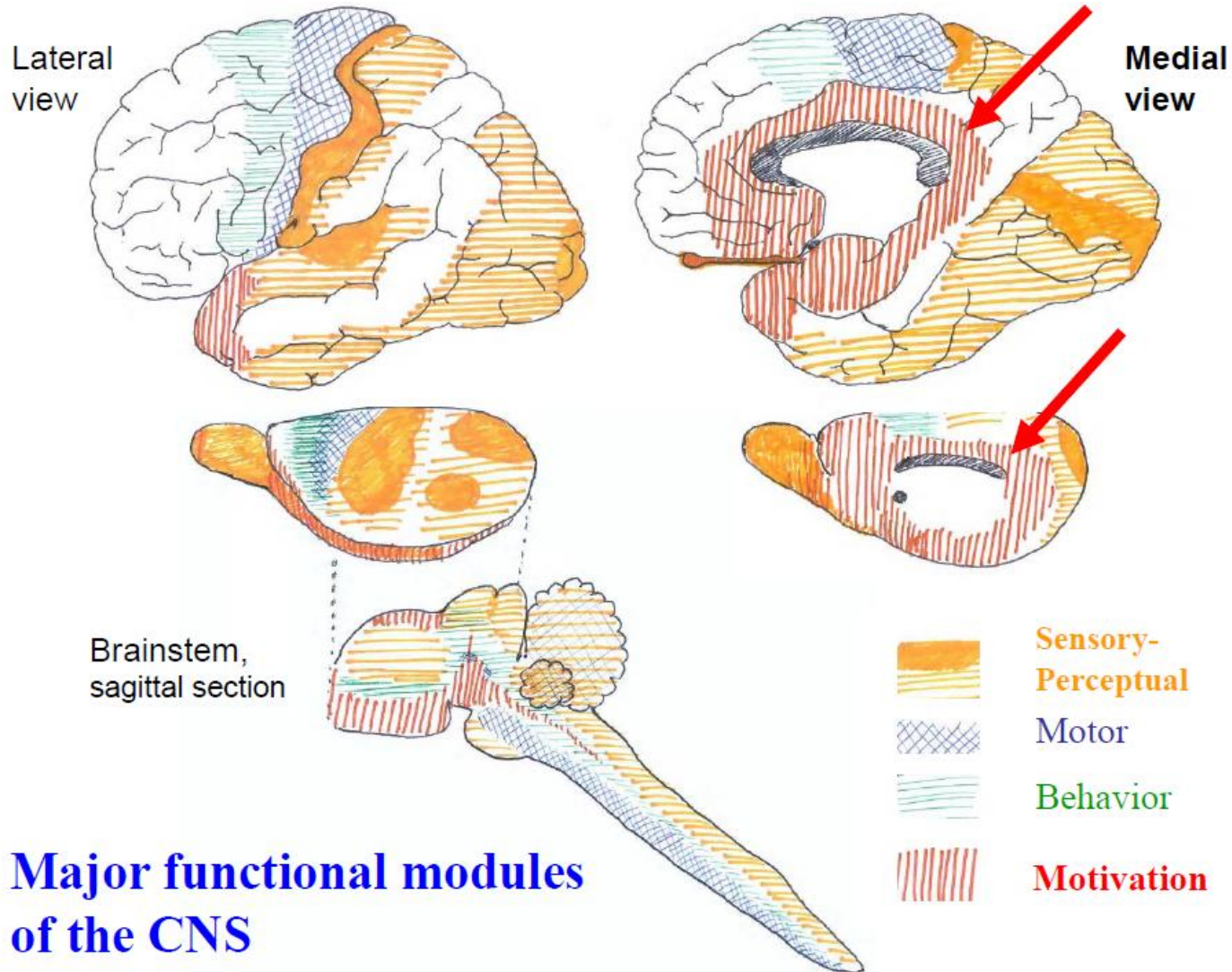


**16**

**Limbic system**

# Limbic system

Limbus = border



## Major functional modules of the CNS

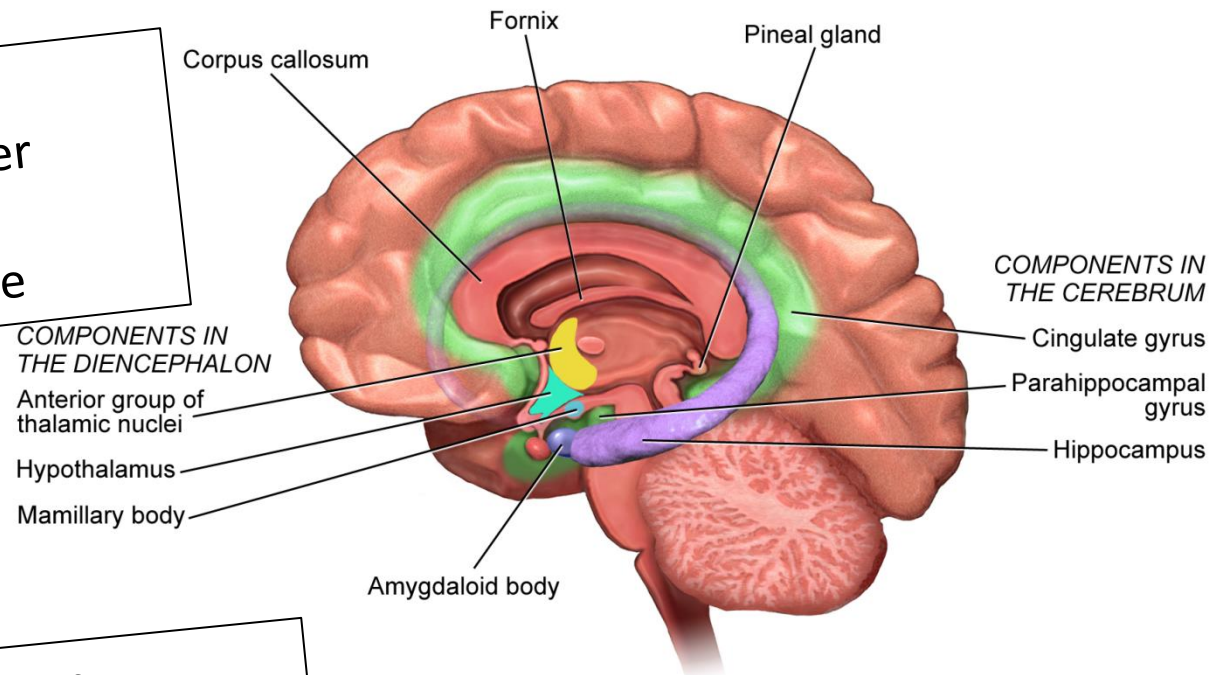
# Concept of the limbic system

- Voluntary

Somatic nervous system  
Inputs – mainly from outer environment  
Control – skeletal muscle

- Automatic

Autonomic nervous system  
Inputs – mainly inner environment  
Control – smooth/cardiac m., glands



# Concept of the limbic system

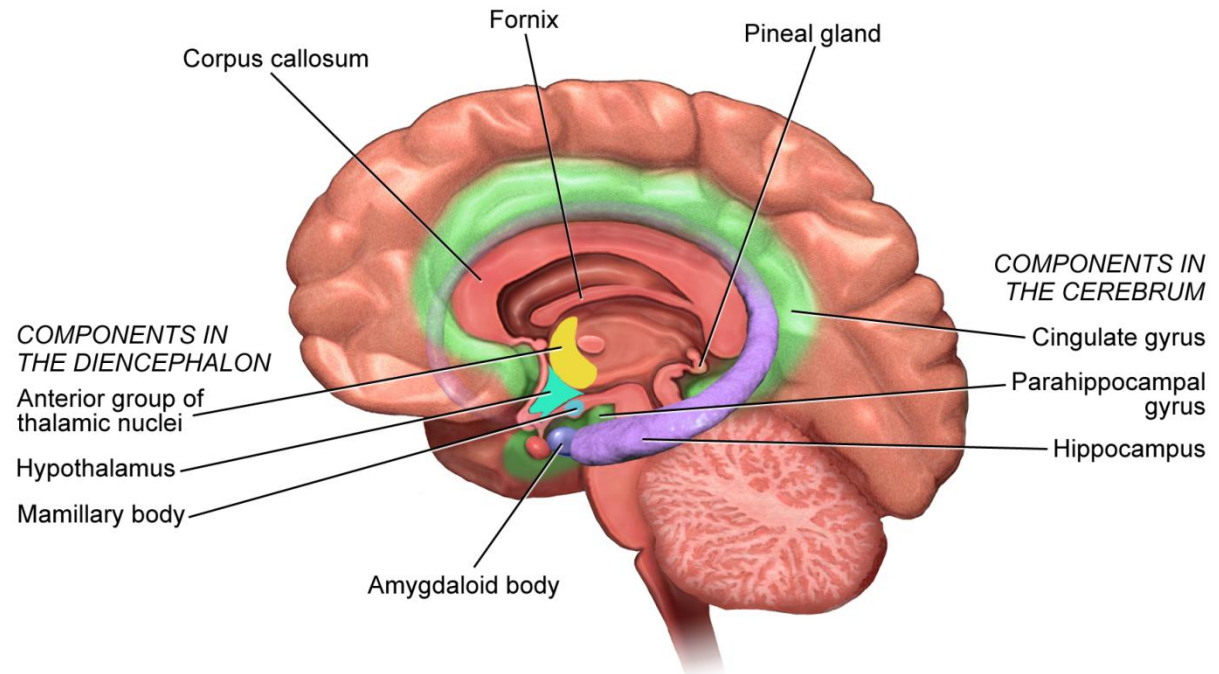
- Voluntary

↑  
Modulation

**Limbic system**

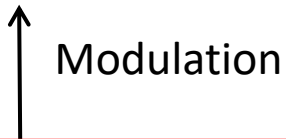
↓  
Control

- Automatic

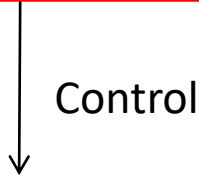


# Concept of the limbic system

- Voluntary

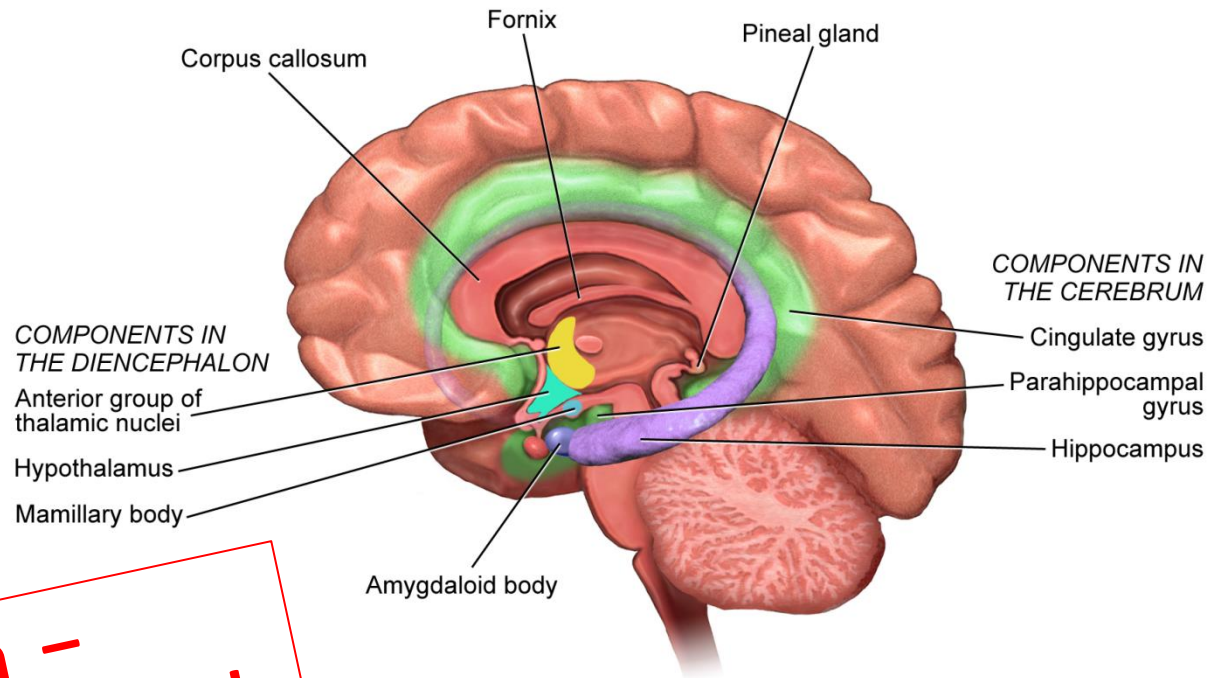


**Limbic system**



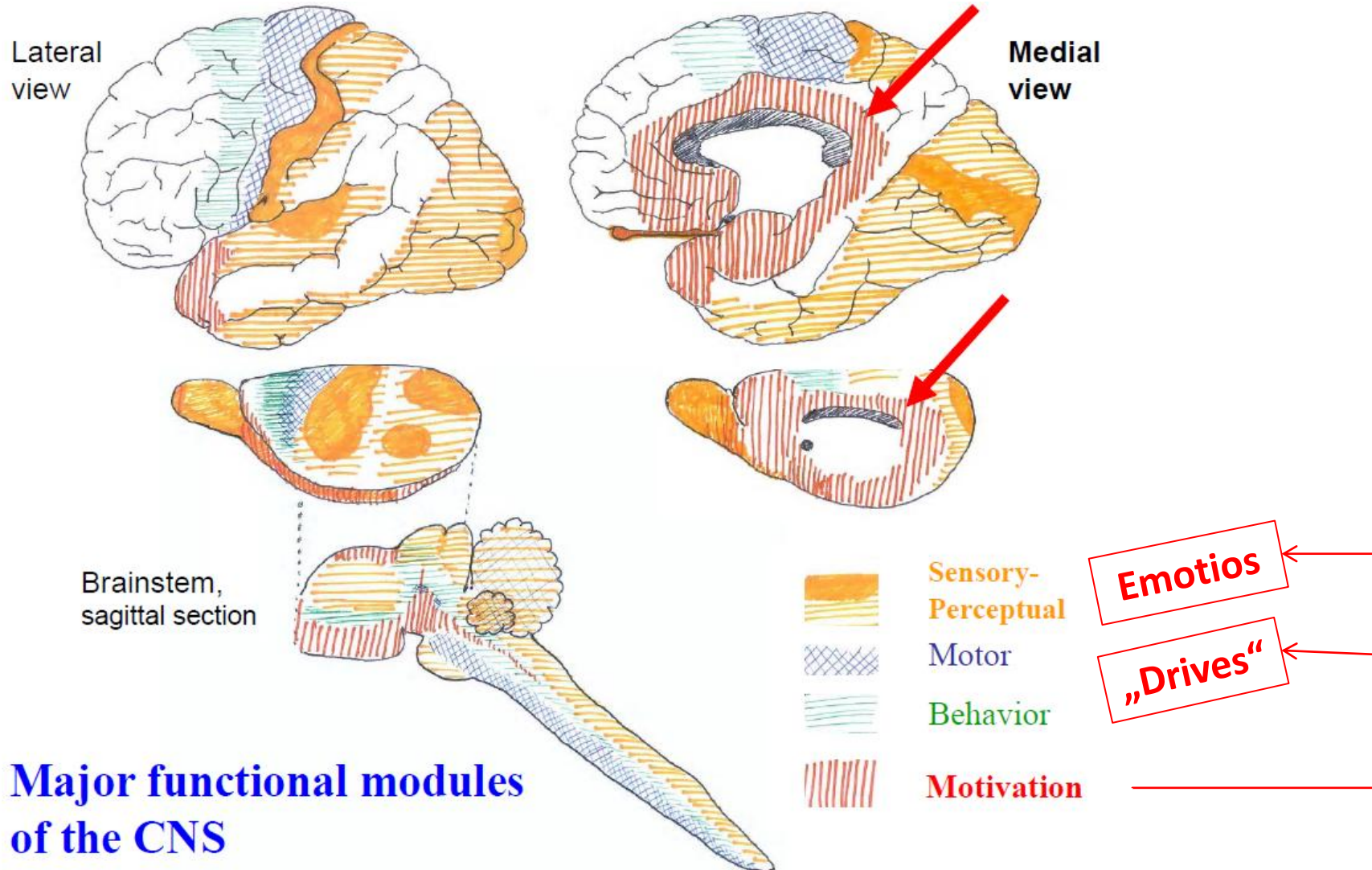
- Automatic

**Limbic system –  
hypothalamus and related  
structures**

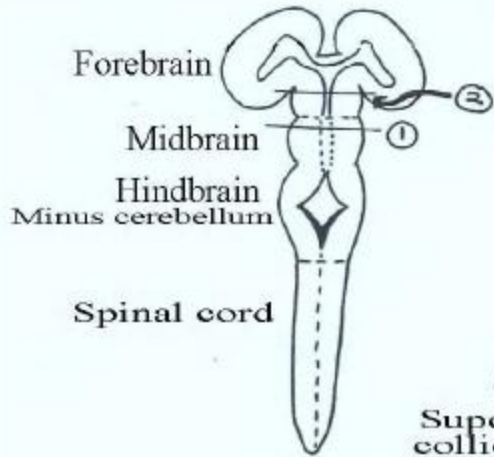




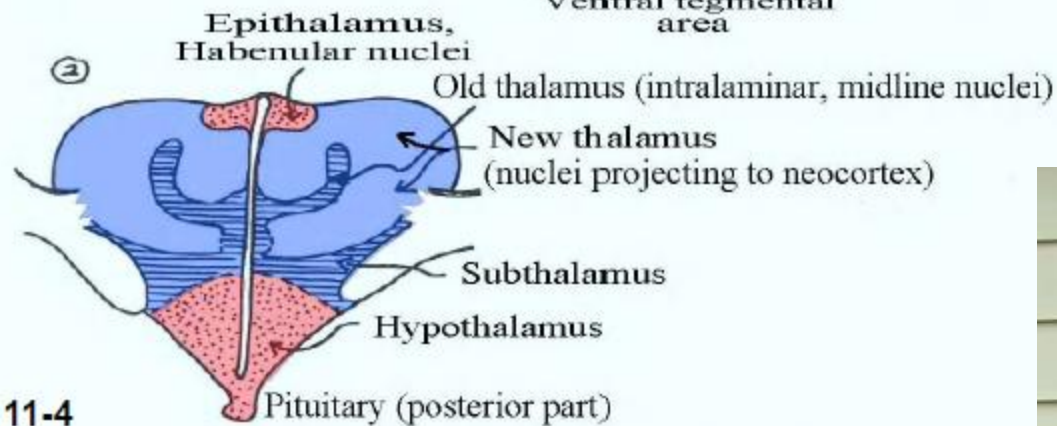
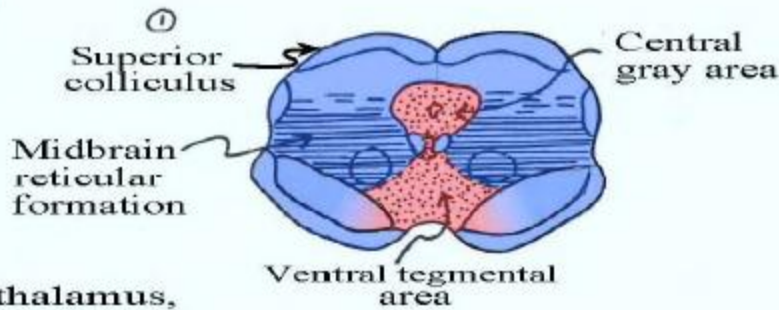
# Limbický systém



## Major functional modules of the CNS



**Somatic regions**  
**Limbic regions**

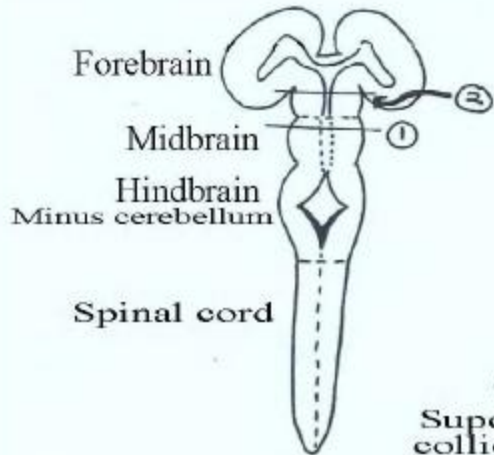


**Fig 11-4**

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Schneider, G. E. Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind. MIT Press, 2014. ISBN: 9780262026734.

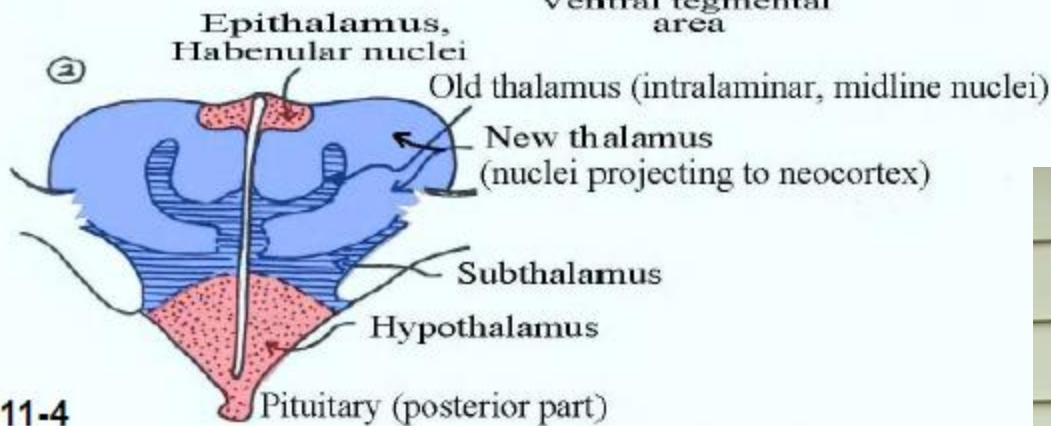
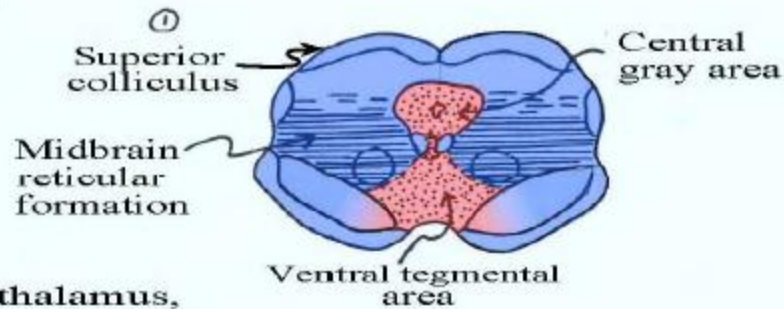


**Prof. Gerald Schneider**



**Somatic regions: arousal type 1**

**Limbic regions: arousal type 2**



**Fig 11-4**

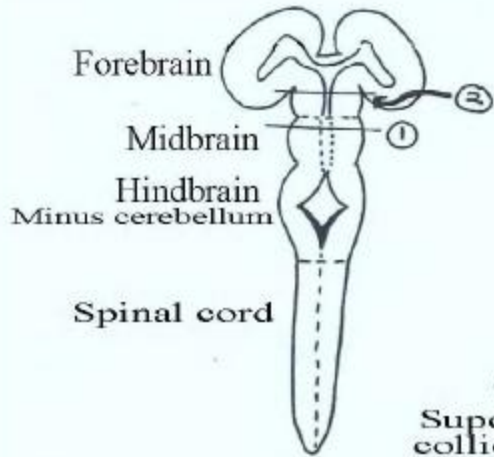
Courtesy of MIT Press. Used with permission.  
Schneider, G. E. *Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

31



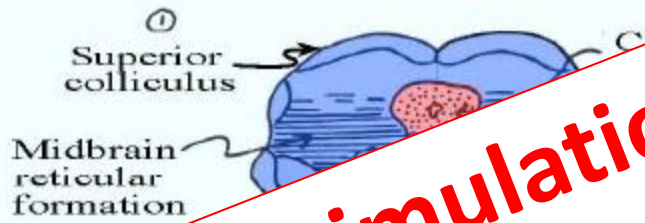
**Prof. Gerald Schneider**





**Somatic regions: arousal type 1**

**Limbic regions: arousal type 2**



**Effect of stimulation**

- Increased EEG activity
- Activation of sympathetic nervous system



Prof. Gerald Schneider

## Arousal type 1 (somatic)

## Arousal type 2 (limbic)

### ARAS (ascendent retikulation activation system)

- Effect of stimulation
  - Habituation
  - Minimal ctivation of „reward/punishing“ system
- Effect of stimulation
  - Minimal habituation
  - Strong activation of „reward/ punishing“ system
    - Central gray area –CGA - negative
    - Ventral tegmental area – VTA – positive

## Arousal type 1 (somatic)

## Arousal type 2 (limbic)

### ARAS (ascendent retikulation activation system)

- Effect of stimulation
  - Habituation
  - Minimal ctivation of „reward/punishing“ system
- Ascendent connections
  - Somatosensetivity, visual s., auditory s., vestibular s., cerebellum
- Descendent connections
  - Neocortex, corpus striatum, thalamus
- Effect of stimulation
  - Minimal habituation
  - Strong activation of „reward/ punishing“ system
    - Central gray area –CGA - negative
    - Ventral tegmental area – VTA – positive
- Ascendent connections
  - Mainly viscerosenzitivity, pain
- Descendent connections
  - Hypothalamus and other limbic areas, amygdala

## Arousal type 1 (somatic)

## Arousal type 2 (limbic)

### ARAS (ascendent retikulation activation system)

- Effect of stimulation
  - Habituation
  - ...

**Effect of stimulation**

➤ **Increased EEG activity**

➤ **Activation of sympathetic nervous system**

- Ascendent connections

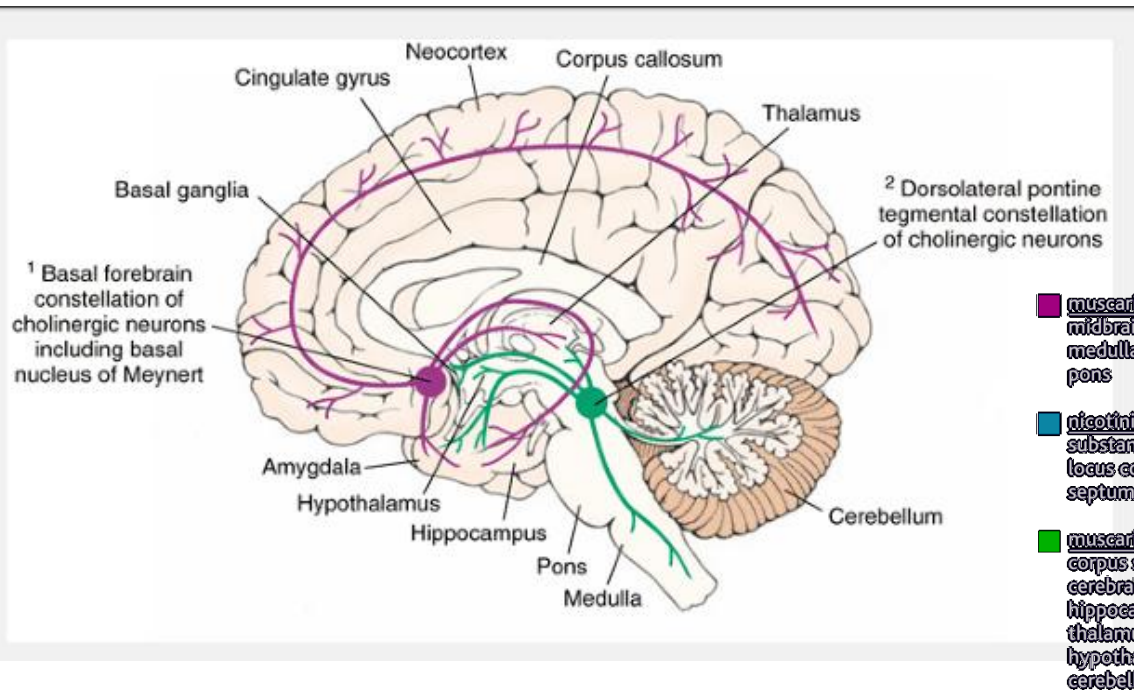
**Cooperation of both systems is a key to maintaining consciousness (through neuromodulation)**

- Descendent connections
  - Hypothalamus and other limbic areas, amygdala

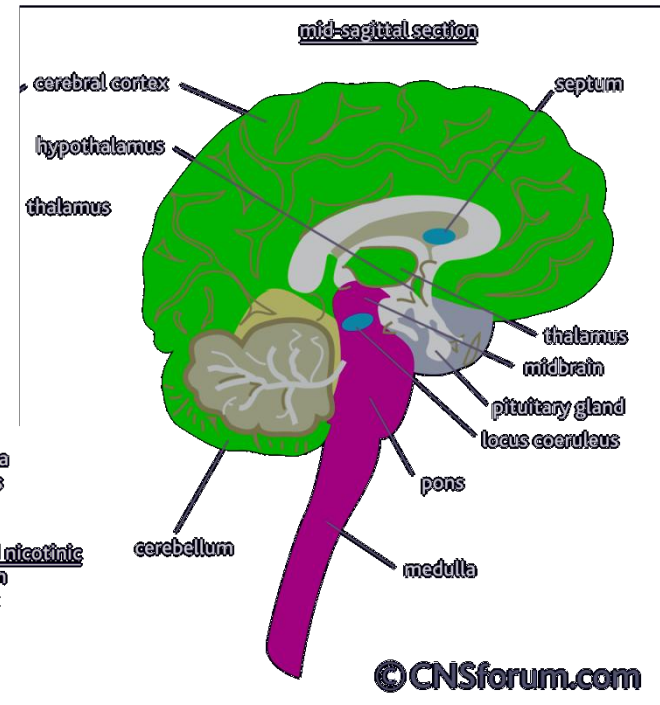


# Acetylcholine

- Nucleus basalis (Meynerti) and other nuclei
- Nicotin receptors
- Muscarin receptors
- Sleep/wake regulation
- Cognitive functions
- Behavior
- Emotions

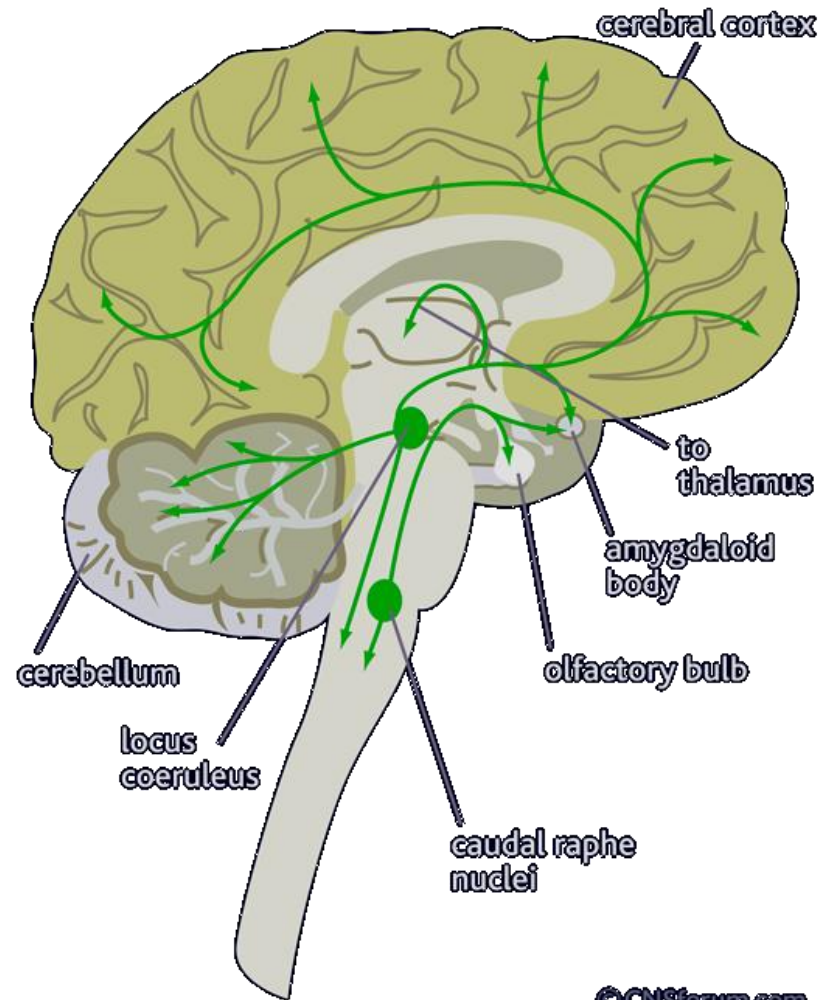


- muscarinic  
midbrain  
medulla  
pons
- nicotinic  
substantia nigra  
locus coeruleus  
septum
- muscarinic and nicotinic  
corpus striatum  
cerebral cortex  
hippocampus  
thalamus  
hypothalamus  
cerebellum



# Norepinephrine

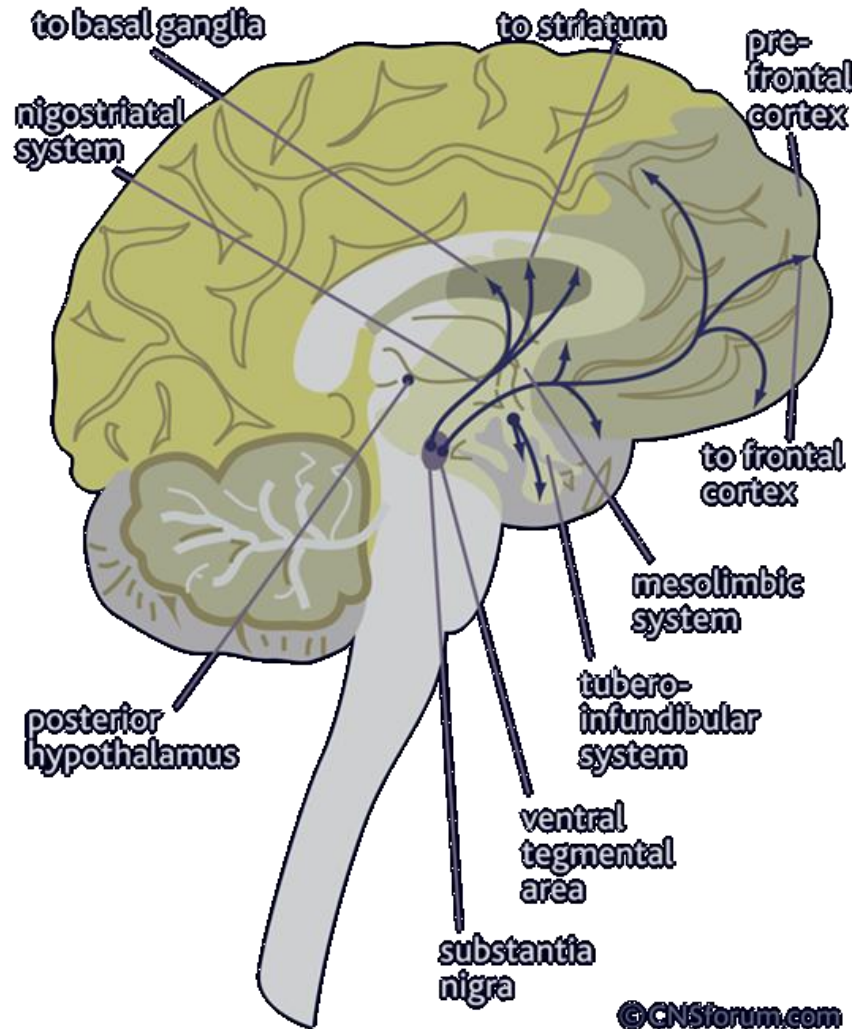
- Locus coeruleus
- Nuclei raphe caudalis
  
- Vigilance
- Responsiveness to unexpected stimuli
  
- Memory
- Learning



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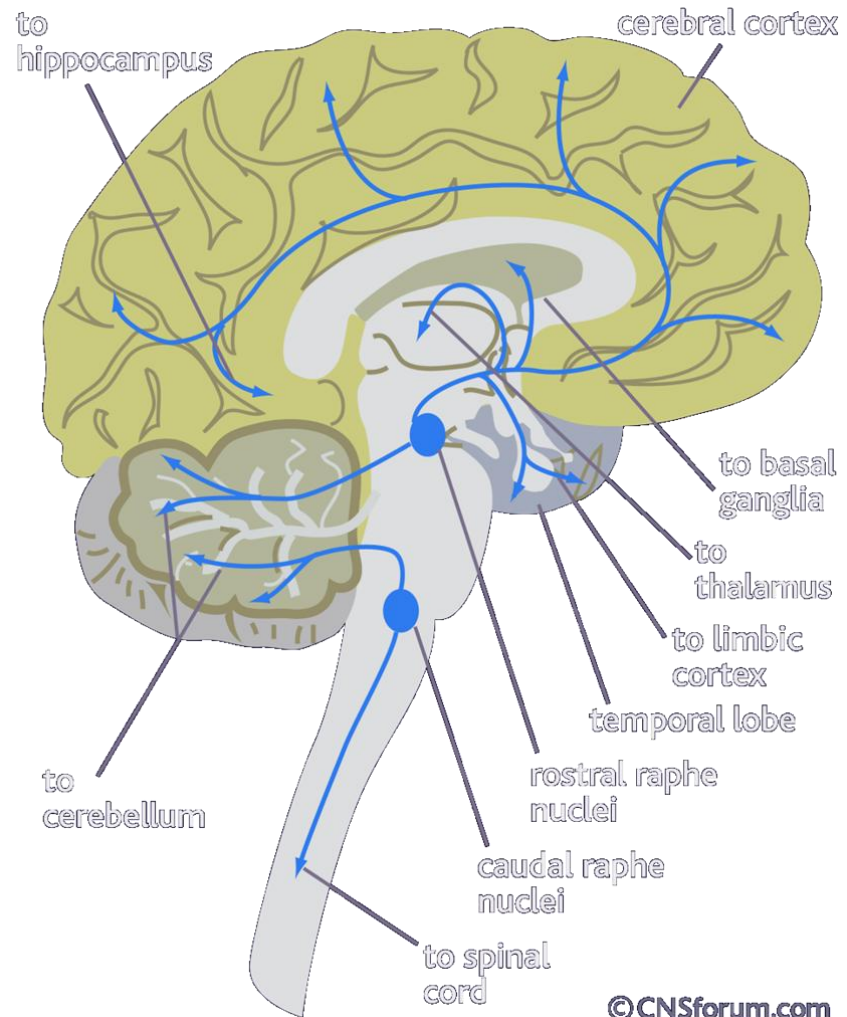
# Dopamine

- Nigrostriatal system
  - Movement
  - Sensory stimuli
- Ventro tegmentno-mesolimbic-frontal system
  - Reward
  - Cognitive function
  - Emotional behavior
- Tubero-infundibular system
  - Hypothalamic-pituitary regulation
- D1 receptors – excitatory
- D2 receptors - inhibitory



# Serotonin

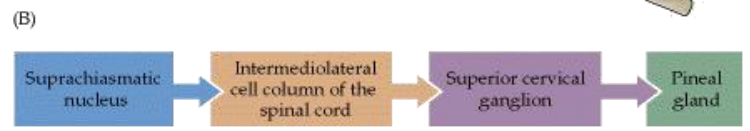
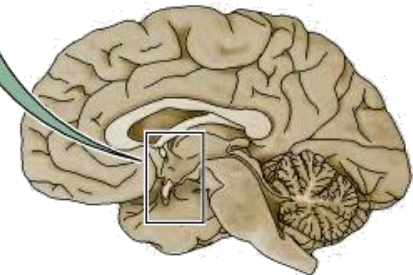
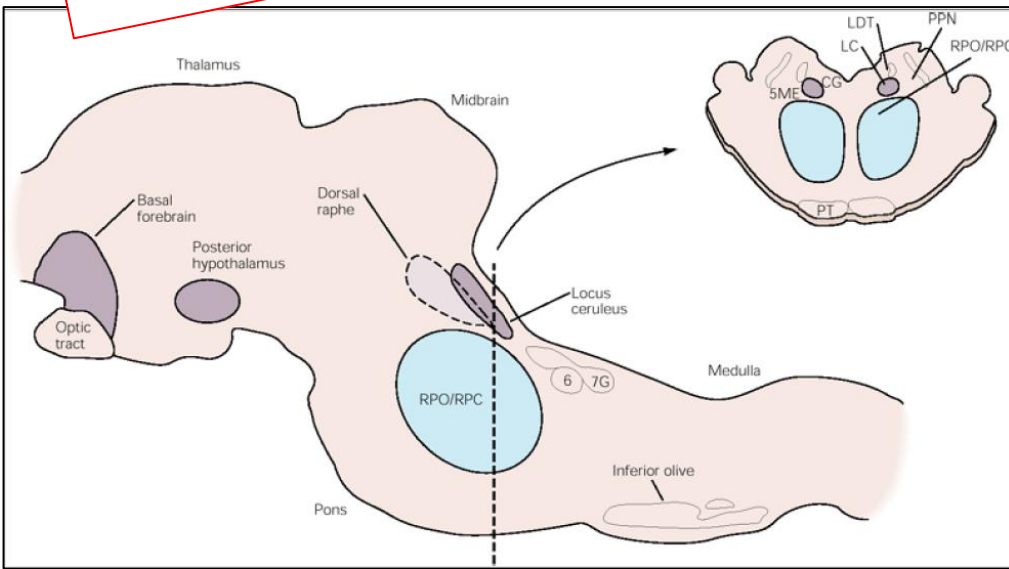
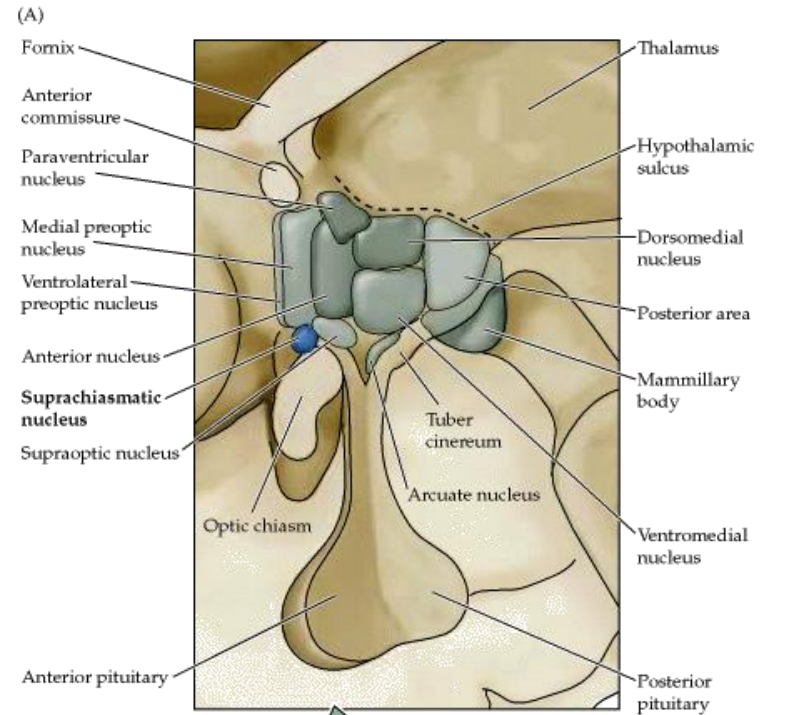
- Nuclei raphe rostralis
- Nuclei raphe caudalis
  
- Anxiety
- Impulsive behavior





# Sleep and wakefulness

**Cooperation of ARAS and limbic activating system**



# Sleep

## The sleep cycle

There are two very different types of sleep:

1. Rapid Eye Movement or REM sleep, which is associated with fast brain activity and active dreaming; and
2. Non-REM sleep, which is associated with slower brain activity and divided into 4 stages:
  - » Stages 1-2 light sleep
  - » Stages 3-4 deep slow-wave sleep.

All these combine to make the non-REM/REM sleep cycle, which is about 90 minutes long on average, but can be up to 120 minutes.

For most people, a good night's sleep is around 4 – 5 cycles long.

Good quality sleep requires both non-REM and REM sleep in uninterrupted cycles.

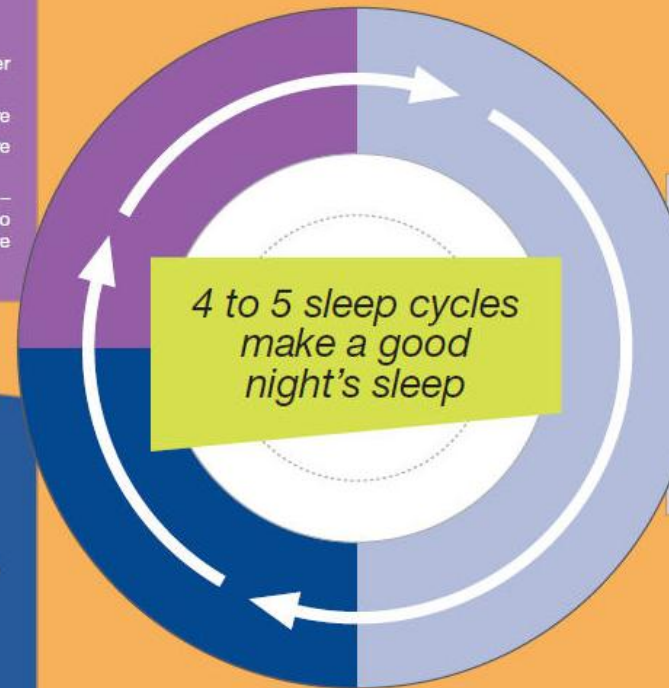
### REM SLEEP

- › Eyes move rapidly under closed eyelids
- › Most dreaming occurs here
- › Brain is active, muscles are relaxed
- › Can't move voluntarily – signals from the brain to the postural muscles are blocked

### DEEP NON-REM SLEEP

- › Stages 3-4
- › Difficult to wake up
- › Sleep inertia when woken

## Rapid Eye Movement (REM)

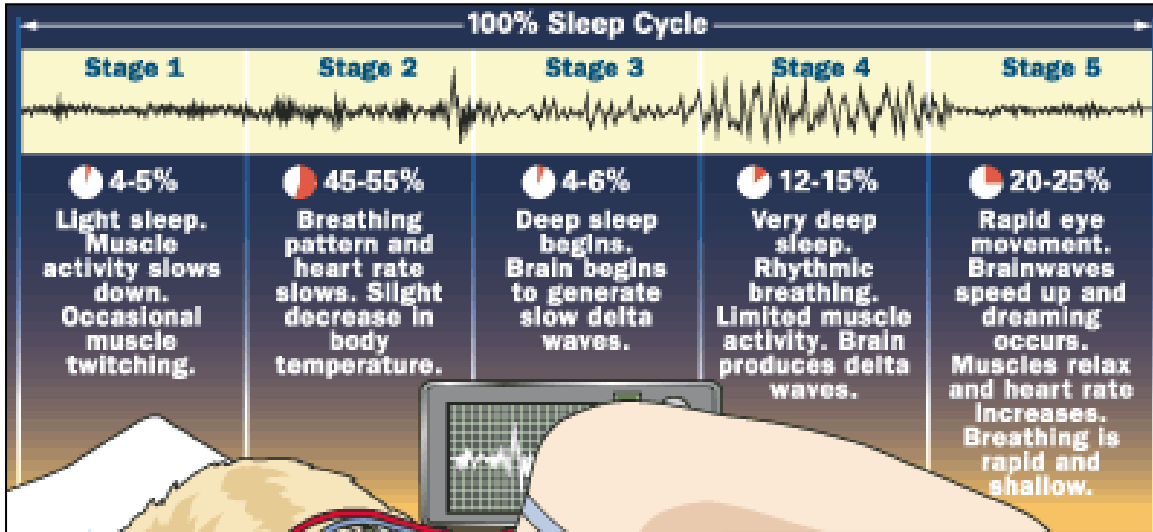


### LIGHT NON-REM SLEEP

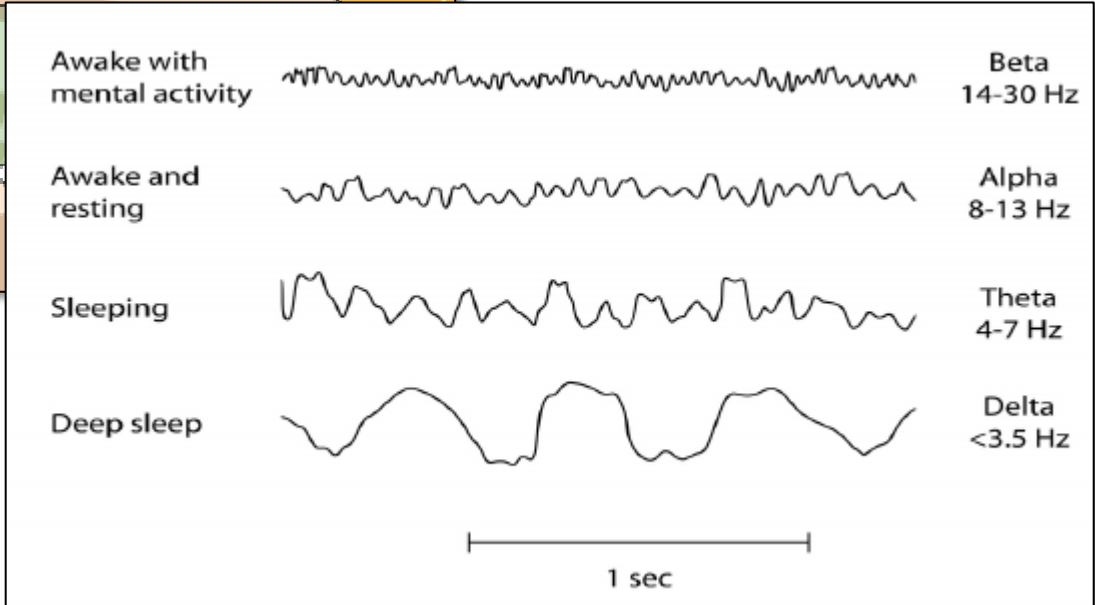
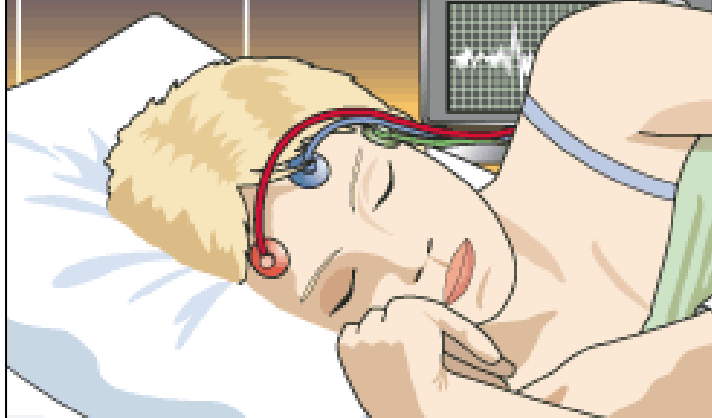
- › Stages 1-2
- › May drift in and out of sleep several times at the start
- › Easy to wake up, disturbs easily

# Sleep

http://www.slideshare.net/drpsdeb/presentations



http://www.dailymail.co.uk/sciencetech/article-3042230/Sleeping-habits-world-revealed-wakes-grumpy-China-best-quality-shut-eye-South-Africa-wakes-earliest.html



https://www.researchgate.net/profile/Priyanka\_Abhang3/publication/281801676/figure/fig4/AS:305025248186371@1449735094401/Fig-4-EEG-waves-for-different-signals.png

LIGHT NON-REM SLEEP	DEEP NON-REM SLEEP	REM SLEEP
<ul style="list-style-type: none"> <li>Stages 1-2</li> <li>May drift in and out of sleep several times at the start</li> <li>Easy to wake up, disturbs easily</li> </ul>	<ul style="list-style-type: none"> <li>Stages 3-4</li> <li>Difficult to wake up</li> <li>Sleep inertia when woken</li> </ul>	<ul style="list-style-type: none"> <li>Eyes move rapidly under closed eyelids</li> <li>Most dreaming occurs here</li> <li>Brain is active, muscles are relaxed</li> <li>Can't move voluntarily – signals from the brain to the postural muscles are blocked</li> </ul>

# Sleep and wakefulness

## Brainstem nuclei responsible

## Neurotransmitter

## Activity state

### *WAKEFULNESS*

**Cholinergic nuclei of pons-midbrain junction**

**Acetylcholine**

**Active**

**Locus coeruleus**

**Norepinephrine**

**Active**

**Raphe nuclei**

**Serotonin**

**Active**

### *NON-REM SLEEP*

**Cholinergic nuclei of pons-midbrain junction**

**Acetylcholine**

**Decreased**

**Locus coeruleus**

**Norepinephrine**

**Decreased**

**Raphe nuclei**

**Serotonin**

**Decreased**

### *REM SLEEP ON*

**Cholinergic nuclei of pons-midbrain junction**

**Acetylcholine**

**Active**

**Raphe nuclei**

**Serotonin**

**Inactive**

### *REM SLEEP OFF*

**Locus coeruleus**

**Norepinephrine**

**Active**



# Hypothalamus

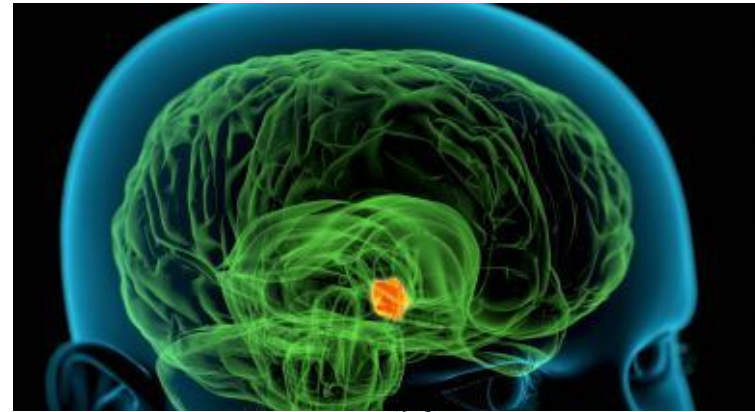
- Key center of autonomic regulations and coordination
- Integration of the information from inner and outer environment



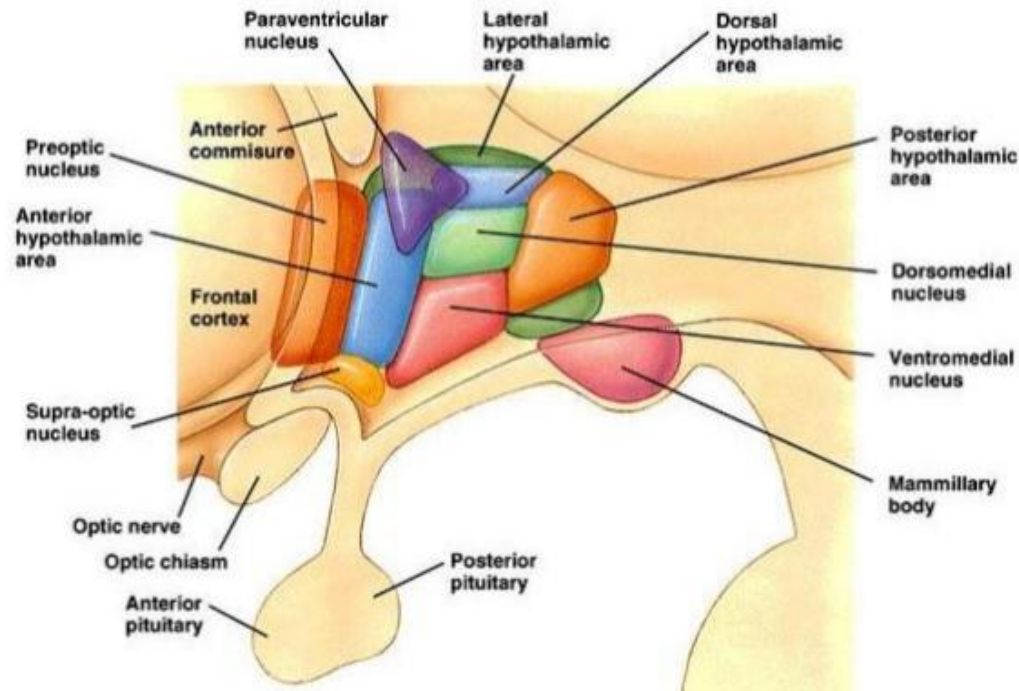
- Behavioral modulation
- Regulation of autonomic nervous system



- **Maintenance of homeostasis**



<http://biology.about.com/od/anatomy/p/Hypothalamus.htm>



<http://www.slideshare.net/physiologymgmcri/hypothalamus-15-apr-2016>

# Hypothalamus

- Key center of autonomic regulations and coordination

- Interacts with

✓ **Biological clock – circadian /seasonal activity**

✓ **Autonomic nervous system regulation**

✓ **Endocrine system regulation**

✓ **Food and water intake regulation**

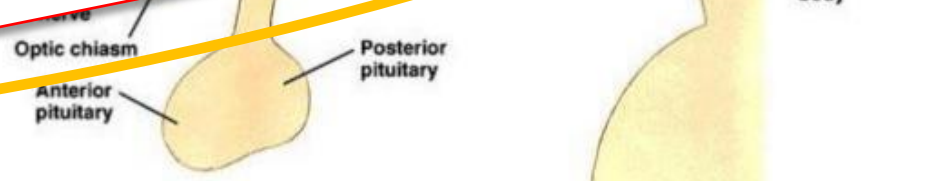
✓ **Regulation of body temperature**

✓ **„Immediate“ behavior regulation (e.g. when hunger)**

✓ **„Long-term“ behavior regulation (e.g. maternal beh.)**

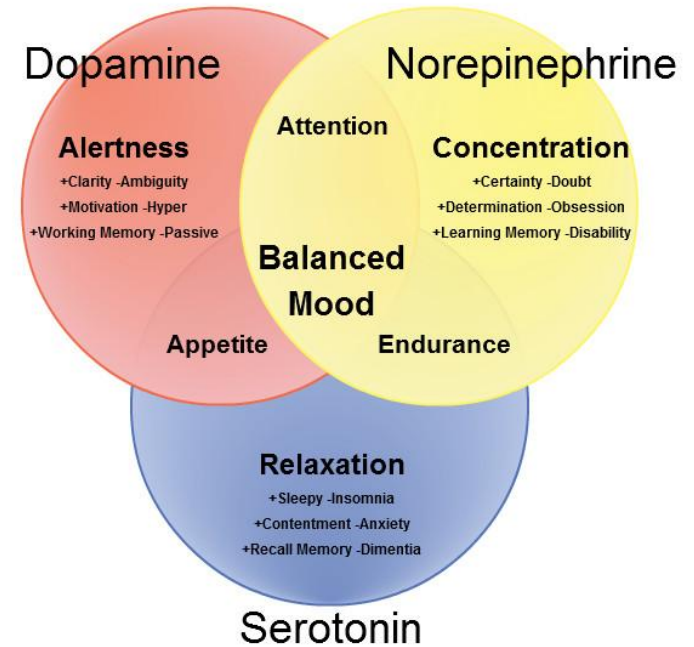
• **Main**

✓ **Instinctive behavior regulation (e.g. sexuality)**



# Influence of hypothalamus on neocortex

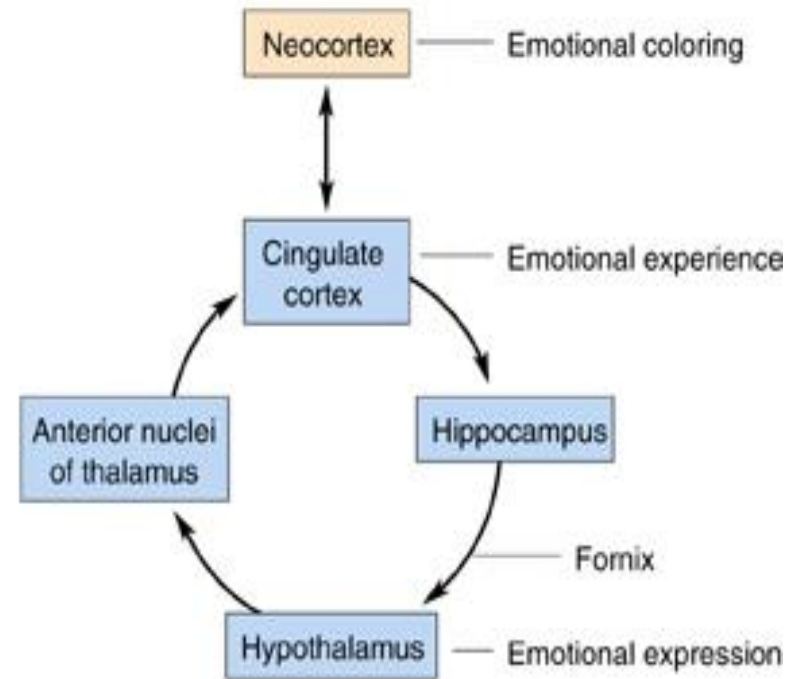
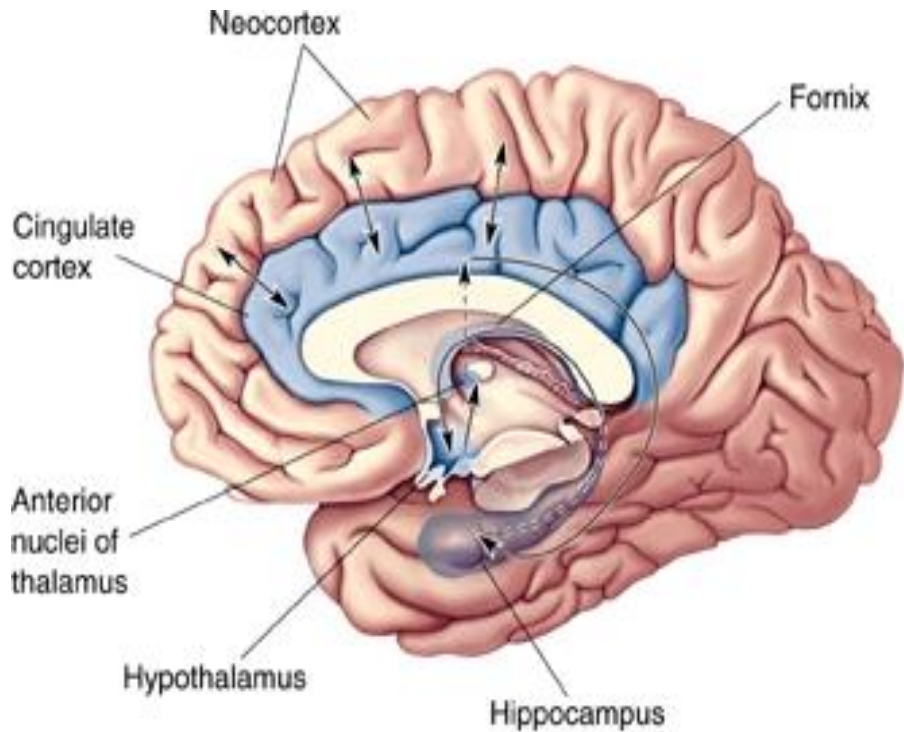
- Via neuromodulating systems
  - Consciousness (viz. výše)
  - Mood
- Via thalamus
  - Via nucleus mediodorsalis to orbitofrontal cortex (influence on decision making)
  - Influence gating function of other thalamic nuclei
- Papez circuit



Orbitofrontal  
cortex



# Papez circuit

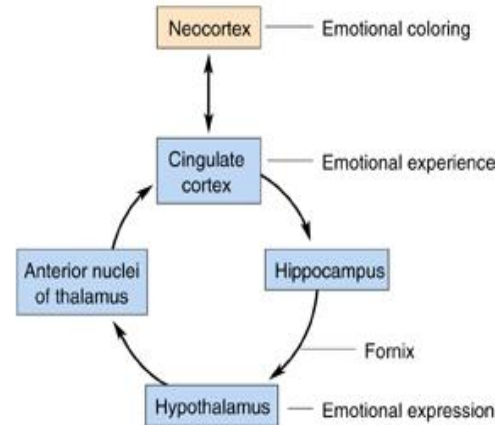
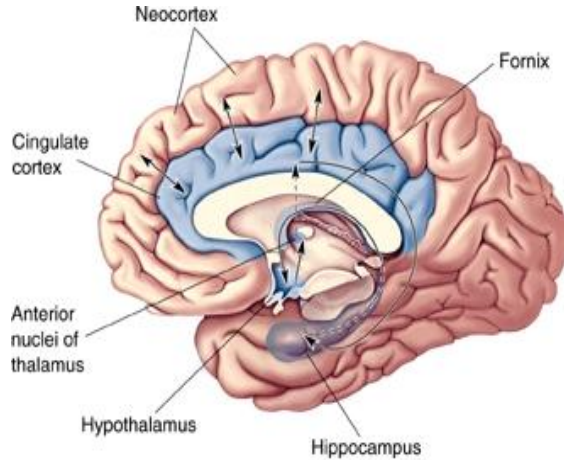


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<http://www.slideshare.net/drsunilsuthar/neurobiology-of-emotion>

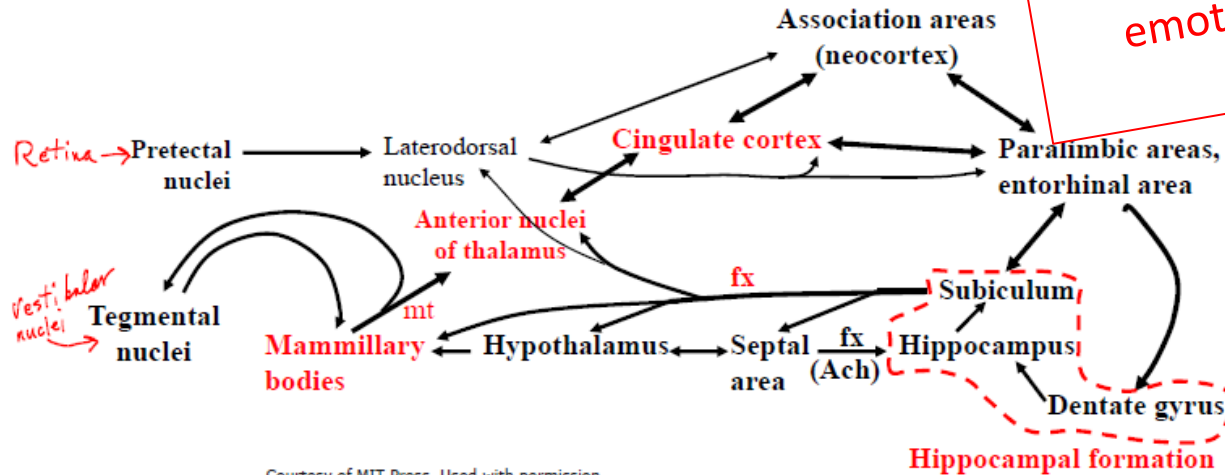


# Papez circuit



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**mt** = mammillothalamic tract  
**fx** = fornix bundle



Spatial orientation and emotions associated with particular place



Prof. Gerald Schneider

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 Schneider, G. E. Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind. MIT Press, 2014. ISBN: 9780262026734.

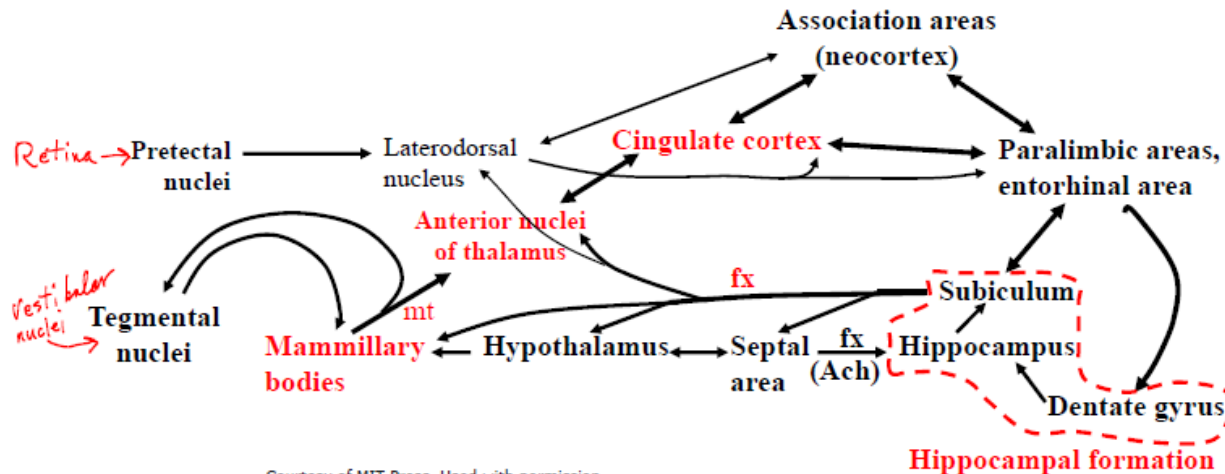
Gerald Schneider. 9.14 Brain Structure and its Origins, Spring 2014. (Massachusetts Institute of Technology: MIT OpenCourseWare). <http://ocw.mit.edu> (Accessed). License: Creative Commons BY-NC-SA





- Origins of endbrain: Structures underlying olfaction
- Two major links between olfactory system and the motor systems of the midbrain
  - 1) Through the ventral endbrain, which became corpus striatum and basal forebrain (including much of the septal area)
    - Outputs to hypothalamus, (epithalamus, subthalamus), midbrain
    - These outputs affected locomotion and orienting movements
    - The links were plastic, so habits were formed according to rewarding effects mediated, e.g., by taste effects.
  - 2) **Through the medial part of the dorsal endbrain, which became medial pallium—the hippocampal formation**
    - Outputs to ventral striatum, hypothalamus, epithalamus
    - The links were plastic, but the “habits” formed were different: The association of place with good or bad consequences of approach.

mt = mammillothalamic tract  
 fx = fornix bundle



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 Schneider, G. E. Brain Structure and its Origins: In the Development and in  
 Evolution of Behavior and the Mind. MIT Press, 2014. ISBN: 9780262026734.

Gerald Schneider. 9.14 Brain Structure and Its Origins, Spring 2014. (Massachusetts Institute of Technology: MIT OpenCourseWare). <http://ocw.mit.edu> (Accessed). License: Creative Commons BY-NC-SA



Prof. Gerald Schneider

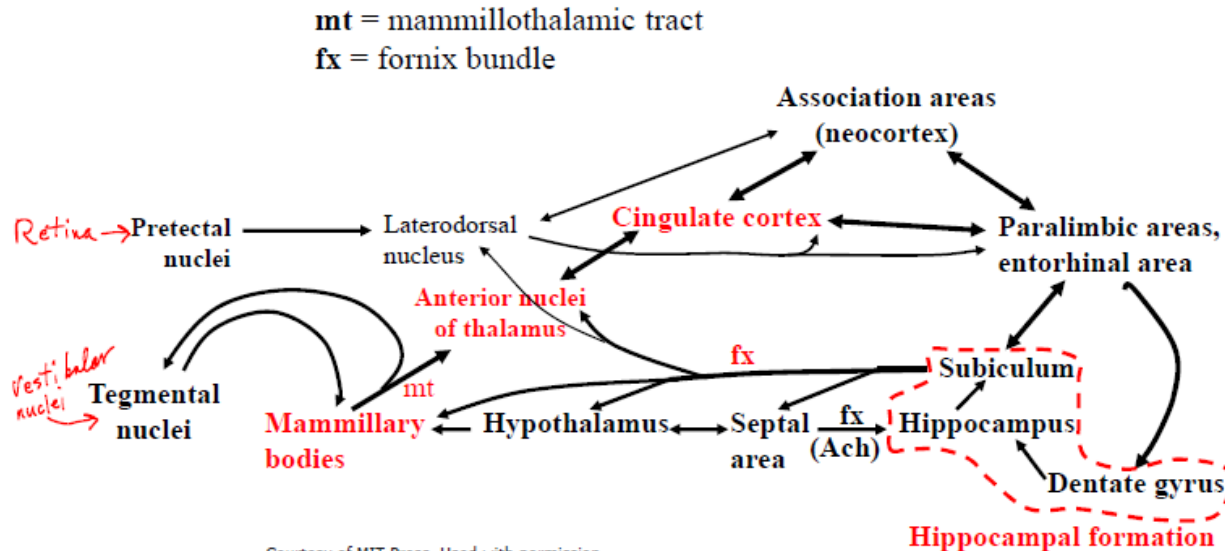
- Origins of endbrain: Structures underlying olfaction
- Two major links between olfactory system and the motor systems of the midbrain

Object oriented...

- 1) Through the ventral endbrain, which became corpus striatum and basal forebrain (including much of the septal area)
  - Outputs to hypothalamus, (epithalamus, subthalamus), midbrain
  - These outputs affected locomotion and orienting movements
  - The links were plastic, so habits were formed according to rewarding effects mediated, e.g., by taste effects.

Location oriented...

- 2) Through the medial part of the dorsal endbrain, which became medial pallium—the hippocampal formation
  - Outputs to ventral striatum, hypothalamus, epithalamus
  - The links were plastic, but the “habits” formed were different: The association of place with good or bad consequences of approach.



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Gerald Schneider. 9.14 Brain Structure and Its Origins, Spring 2014. (Massachusetts Institute of Technology: MIT OpenCourseWare). <http://ocw.mit.edu> (Accessed). License: Creative Commons BY-NC-SA



Prof. Gerald Schneider



# Evolution of corpus striatum: *basic outline of a story*

1. Beginnings: a link between olfactory inputs and motor control: The link becomes “Ventral striatum”. It was a modifiable link (capable of experience-induced change).

2. Non-olfactory inputs invade the striatal integrating mechanisms (via paleothalamic structures).

3. Early expansions of endbrain: striatal and pallial.

4. Pre-mammalian & then mammalian expansions of cortex and striatum: For the striatum, the earlier outputs and inputs remain as connections with neocortex expand.

Figure 1. Postulated beginnings in primitive chordates

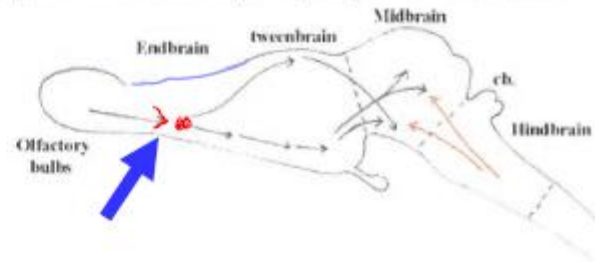


Figure 2. Other inputs reached the striatum

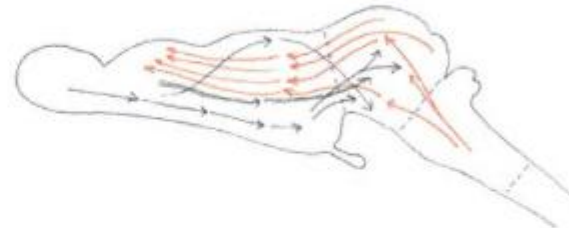


Figure 3. Early expansion of striatal and adjacent "limbic" areas

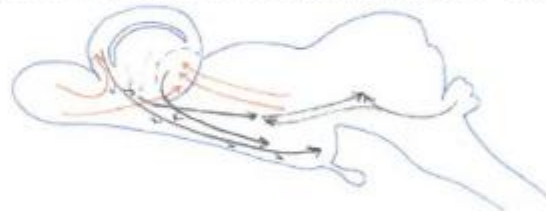


Figure 4. Pre-mammalian, and then mammalian expansions



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Schneider, G. E. *Brain structure and its Origins: In the Development of Behavior and the Mind*. MIT Press, 2014. ISBN: 97

# Learning and memory

- Connections of striatum and hippocampus are plastic
- Plasticity is a base of learning
- Learning is a forming of long- term memory

**Working memory**  
– „RAM“

**Long term memory**  
– „Hard disk“



# Learning and memory

- Connections of striatum and hippocampus are plastic
- Plasticity is a base of learning
- Learning is a forming of long- term memory
- Declarative memory (explicit)
  - Based on hippocampus
  - Explicit information is stored and later recollected
  - „Construction of the maps (relationships)“ – spatial or abstract
- Procedural memory (implicit)
  - Based on striatum
  - Habitual learning – motor skills, but also social habits
  - „Construction of the algorithms“

**Working memory**  
– „RAM“  
**Long term memory**  
– „Hard disk“

# Learning and memory

- Connections of striatum and hippocampus are plastic
  - Plasticity is a base of learning
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  - Declarative memory (explicit)
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  - Procedural memory (implicit)
    - Based on striatum
    - Habitual learning – motor skills, but also social habits
    - „Construction of the algorithms“
- Location oriented:  
Where am I and what has happened here?
- Object oriented:  
Can I eat it and how to eat it?

# Amygdala

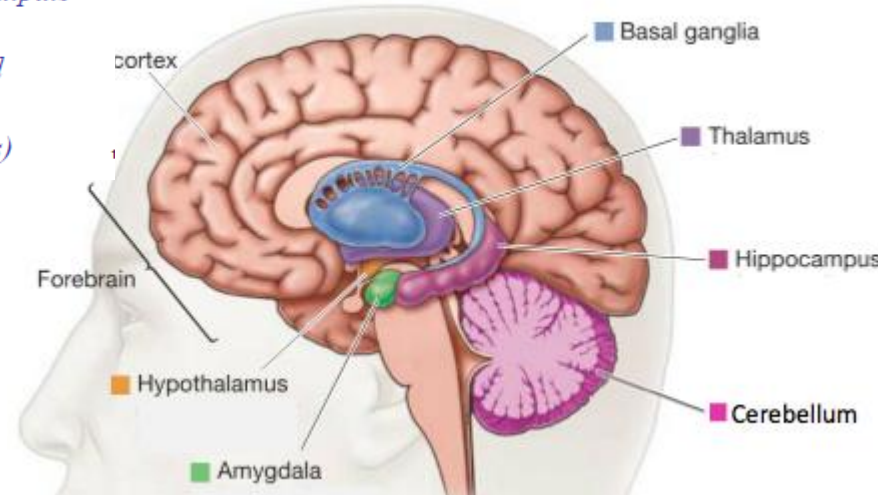
[http://proprofs-cdn.s3.amazonaws.com/images/FC/user\\_images/1406217/9806788916.png](http://proprofs-cdn.s3.amazonaws.com/images/FC/user_images/1406217/9806788916.png)

*Corticomedial: Inputs from olfactory bulbs, hypothalamus & lateral amygdala; outputs to hypothalamus, amygdala, ANS*

*Basolateral: Inputs from thalamus, neocortex, hippocampus; outputs to prefrontal cortex, ventral striatum, other amygdala nuclei*

*Central: Intra-amygdalar inputs; outputs through stria terminalis (see later slides)*

- Connections to all major cortical and subcortical structures
- Modified corpus striatum
- Plasticity – memory formation



# Amygdala

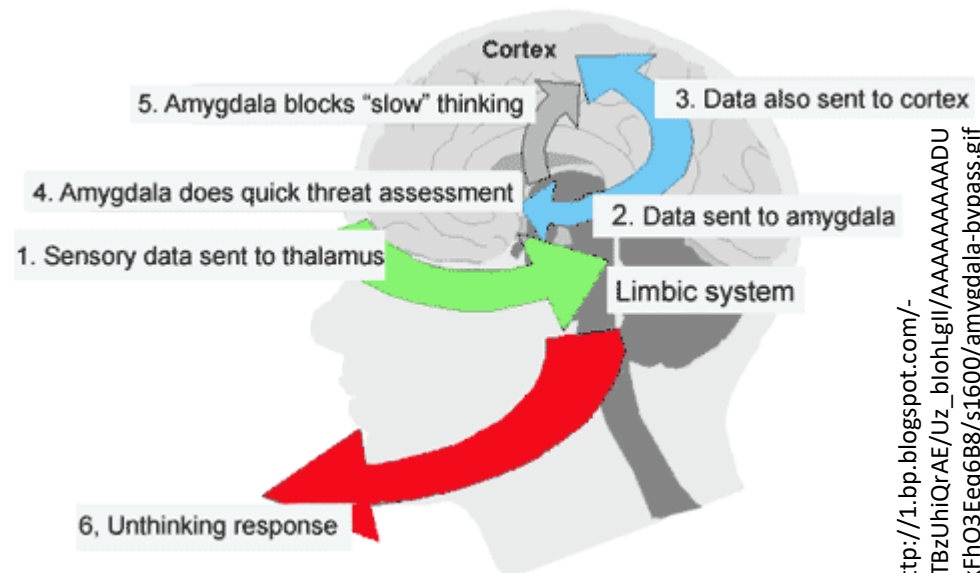
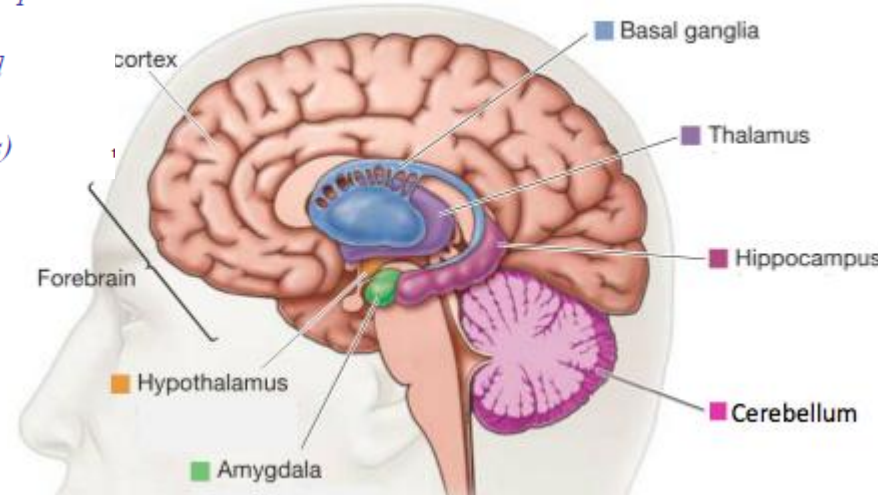
[http://proprofs-cdn.s3.amazonaws.com/images/FC/user\\_images/1406217/9806788916.png](http://proprofs-cdn.s3.amazonaws.com/images/FC/user_images/1406217/9806788916.png)

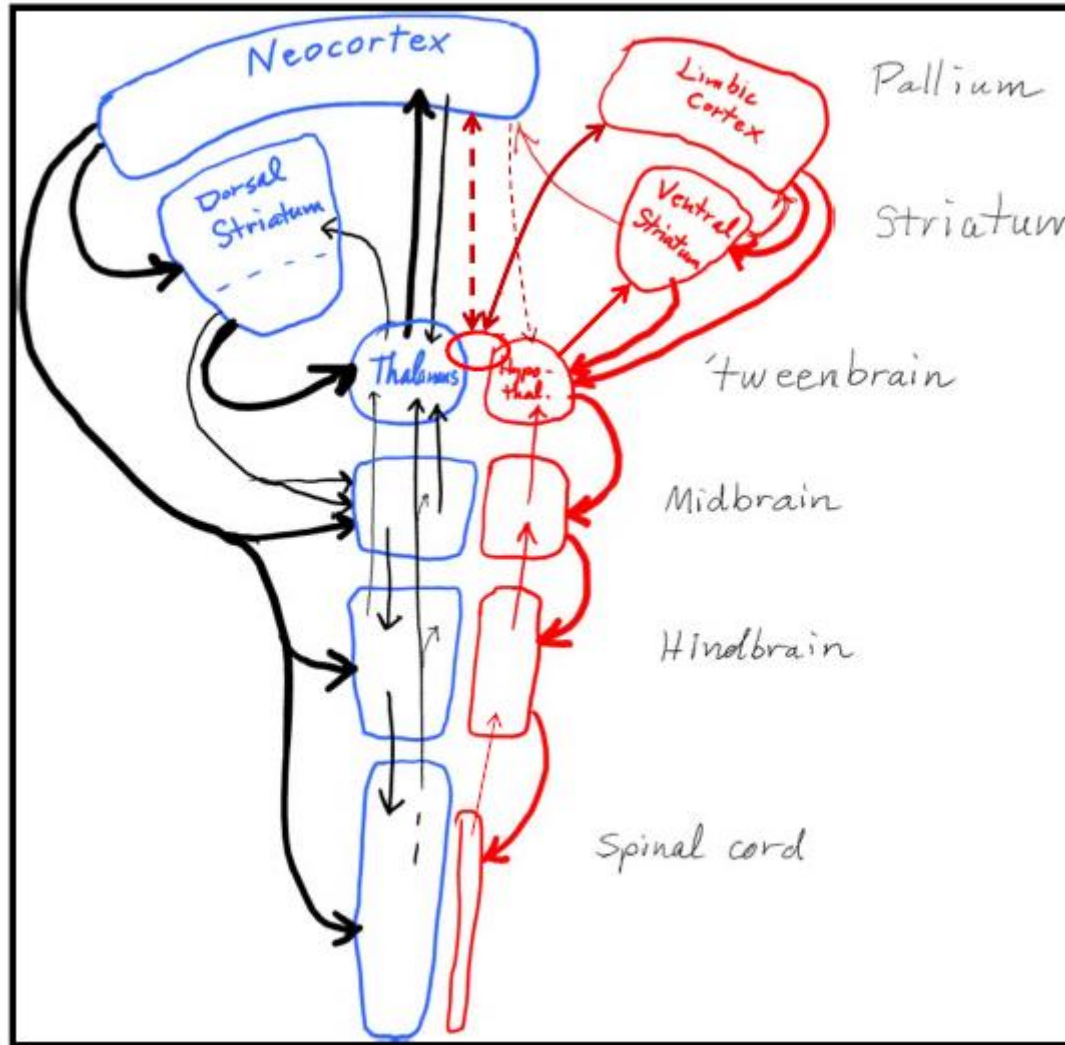
*Corticomedial: Inputs from olfactory bulbs, hypothalamus & lateral amygdala; outputs to hypothalamus, amygdala, ANS*

*Basolateral: Inputs from thalamus, neocortex, hippocampus; outputs to prefrontal cortex, ventral striatum, other amygdala nuclei*

*Central: Intra-amygdalar inputs; outputs through stria terminalis (see later slides)*

- Connections to all major cortical and subcortical structures
- Modified corpus striatum
- Plasticity – memory formation
- „Influence of information from outer environment on limbic system“
- „Amygdala hijack“
- „Affective tags“
  - Both positive and negative
  - Higher responsiveness to negative





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 Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.