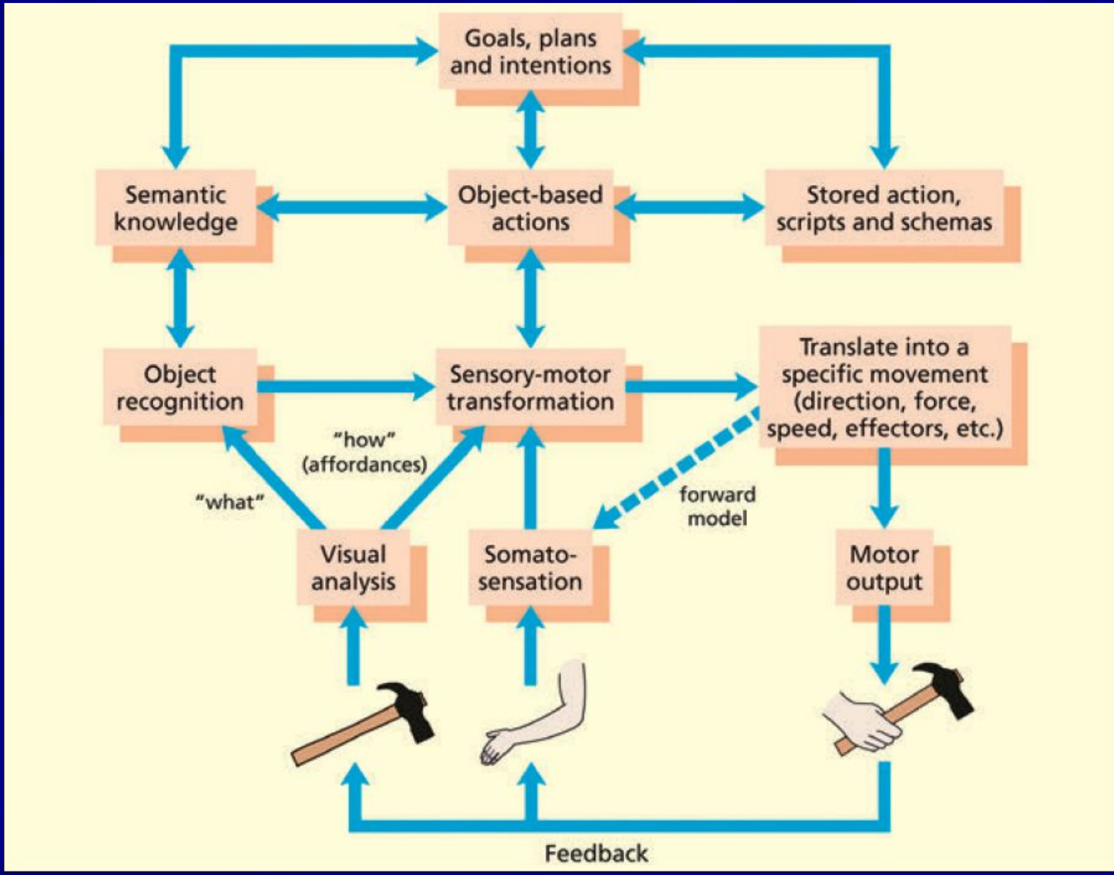
Cognitive neuroscience of movement

A BASIC COGNITIVE FRAMEWORK FOR MOVEMENT AND ACTION

- A simple model of movement and action
- At the highest level, there is action planning based on the goals and intentions of the individual.
- At the lowest level, there are the perceptual and motor systems that interface with the external world.
- Action can be considered to be an outcome of all these processes that work together in a concerted fashion, combining the needs of the person with the current environmental reality.



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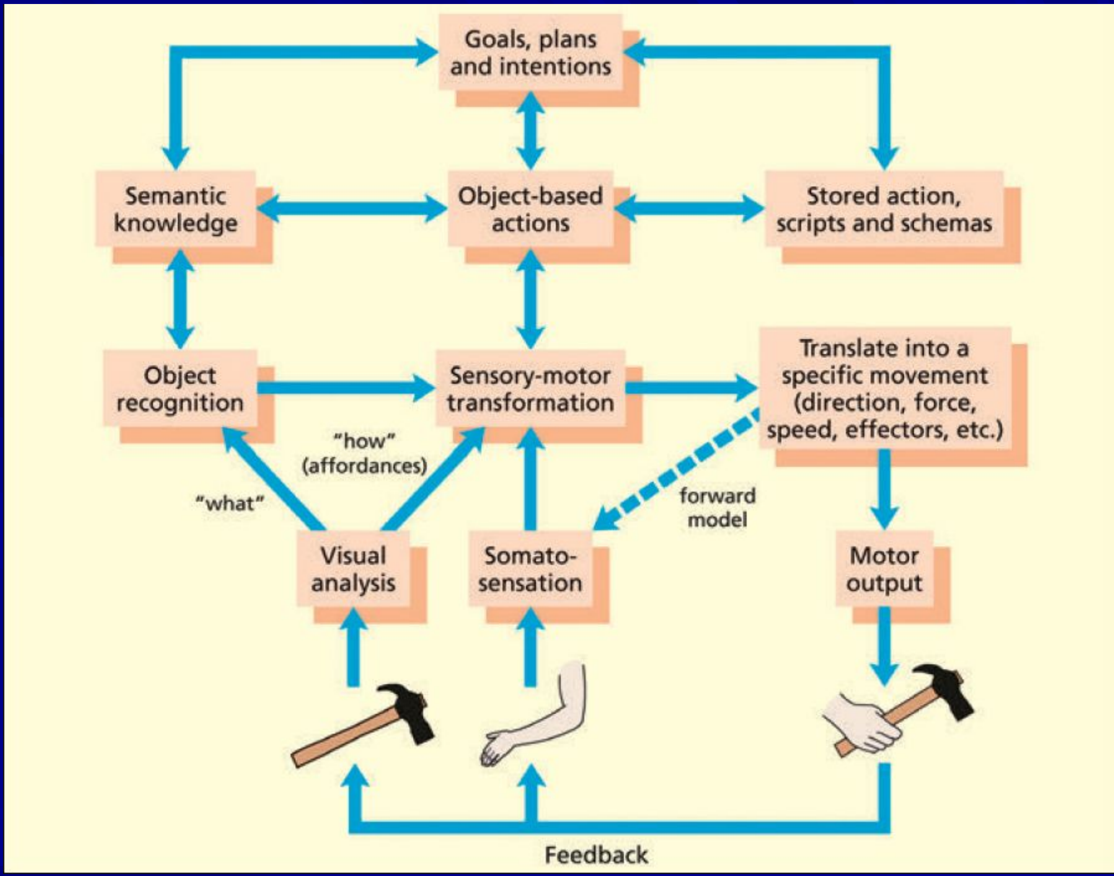
- Most theories of action postulate the existence of generalized motor programs
- Motor programs may code general aspects of the movement rather than the actual means of performing the movement.
- Most actions are directed toward externally perceived objects, particularly via vision.
- After early visual analysis, two routes diverge into different streams specialized for object recognition (the “what” or ventral stream) and object location (the “how,” “where” or dorsal stream).



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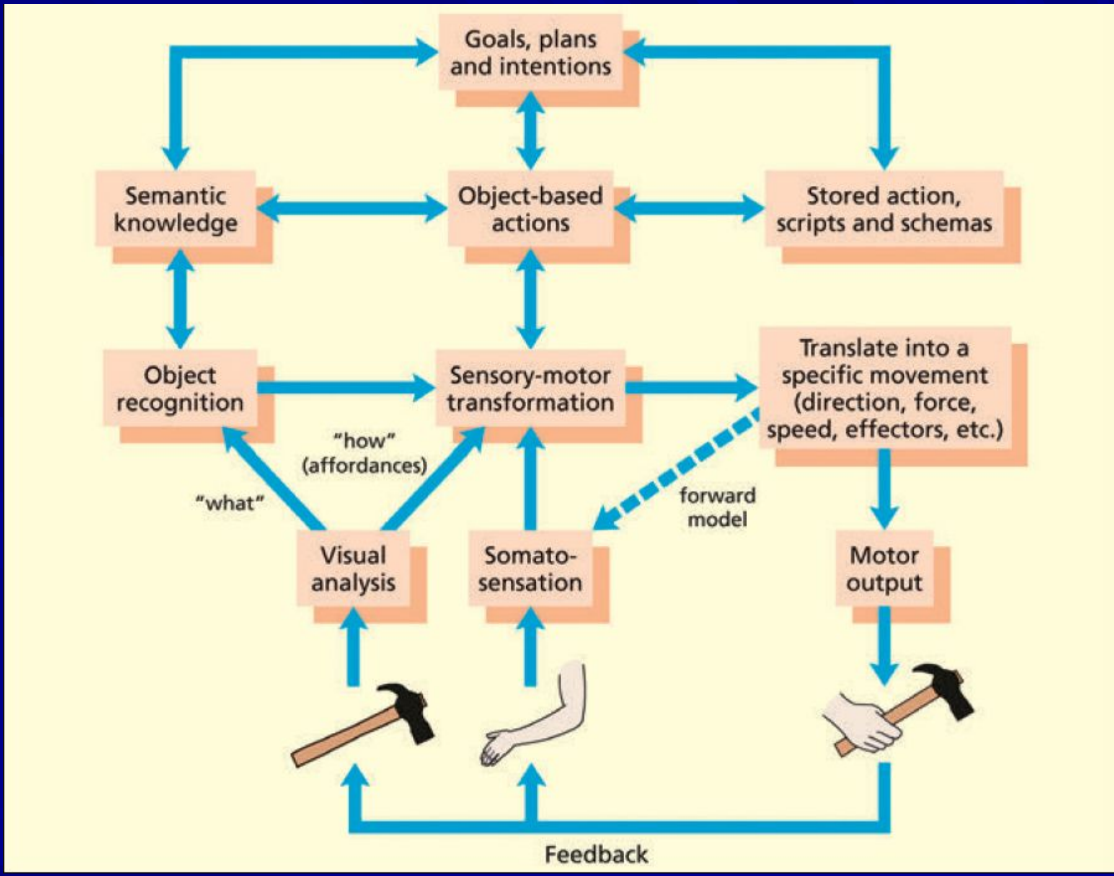
- How this visual information is integrated with somatosensory information.
- Somatosensation refers to a cluster of perceptual processes that relate to the skin and body (includes touch, pain, thermal sensation and limb position).
- The position of the limbs in space is computed by receptors in the muscles and joints - proprioception.
- There is a need to co-register different types of information into a common spatial reference frame.
- In the context of action, this process will be referred to as sensorimotor transformation



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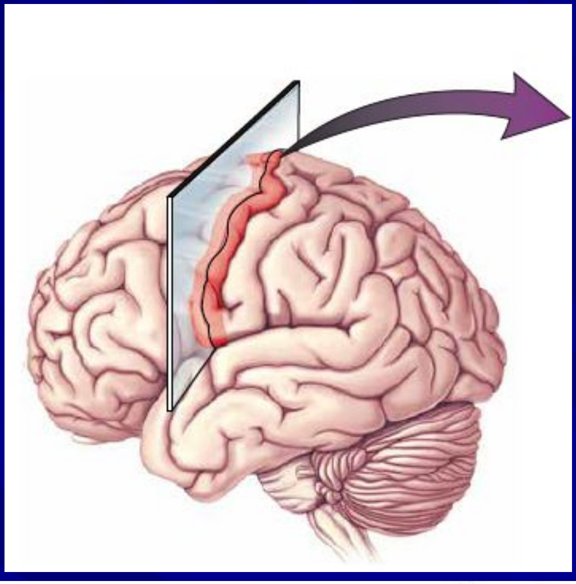
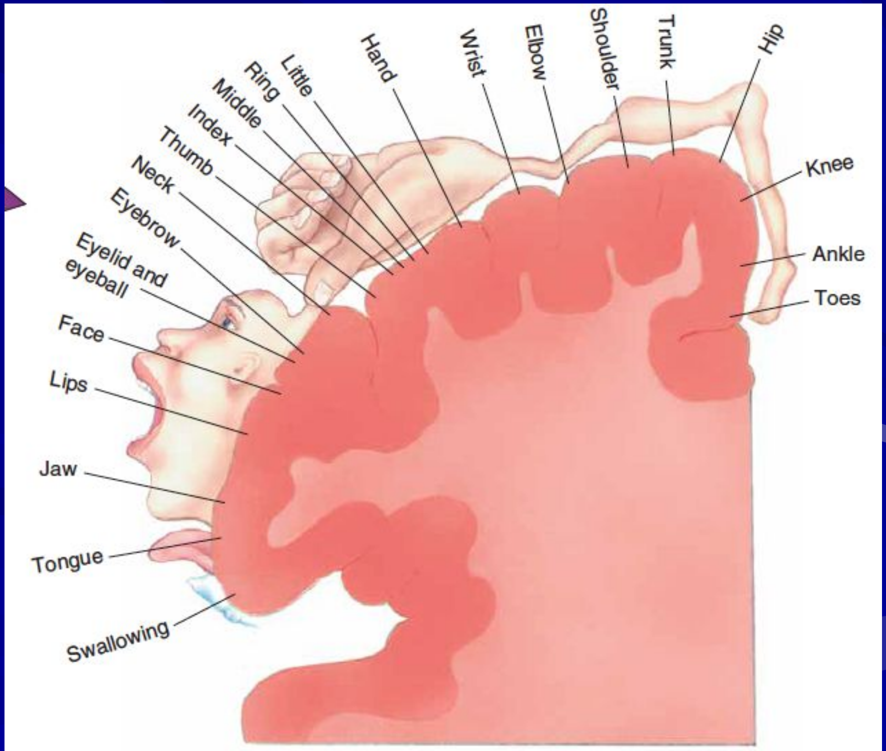
THE ROLE OF THE FRONTAL LOBES IN MOVEMENT AND ACTION

Primary motor cortex

- The primary motor cortex is responsible for execution of all voluntary movements of the body.
- Most other frontal regions are related to action planning
- Different regions of the primary motor cortex represent different regions of the body (somatotopically organized).





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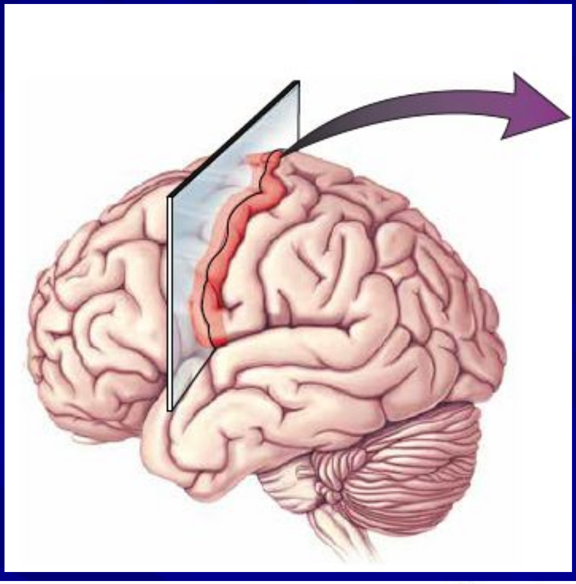
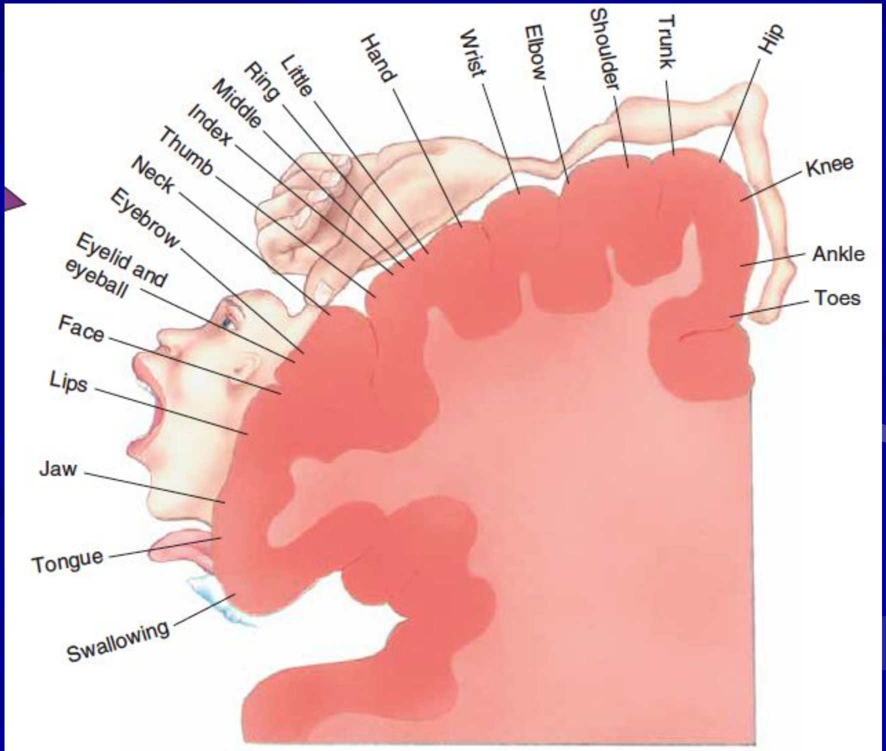
THE ROLE OF THE FRONTAL LOBES IN MOVEMENT AND ACTION

Primary motor cortex

- The left hemisphere is specialized for movements of the right side of the body and the right hemisphere is specialized for movements of the left side of the body.
- Thus, damage to one hemisphere could result in a failure to move the other side of the body —hemiplegia .
- Some parts of the body (such as the hands) have a particularly large representation because of the need for fine levels of movement control.





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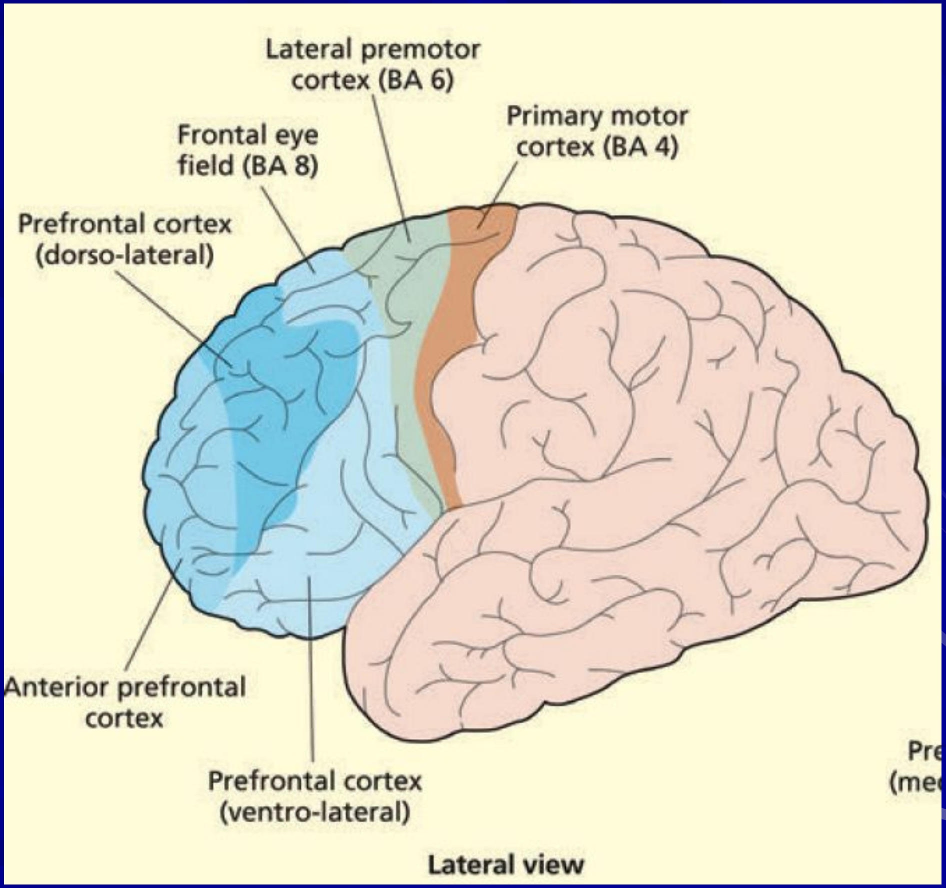
Frontal eye fields

- Voluntary movement of the eyes is not determined by the primary motor cortex but by a separate region of the frontal lobes known as the frontal eye fields
- The separation of body and eyes may reflect the different nature of the input signals that guide movement:

1. eye movement is primarily guided by external senses (vision and hearing)
2. whereas skeletal-based movements rely more heavily on proprioceptive information concerning position of the limbs



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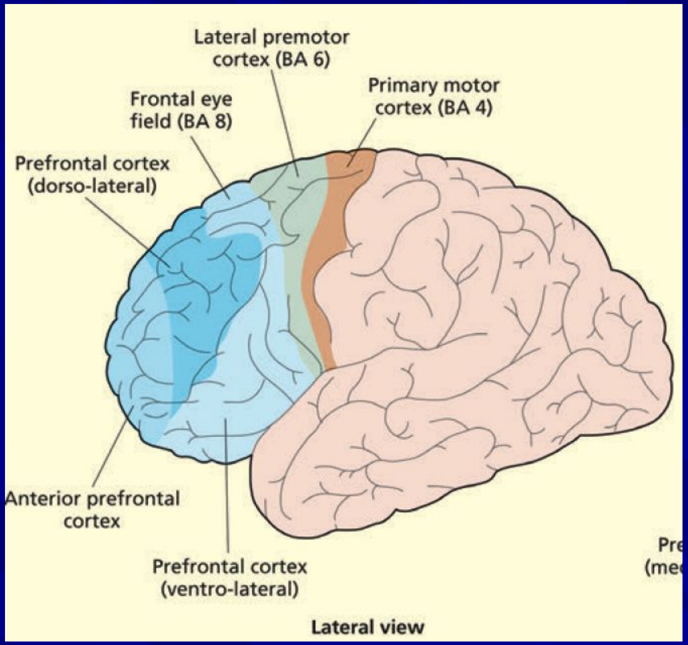
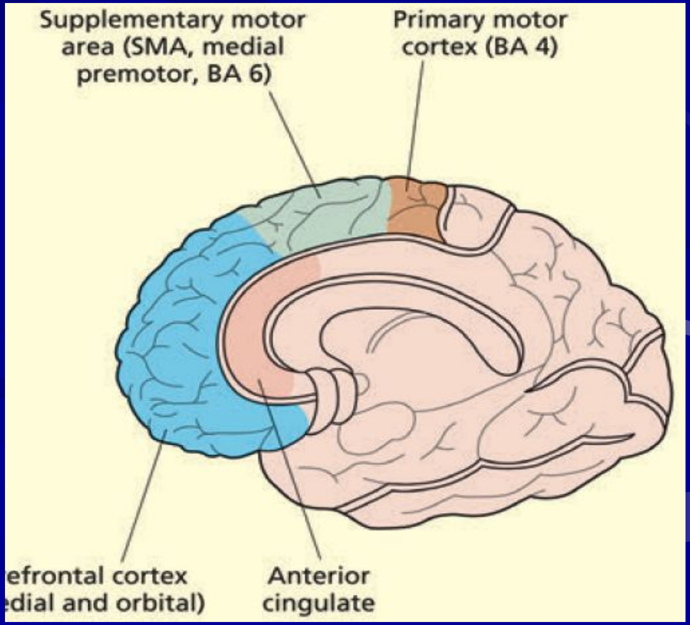
Lateral and medial premotor cortex

- In contrast to the primary motor cortex, electrical stimulation of the premotor cortex does not result in movement per se, but rather modulates the activity of the primary motor cortex
- The lateral premotor cortex has been associated with acting objects in the environment (e.g. reaching for a coffee cup)
- The supplementary motor area (SMA) has been associated with dealing with spontaneous, well-learned actions, particularly action sequences that do not place strong demands on monitoring the environment (e.g. playing a familiar tune on a musical instrument).





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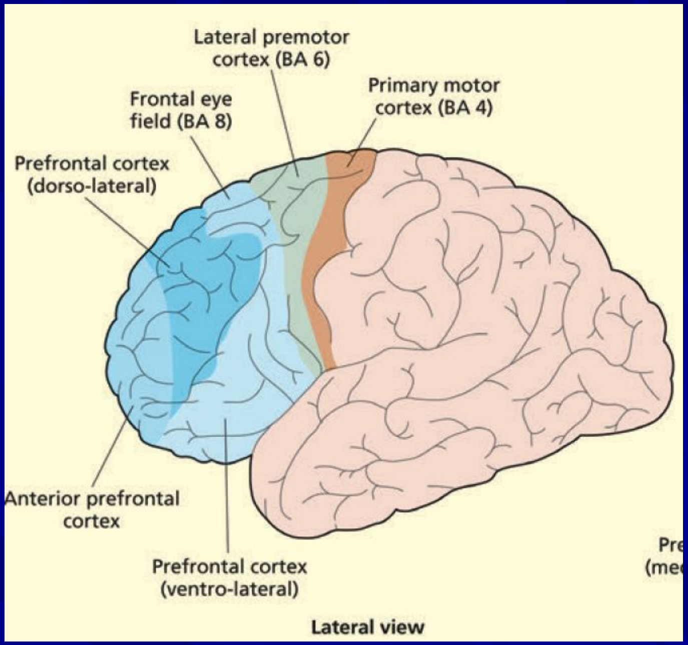
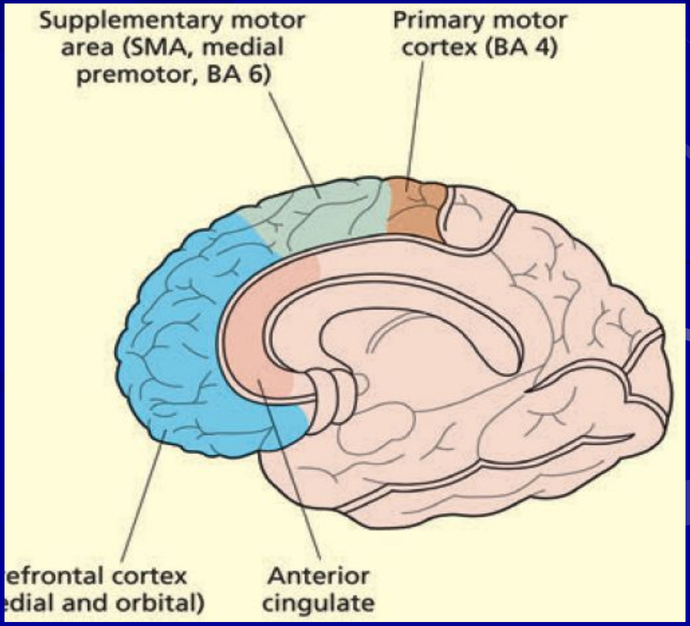
Lateral and medial premotor cortex

- This functional difference reflects the different anatomical connections of these regions.
- The lateral premotor cortex receives visual signals via the parietal cortex (the so-called dorsal route in vision),
- The medial premotor cortex (SMA) receives strong proprioceptive signals concerning the current position of the limbs.
- The SMA has a critical role in organizing forthcoming movements in complex motor sequences that are rehearsed from memory and fit into a precise timing plan.
- If the SMA is important for implementing internally generated actions, the lateral premotor region is more important for producing movements based on external contingencies





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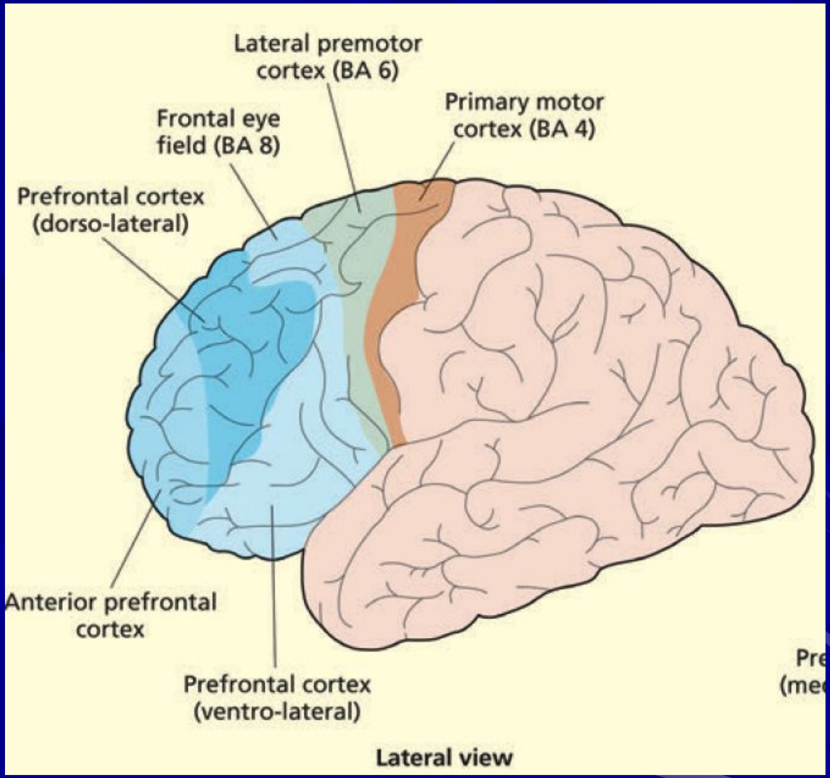
Prefrontal contributions to action

- Prefrontal regions are principally involved in planning and higher aspects of the control of action.
- Unlike premotor and motor regions, prefrontal regions are involved extensively in higher cognition more generally rather than action specifically.
- Premotor regions have a primary role in preparing actions (to internally or externally triggered events), while the prefrontal region mediates their selection and maintains the goal of the action.
- The function of the prefrontal cortex is by no means specific to action.
- For instance, it is involved in holding things in mind (working memory) and in the control of cognition/behavior (executive functions).



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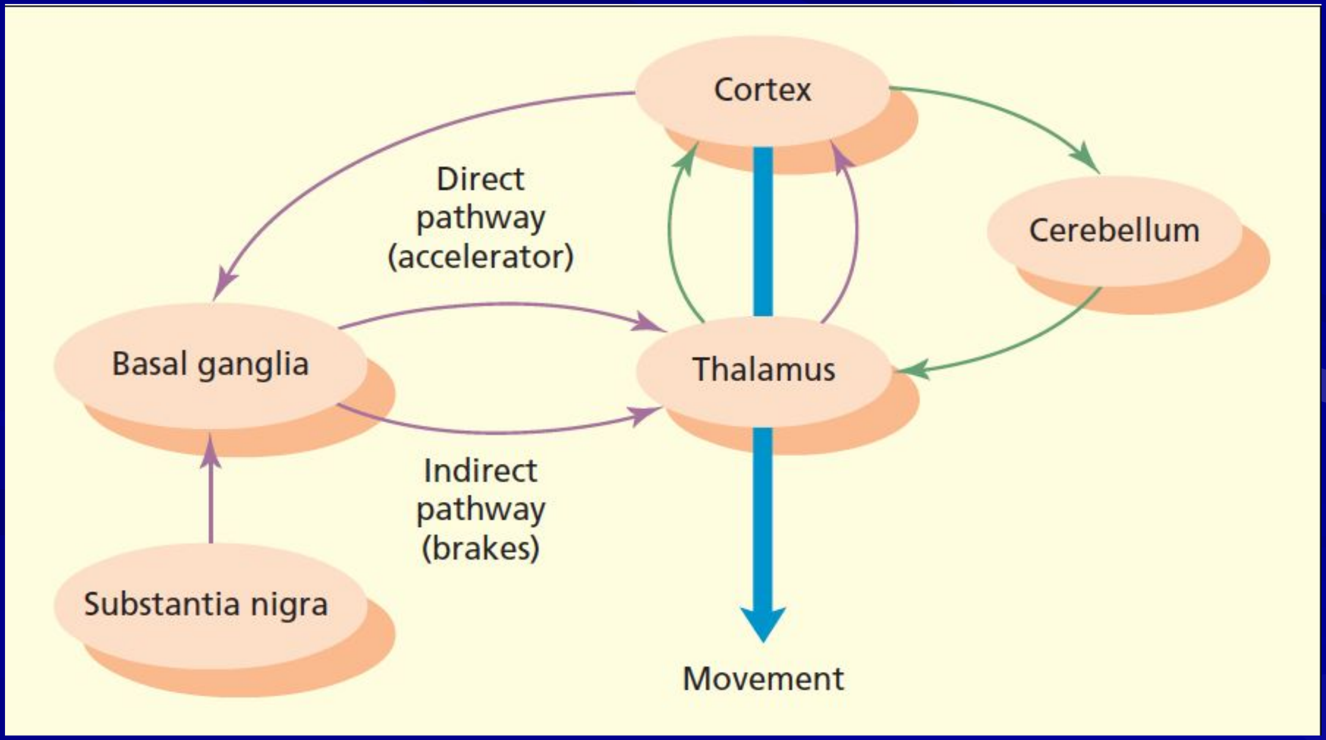
Role of subcortical structures in movement and action

- Subcortical structures have an important role to play particularly with regards to the preparation and execution of actions.
- These structures may be important for setting the particular parameters of the movement, such as the force and duration of movement and for controlling the movement in progress.



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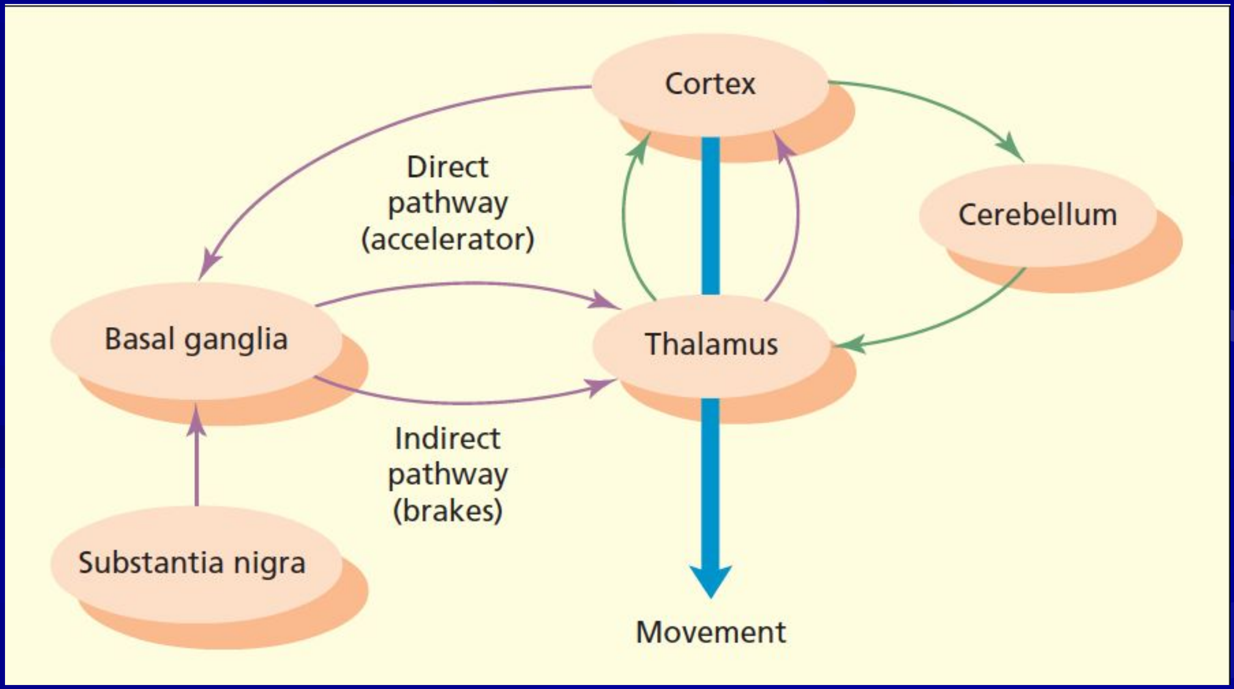
Role of subcortical structures in movement and action

- Two main types of cortical-subcortical loop involved in the generation of movement
- One loop passes through the basal ganglia and the other through the cerebellum. These loops have somewhat different functions.
- The cerebellar loop is involved in the coordination of movements. It may utilize a copy of the cortical motor commands to ensure that the desired movement occurs accurately and occurs at the desired time. For example, it is physiologically active during coordination tasks that require one movement to be synchronized with another.



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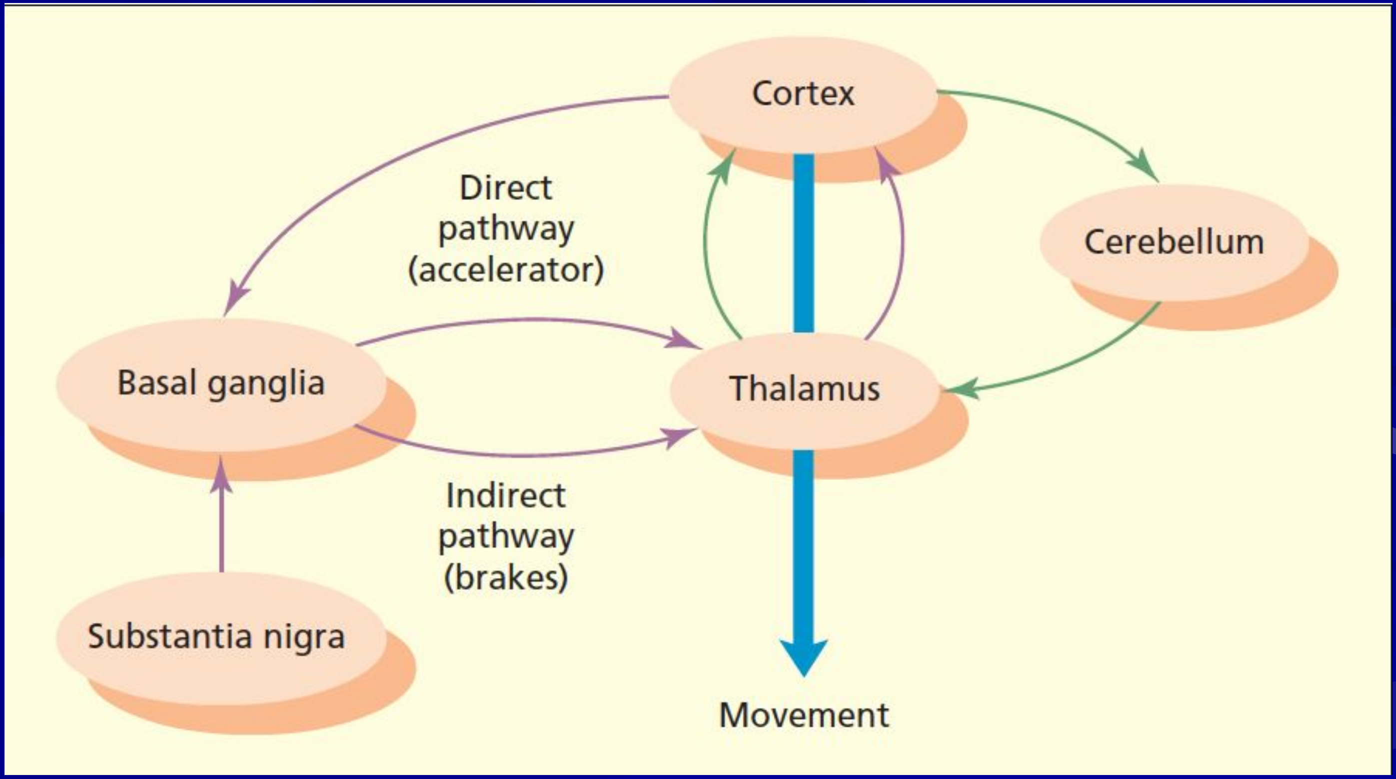
Role of subcortical structures in movement and action

- Patients with cerebellum lesions produce tremulous movements that suggest that they are unable to use information about the progress of the movement to update the initiated motor program.
- Given this role, it is not surprising that the cerebellum connects strongly with lateral premotor and parietal regions involved in sensorimotor transformation.



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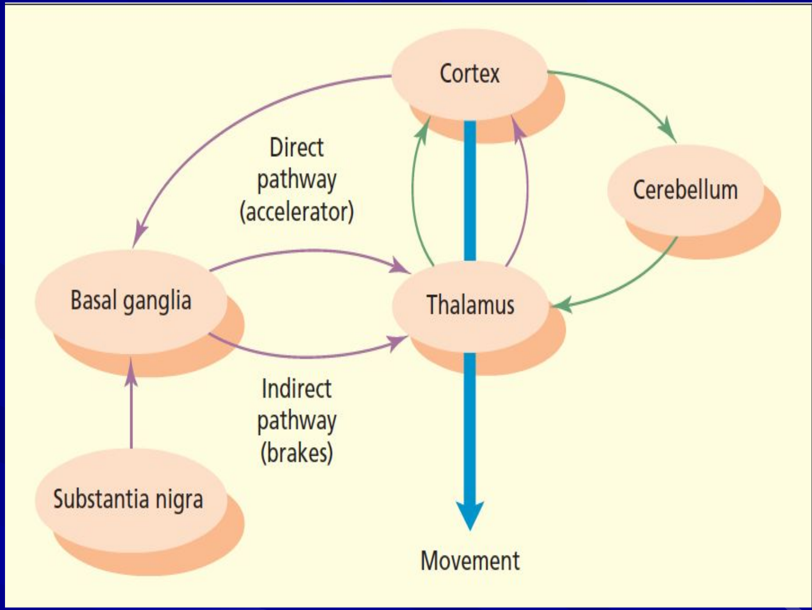
Role of subcortical structures in movement and action

- The basal ganglia "loop" actually consists of several different loops:

1. Motor circuit – it passes through dorsal regions of the basal ganglia and projects to premotor areas and particularly strongly to the SMA
2. Other loops target different regions of the frontal lobes and pass through different structures in the basal ganglia and the thalamus: for instance, an oculomotor circuit projects strongly to the frontal eye fields
3. A limbic circuit passes through more ventral regions of the basal ganglia and projects to the orbitofrontal cortex, amygdala and anterior cingulate
4. Other loops project to the lateral prefrontal cortex



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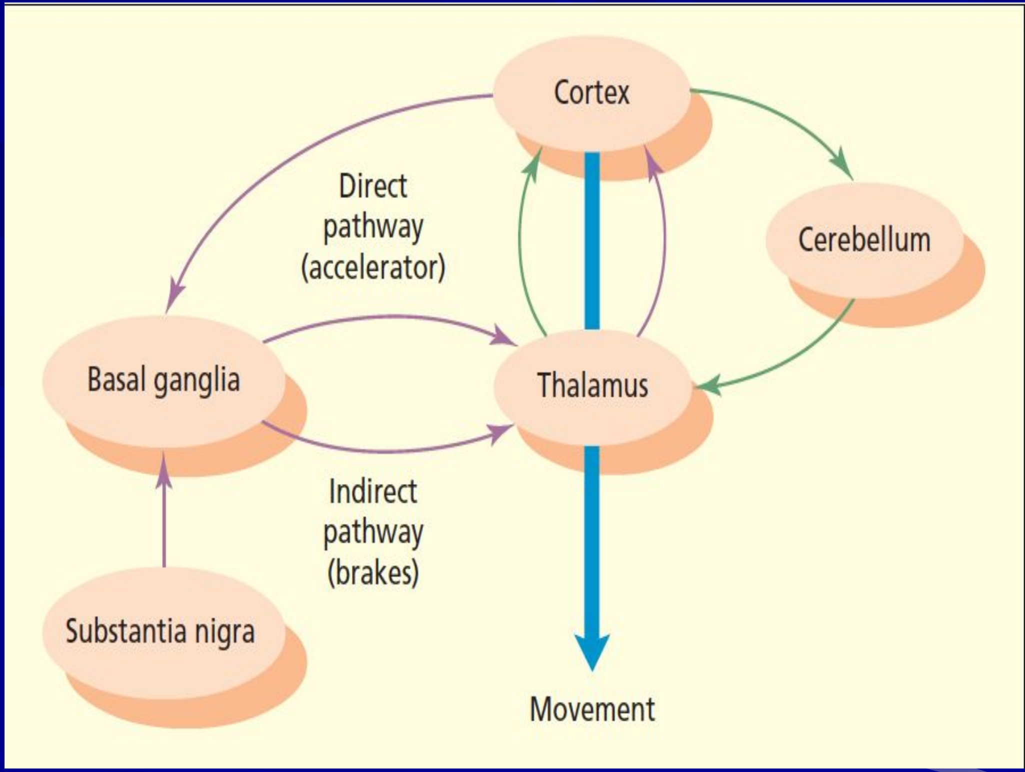
Role of subcortical structures in movement and action

- These different circuits modulate different aspects of behavior:

1. the prefrontal loop relates to the control of cognition
2. the oculomotor circuit relates to the control of eye movements
3. the limbic circuit is linked to reward-based learning
4. the motor circuit itself appears to be particularly important for the initiation and execution of internally generated movements, sequencing of actions, and procedural learning



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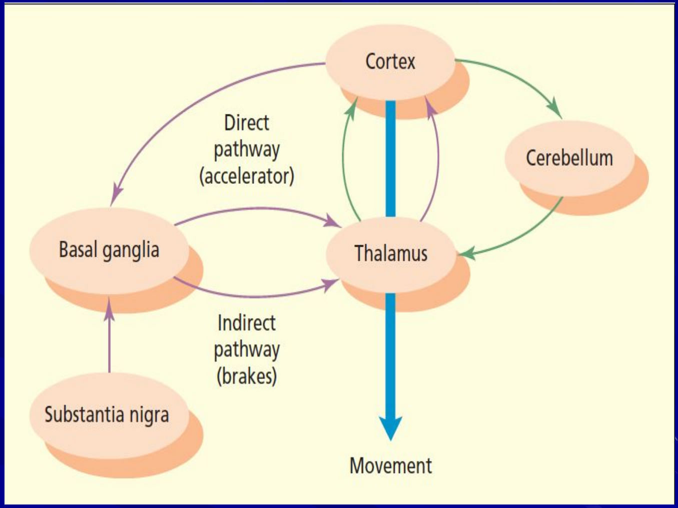
Hypokinetic disorders of the basal ganglia:
Parkinson's disease

- Parkinson's disease affects about 0.15 percent of the total population and has a mean age of onset at around 60 years.
- It was first described by James Parkinson in 1817.
- Dopaminergic brain cells are lost in the pathways linking the substantia nigra and basal ganglia
- Symptoms :

1. akinesia (lack of spontaneous movement)
2. bradykinesia (slowness of movement)
3. decay of movement sequences
4. failure to scale muscle activity to movement amplitude
5. failure to weld several movement components into a single action plan
6. rigidity
7. tremor (when stationary).



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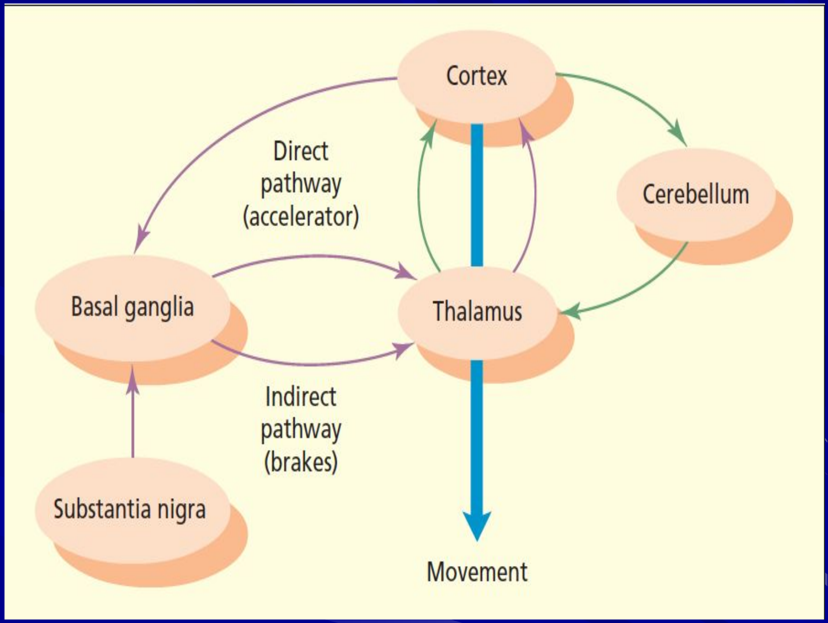
Hyperkinetic disorders of the basal ganglia: Huntington's disease and Tourette's syndrome

- Huntington's disease is a genetic disorder with a well-characterized neuropathology
- The symptoms consist of dance-like, flailing limbs (chorea) and contorted postures.
- The symptoms arise in mid-adulthood and degenerate over time.
- Huntington's disease arises because of depletion of inhibitory neurons in the early part of the indirect pathway linking the basal ganglia with the thalamus
- The net effect of this lesion is that the output of the indirect pathway is reduced, whereas the output of the direct pathway remains normal.
- This shift in the balance of power promotes movement in general.



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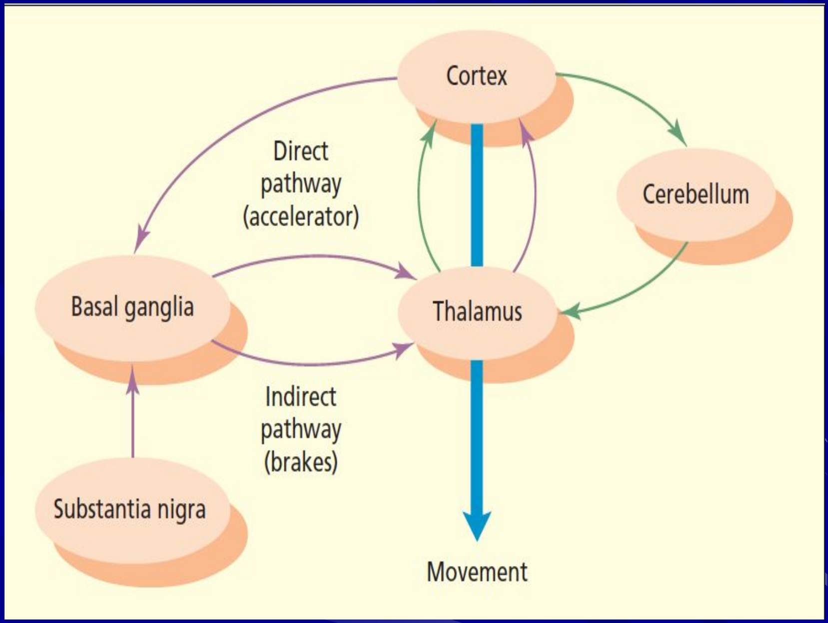
Hyperkinetic disorders of the basal ganglia: Huntington’s disease and Tourette’s syndrome

- Tourette’s syndrome is characterized by excessive and repetitive actions such as motor tics or vocalizations.
- Functional imaging (fMRI) revealed a correlation between tic severity and activation of the substantia nigra and cortical, striatal and thalamic regions in the direct pathway during a cognitive task
- The prefrontal cortex also tends to be more activate in people with Tourette’s relative to controls in complex motor and cognitive tasks.
- Tourette’s syndrome has similar characteristics and co-morbidity with obsessive-compulsive disorder.
- This consists of repetitive thoughts (obsessions) and/or actions (compulsions) such as cleaning, counting or checking.



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Conclusion

- A number of circuits involving the cortex and subcortical structures are critical for the initiation and execution of movement.
- One circuit, involving the cerebellum, is involved in coordinating the movement once initiated.
- Another circuit, involving the basal ganglia, is involved in establishing self initiated movements.
- The basal ganglia loop contains two parallel pathways known as the direct and indirect pathway that promote or reduce cortical excitability.
- Disruptions in the direct and indirect pathways are implicated in a number of movement-related disorders including Parkinson’s disease, Huntington’s disease, and Tourette’s syndrome.