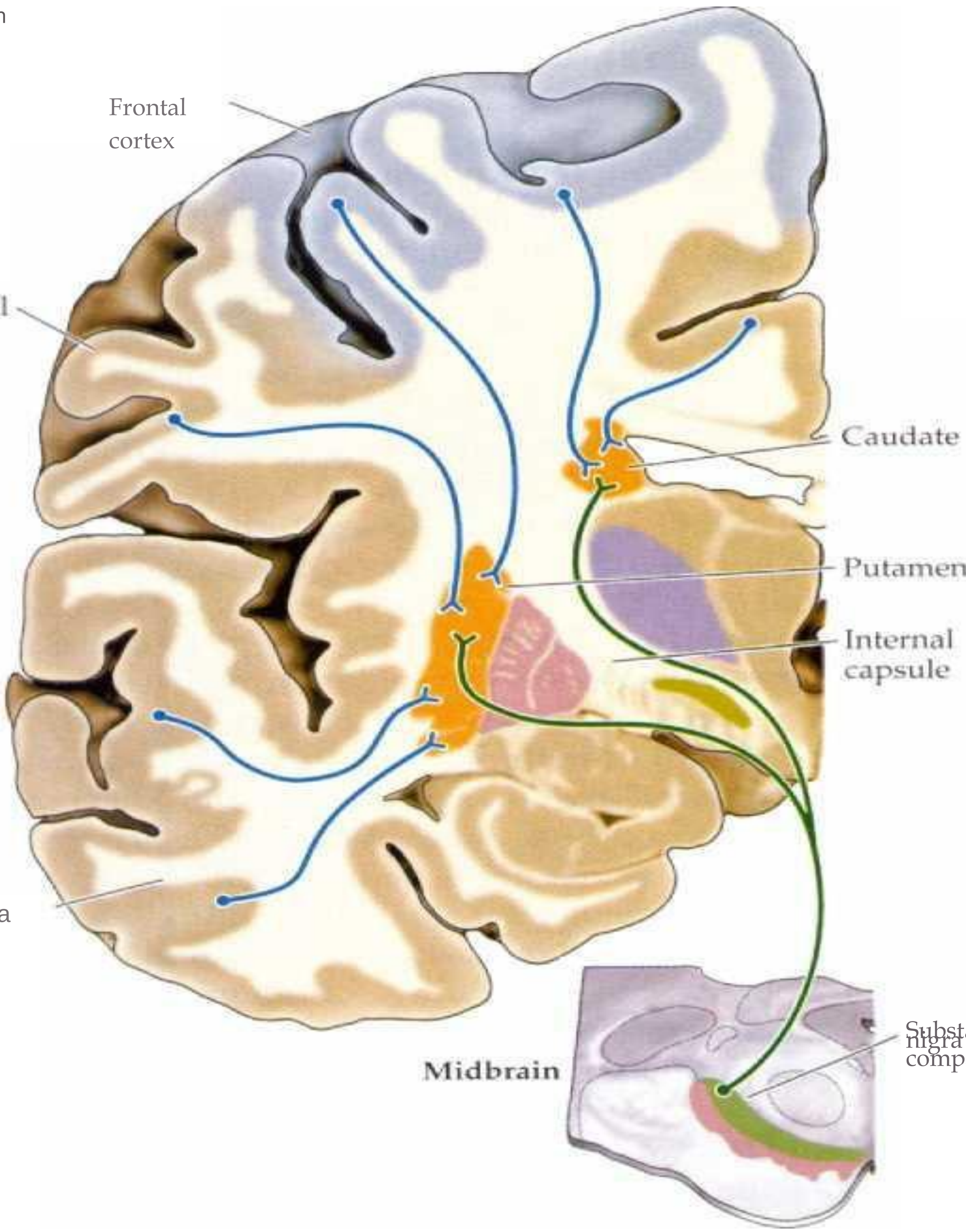
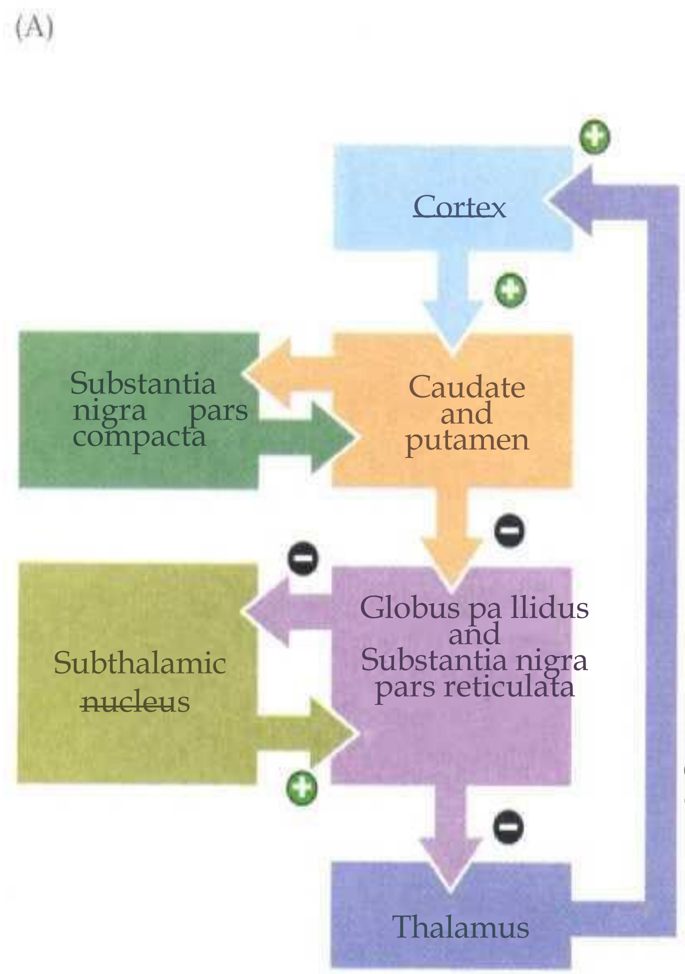
BASAL GANGLIA

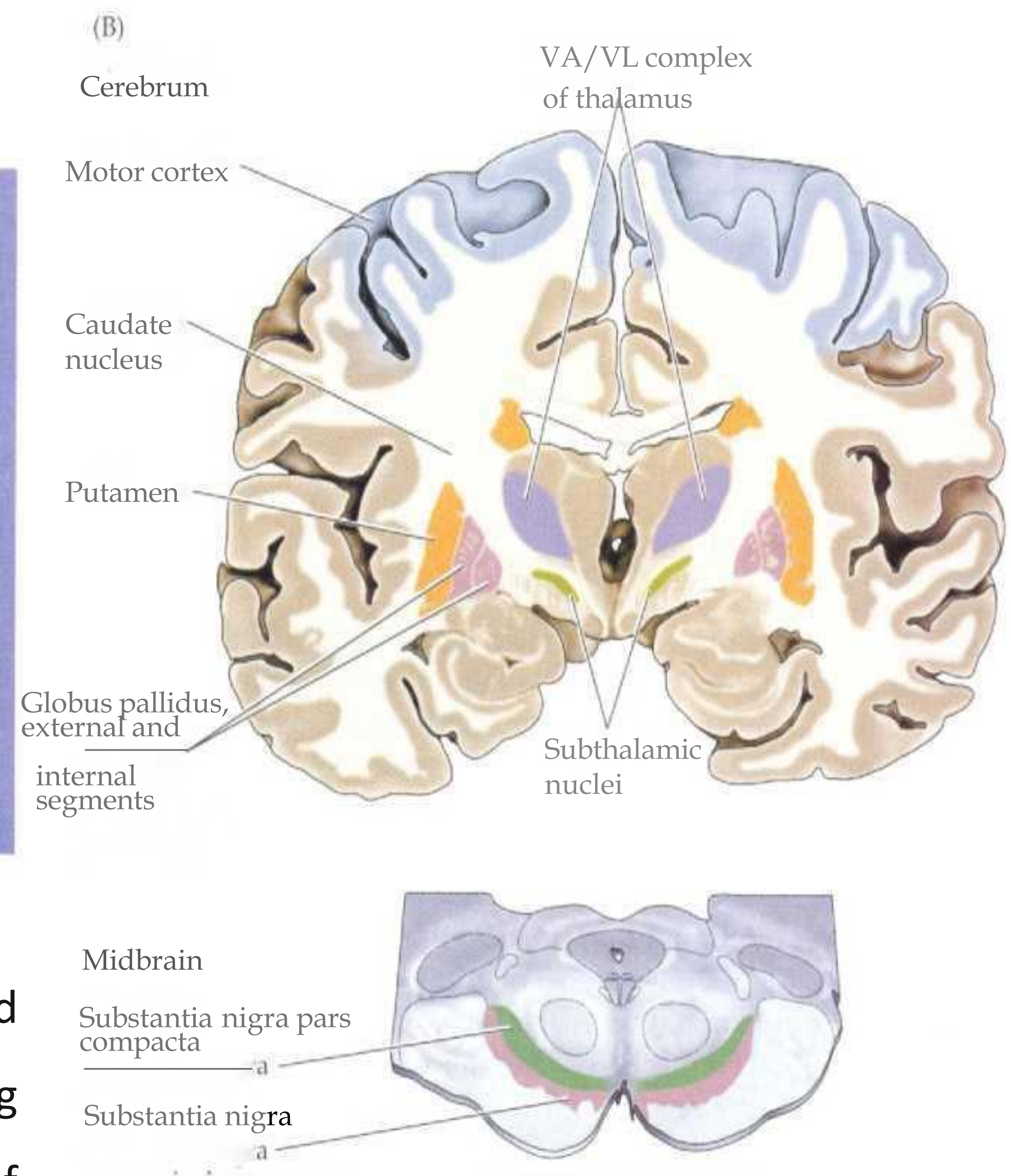
ANATOMICAL ORGANIZATION OF THE INPUTS TO THE BASAL GANGLIA



Coronal section through the human brain, showing the projections from the cerebral cortex and the substantia nigra pars comparta to the caudate and putamen.

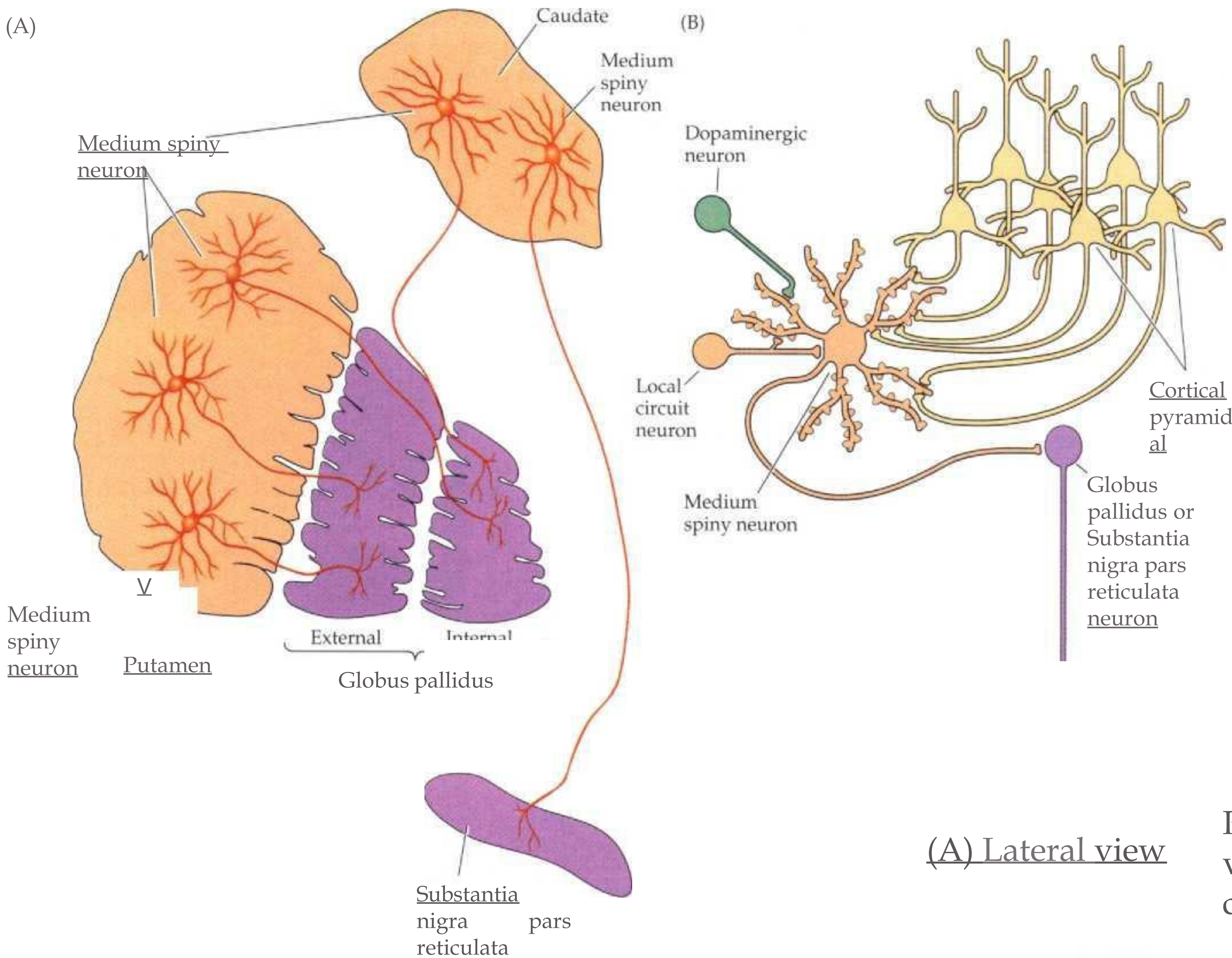
MOTOR COMPONENTS OF THE HUMAN BASAL GANGLIA





(A) Basic circuits of the basal ganglia pathway: (+) and (-) denote excitory and inhibitory connections. (B) Idealized coronal section through the brain showing anatomical locations of structures involved in the basal ganglia pathway. Most of these structures are in the telencephalon, although the substantia nigra is in the midbrain and the thalamic and subthalamic nuclei are in the diencephalon. The ventral anterior and ventral lateral thalamic nuclei (VA/VL complex) are the targets of the basal ganglia, relaying the modulatory effects of the basal ganglia to upper motor neurons in the cortex.

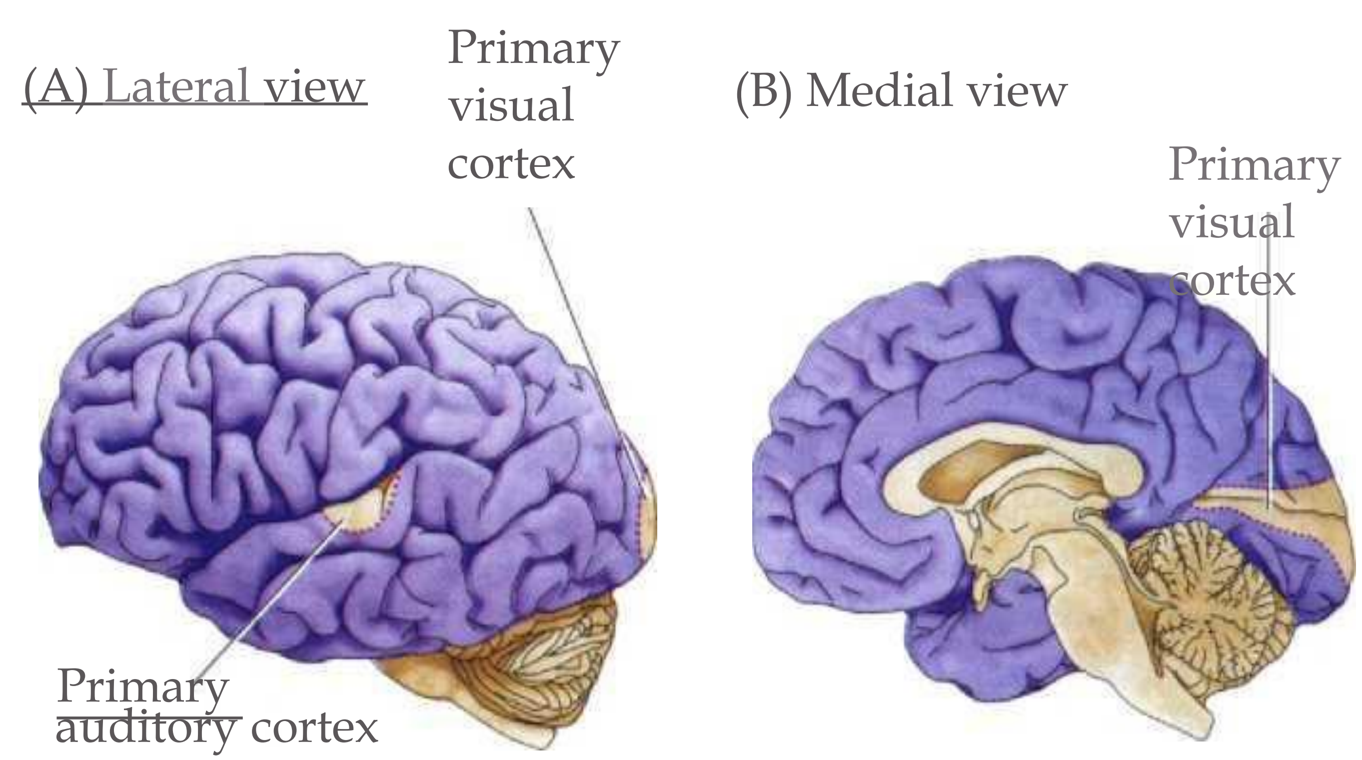
NEURONS AND CIRCUITS OF THE BASAL GANGLIA



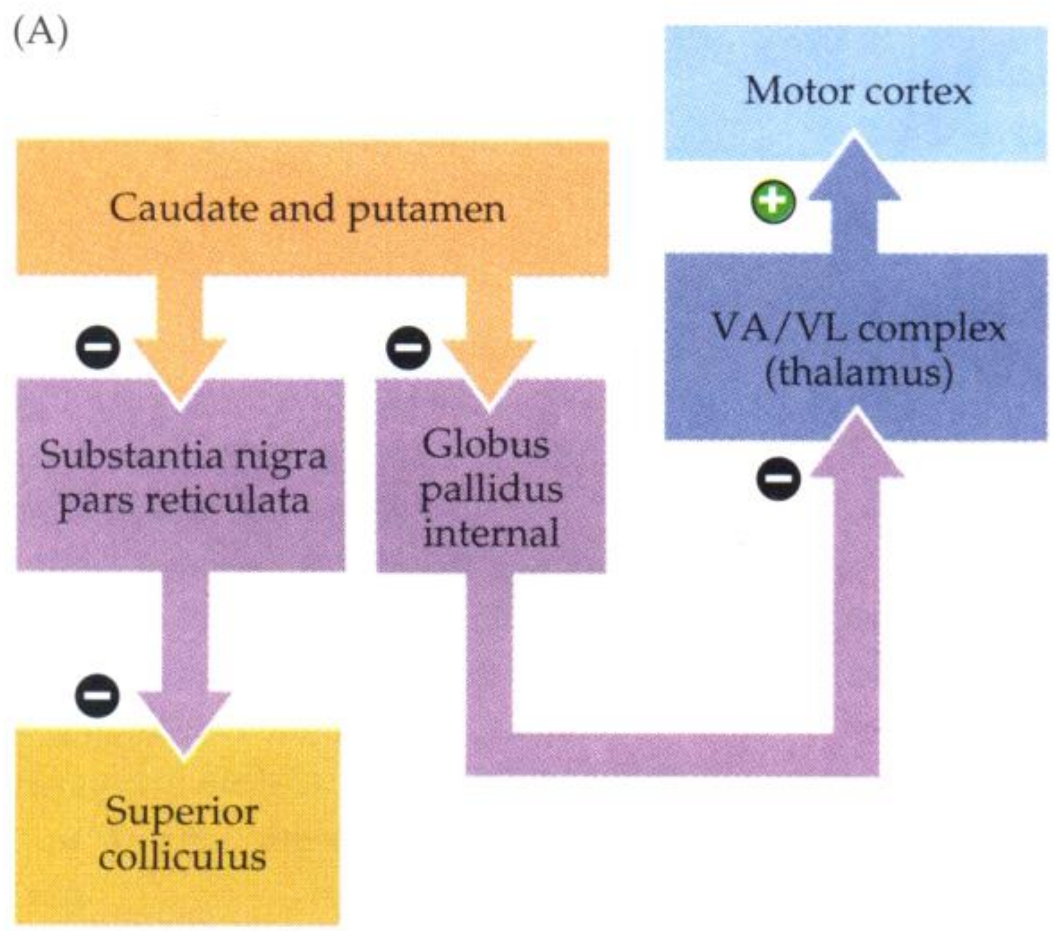
Regions of the cerebral cortex (shown in purple) that project to the caudate, putamen, and ventral striatum (see Box C) in both lateral (A) and medial (B) views.

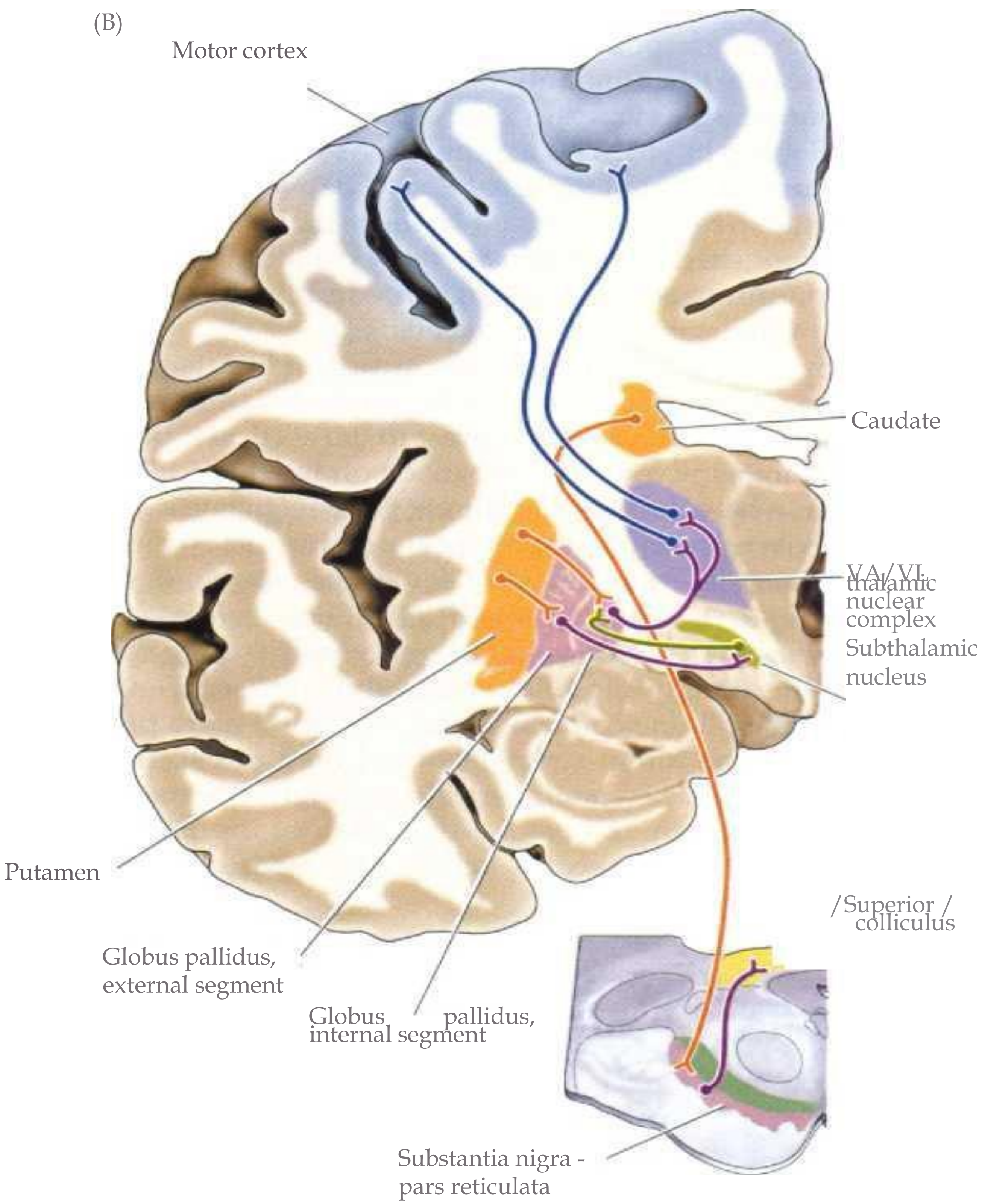
The caudate, putamen, and ventral striatum receive cortical projections primarily from the association areas of the frontal, parietal, and temporal lobes.

(A) Medium spiny neurons in the caudate and putamen. (B) Diagram showing convergent inputs onto a medium spiny neuron from cortical neurons, dopaminergic cells of the substantia nigra, and local circuit neurons. The primary output of the medium spiny cells is to the globus pallidus and to the substantia nigra pars reticulata.



FUNCTIONAL ORGANIZATION OF THE OUTPUTS FROM THE BASAL GANGLIA





(A) Diagram of the targets of the basal ganglia, including the intermediate relay nuclei (the globus pallidus, external segments, and the subthalamic nucleus), the internal and superior colliculus, the thalamus, and the cerebral cortex. (B) An idealized coronal section through the human brain, showing the structures and pathways diagrammed in (A).

DISINHIBITORY CIRCUITS

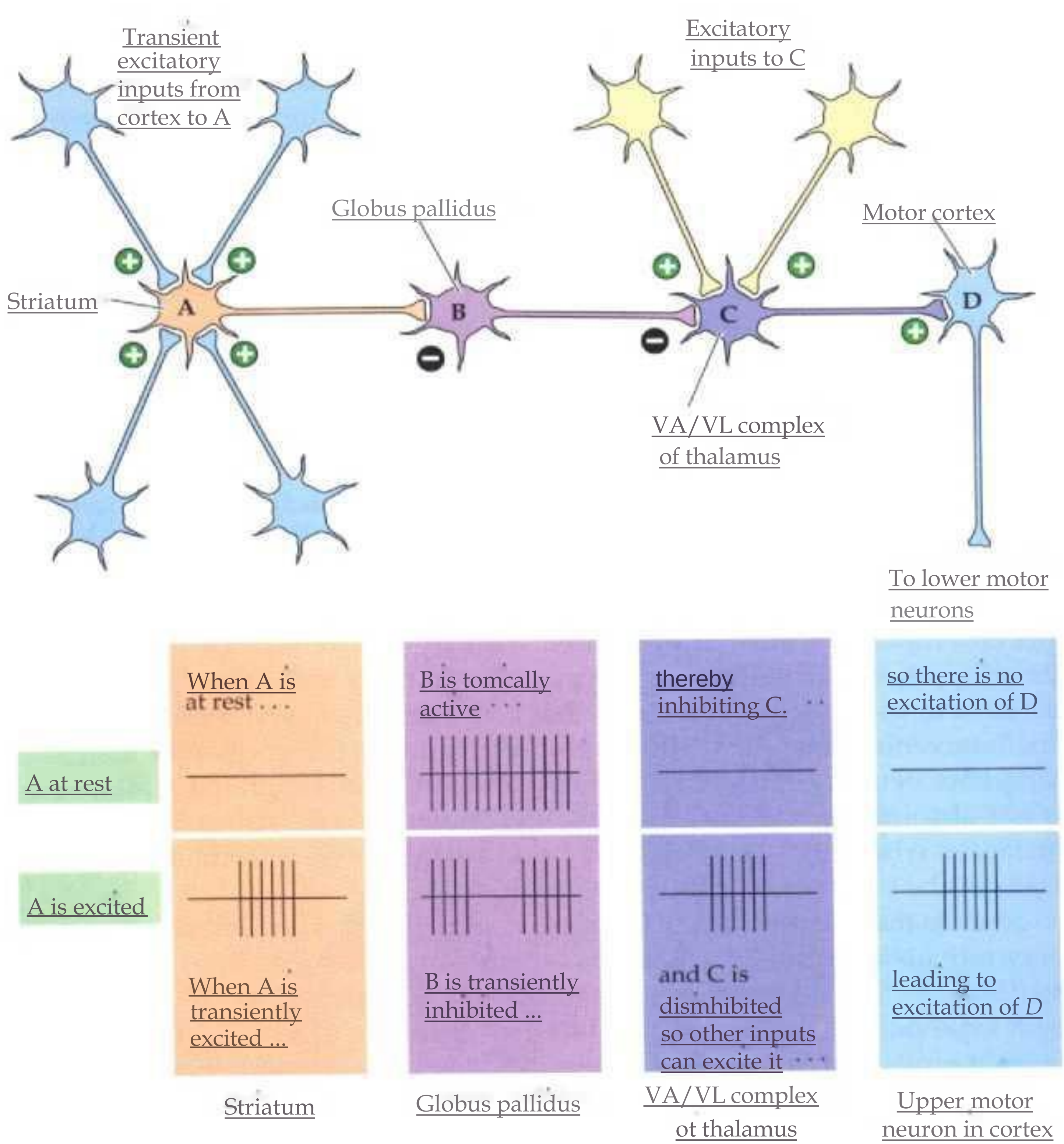
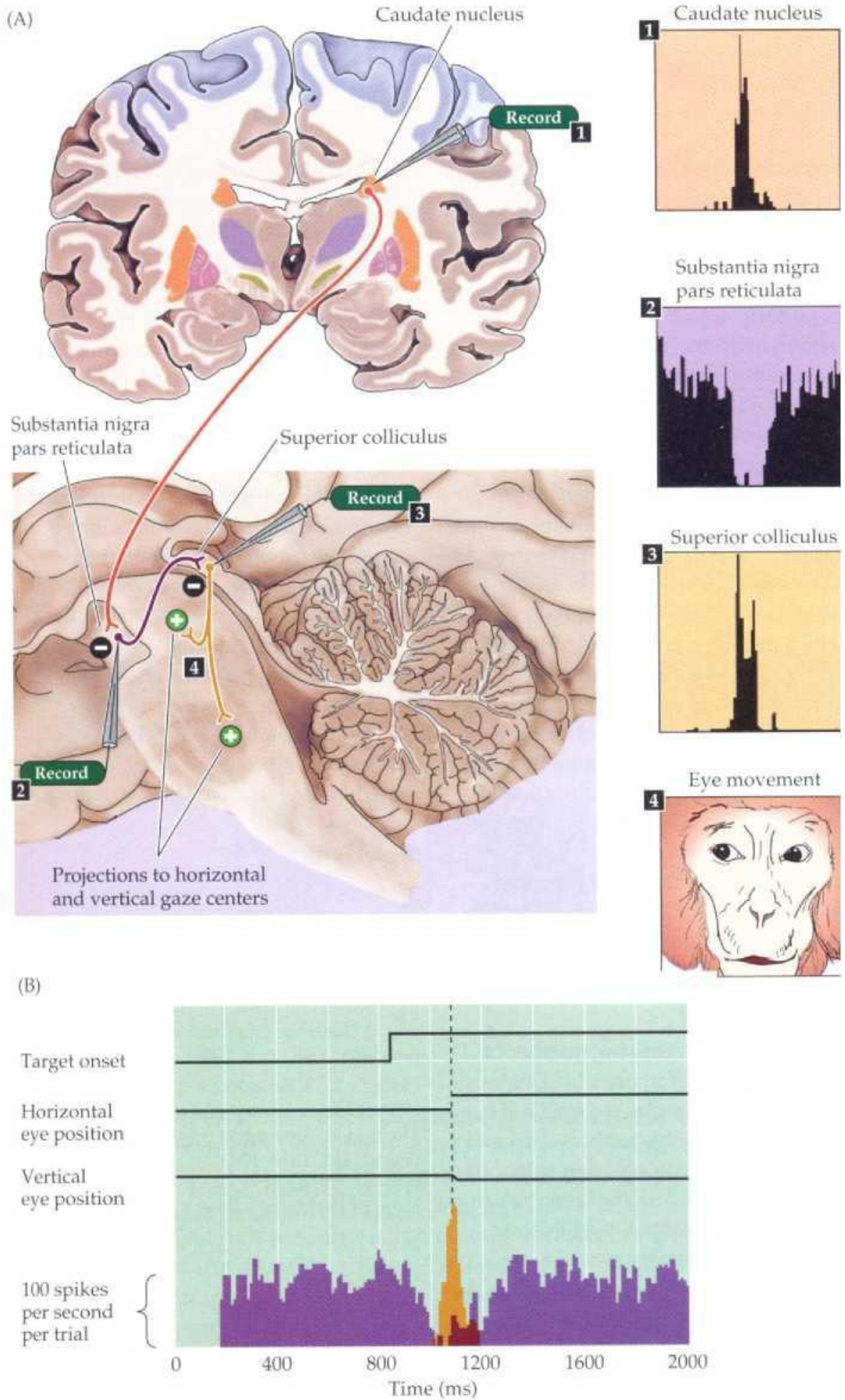


Diagram of the connections between two inhibitory neurons, A and B, and an excitatory neuron, C

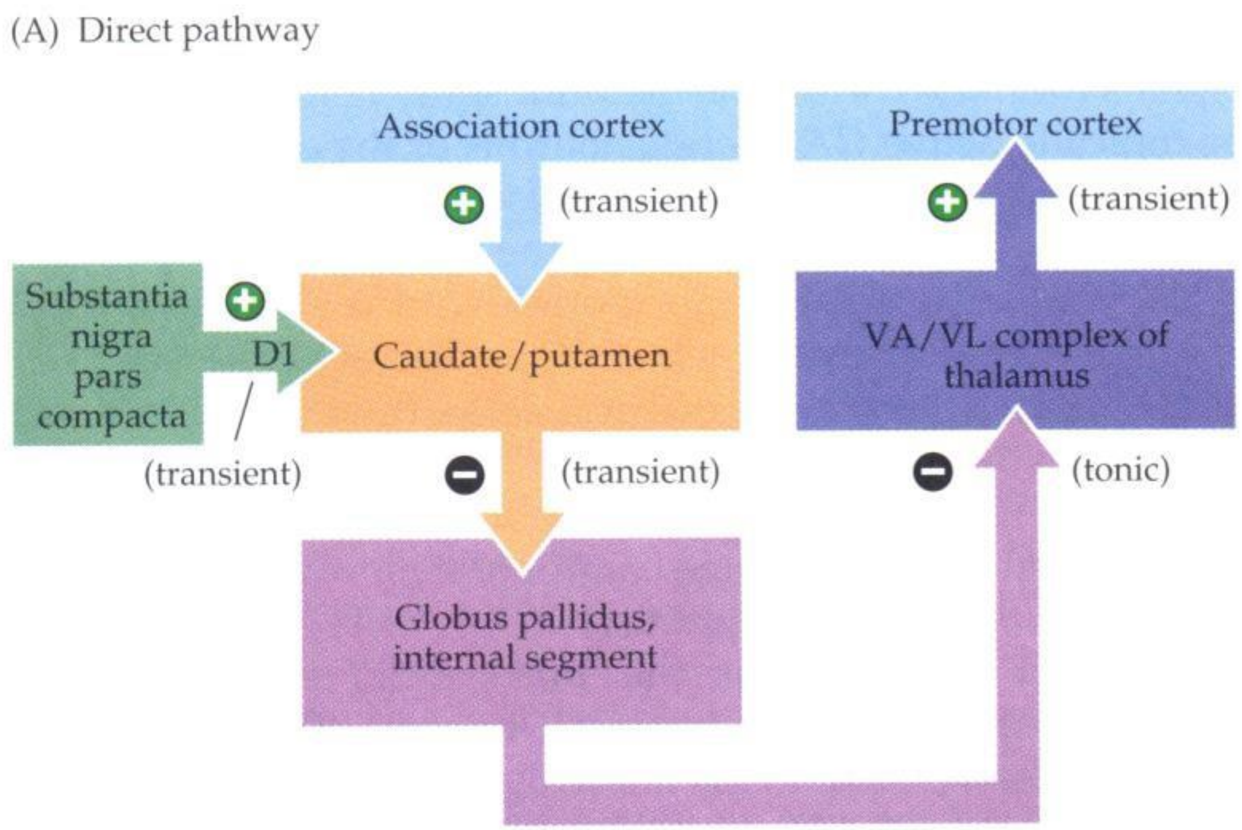
Pattern of the action potential activity of cells A, B, and C when A is at rest, and when neuron A fires transiently as a result of its excitatory inputs. Such circuits are central to the gating operations of the basal ganglia.



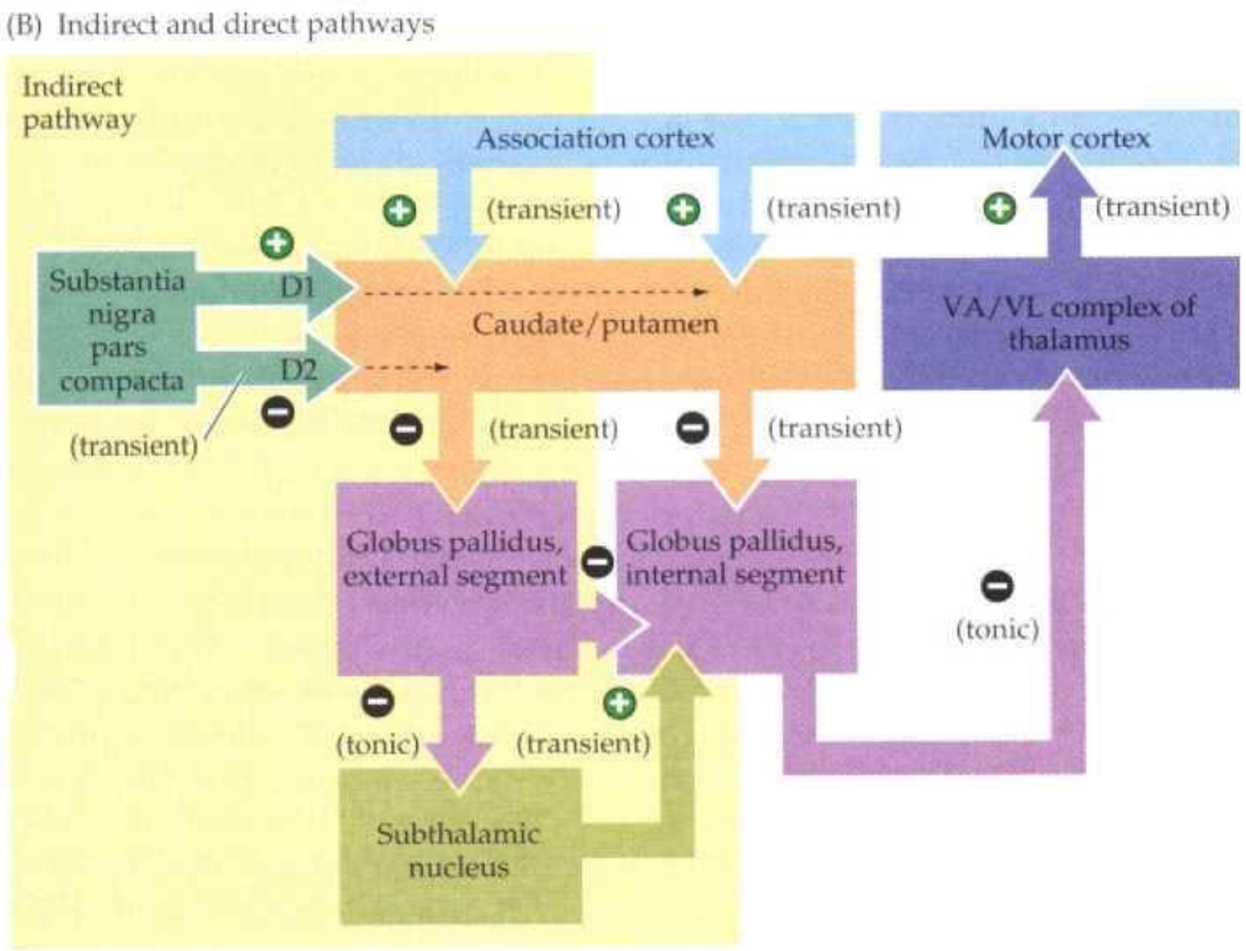
THE ROLE OF BASAL GANGLIA DISINHIBITION IN THE GENERATION OF SACCADIC EYE MOVEMENTS

(A) Medium spiny cells in the caudate nucleus respond with a transient burst of action potentials to an excitatory input from the cerebral cortex (1). The spiny cells inhibit the tonically active GABAergic cells in substantia nigra pars reticulata (2). As a result, the upper motor neurons in the deep layers of the superior colliculus are no longer tonically inhibited and can generate the bursts of action potentials that command a saccade. (B) The temporal relationship between inhibition in substantia nigra pars reticulata (purple) and disinhibition in the superior colliculus (yellow) preceding a saccade to a visual target.

DISINHIBITION IN THE DIRECT AND INDIRECT PATHWAYS THROUGH THE BASAL GANGLIA

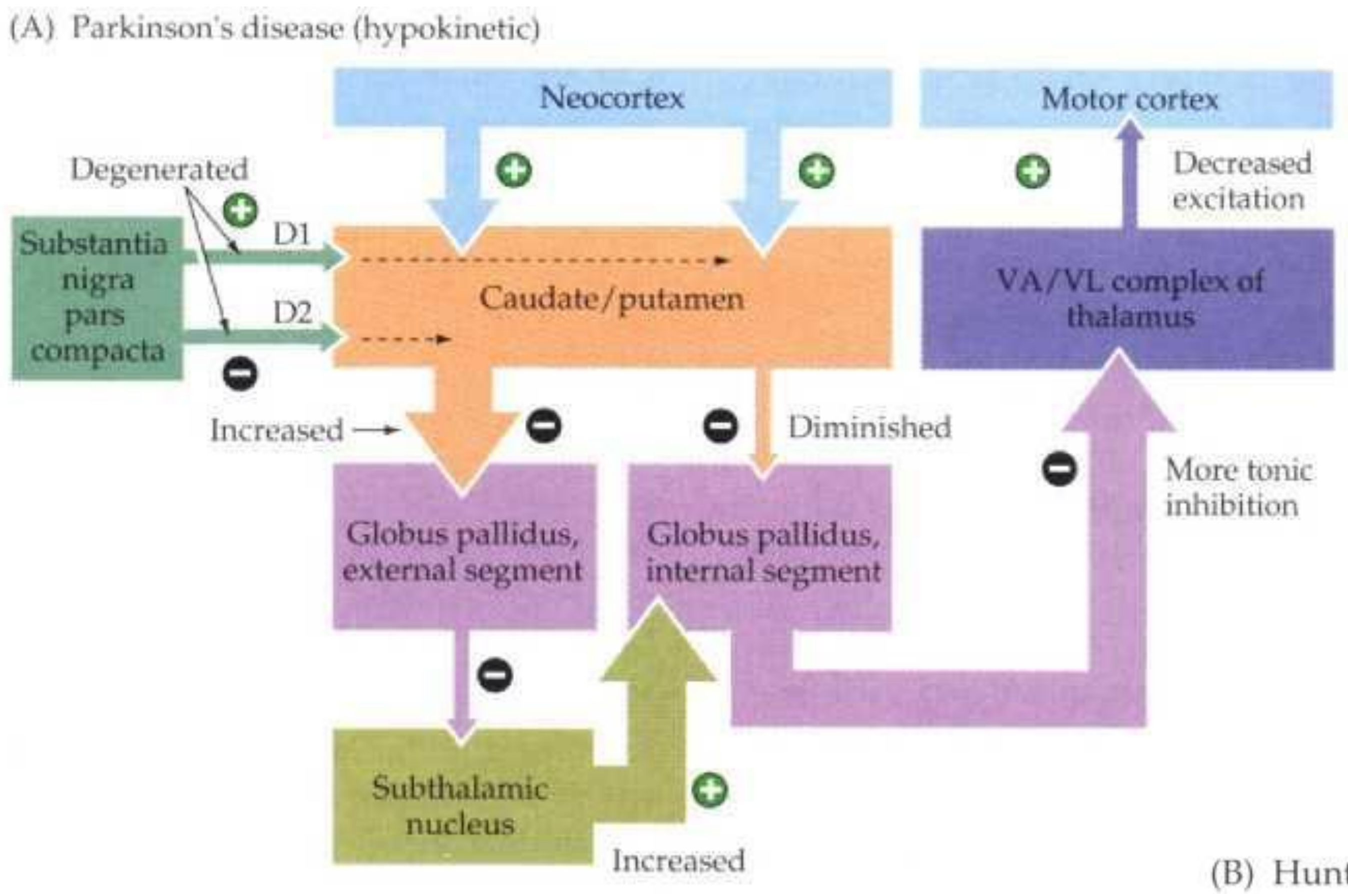


(A) In the direct pathway, transiently inhibitory projections from the caudate and putamen project to tonically active inhibitory neurons in the internal segment of the globus pallidus, which project in turn to the VA/VL complex of the thalamus. Transiently excitatory inputs to the caudate and putamen from the cortex and substantia nigra are also shown, as is the transiently excitatory input from the thalamus back to the cortex.



(B) In the indirect pathway (shaded by yellow), transiently active inhibitory neurons from the caudate and putamen project to tonically active inhibitory neurons of the external segment of the globus pallidus. Note that the influence of nigral dopaminergic input to neurons in the indirect pathway is inhibitory. The globus pallidus (external segment) neurons project to the subthalamic nucleus, which also receives a strong excitatory input from the cortex. The subthalamic nucleus in turn projects to the globus pallidus (internal segment), where its transiently excitatory drive acts to oppose the disinhibitory action of the direct pathway. In this way, the indirect pathway modulates the effects of the direct pathway.

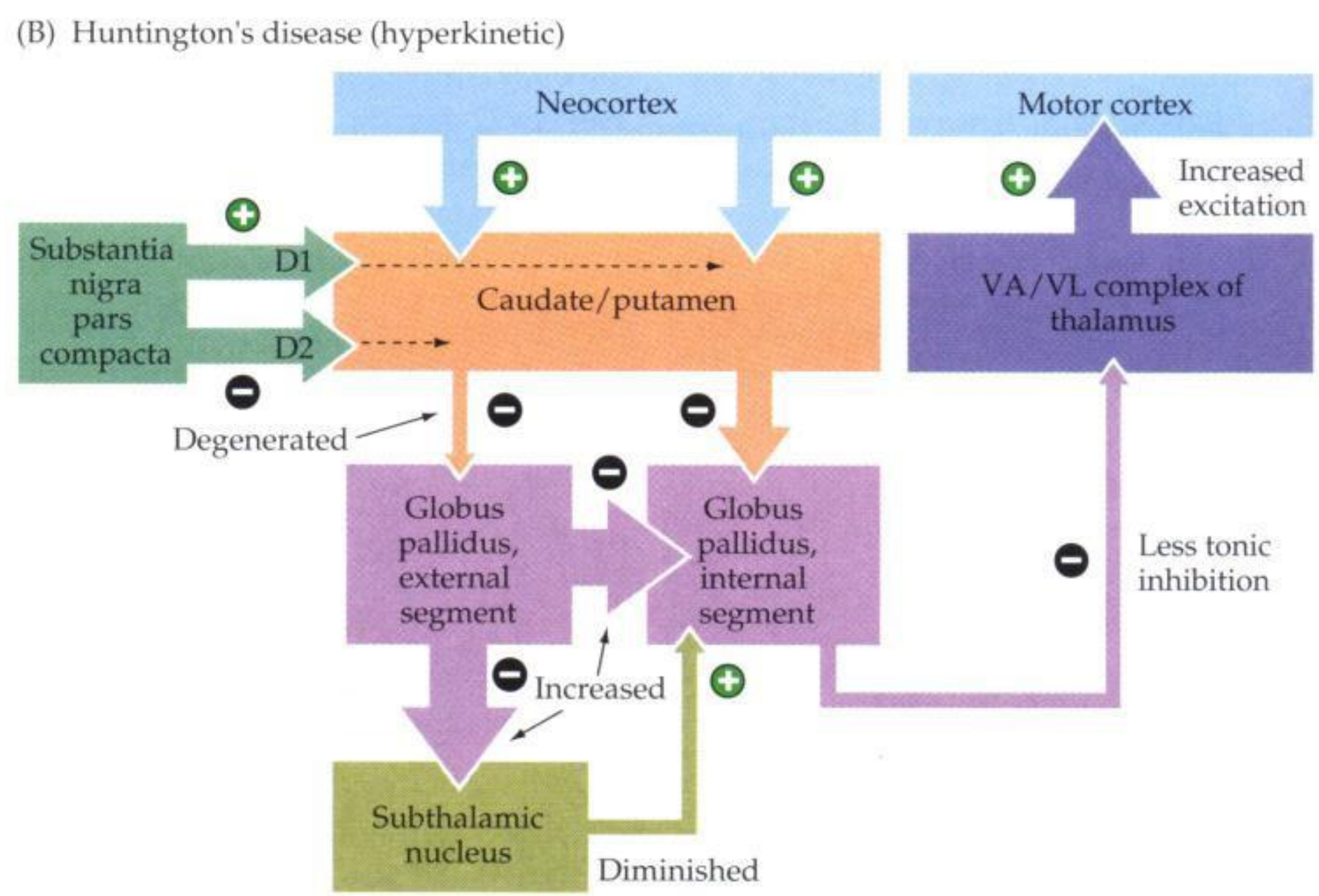
HYPO- AND HYPERKINETIC DISORDERS (PARKINSON'S AND HUNTINGTON'S DISEASES)



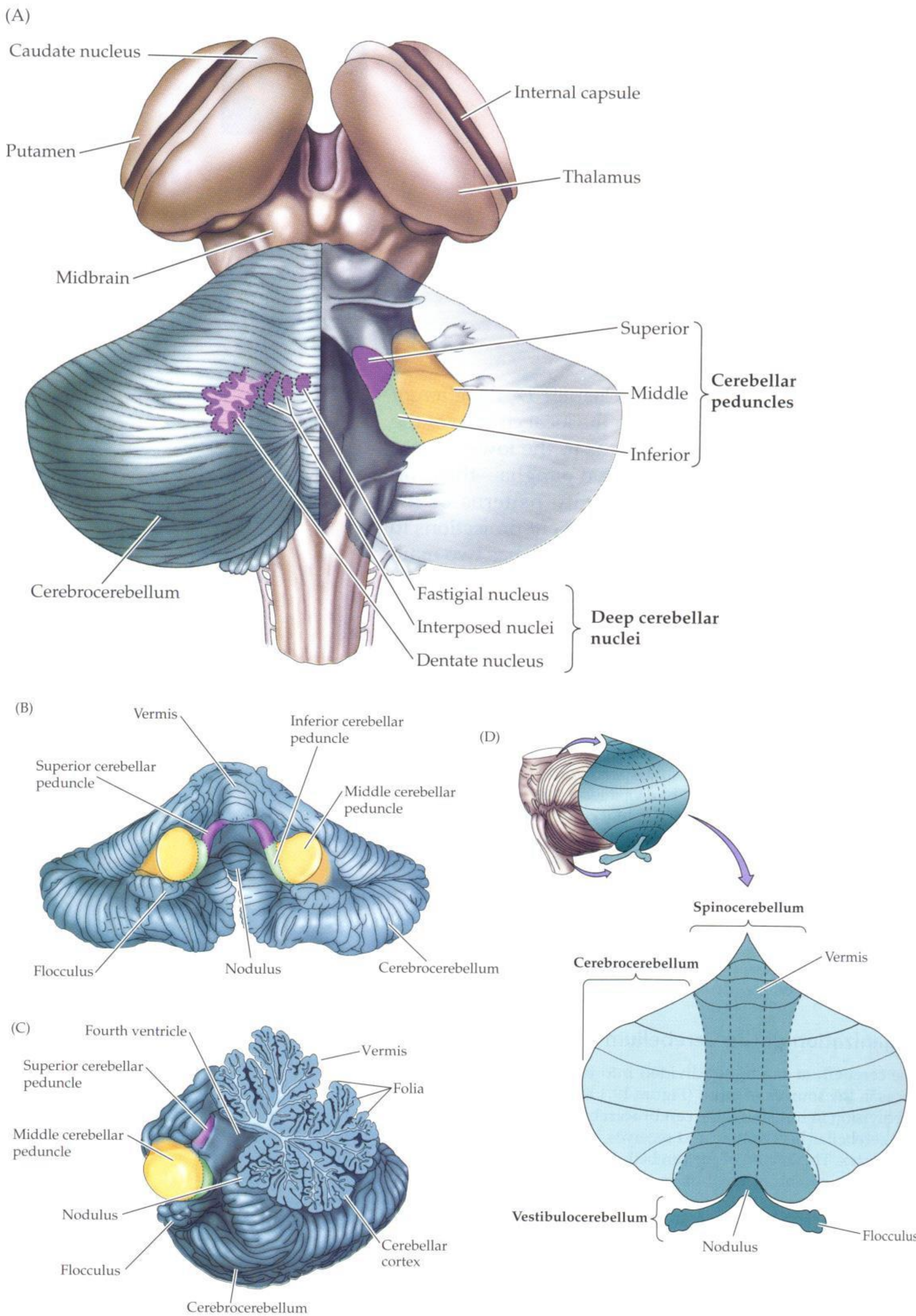
In both cases, the balance of inhibitory signals in the direct and indirect pathways is altered, leading to a diminished ability of the basal ganglia to control the thalamic output to the cortex.

(A) In Parkinson's disease, the inputs provided by the substantia nigra are diminished (thinner arrow), making it more difficult to generate the transient inhibition from the caudate and putamen. The result of this change in the direct pathway is to sustain the tonic inhibition from the globus pallidus (internal segment) to the thalamus, making thalamic excitation of the motor cortex less likely (thinner arrow from thalamus to cortex).

(B) In hyperkinetic diseases such as Huntington's, the projection from the caudate and putamen to the globus pallidus (external segment) is diminished (thinner arrow). This effect increases the tonic inhibition from the globus pallidus to the subthalamic nucleus (larger arrow), making the excitatory subthalamic nucleus less effective in opposing the action of the direct pathway (thinner arrow). Thus, thalamic excitation of the cortex is increased (larger arrow), leading to greater and often inappropriate motor activity.



ORGANIZATION AND SUBDIVISIONS OF THE CEREBELLUM



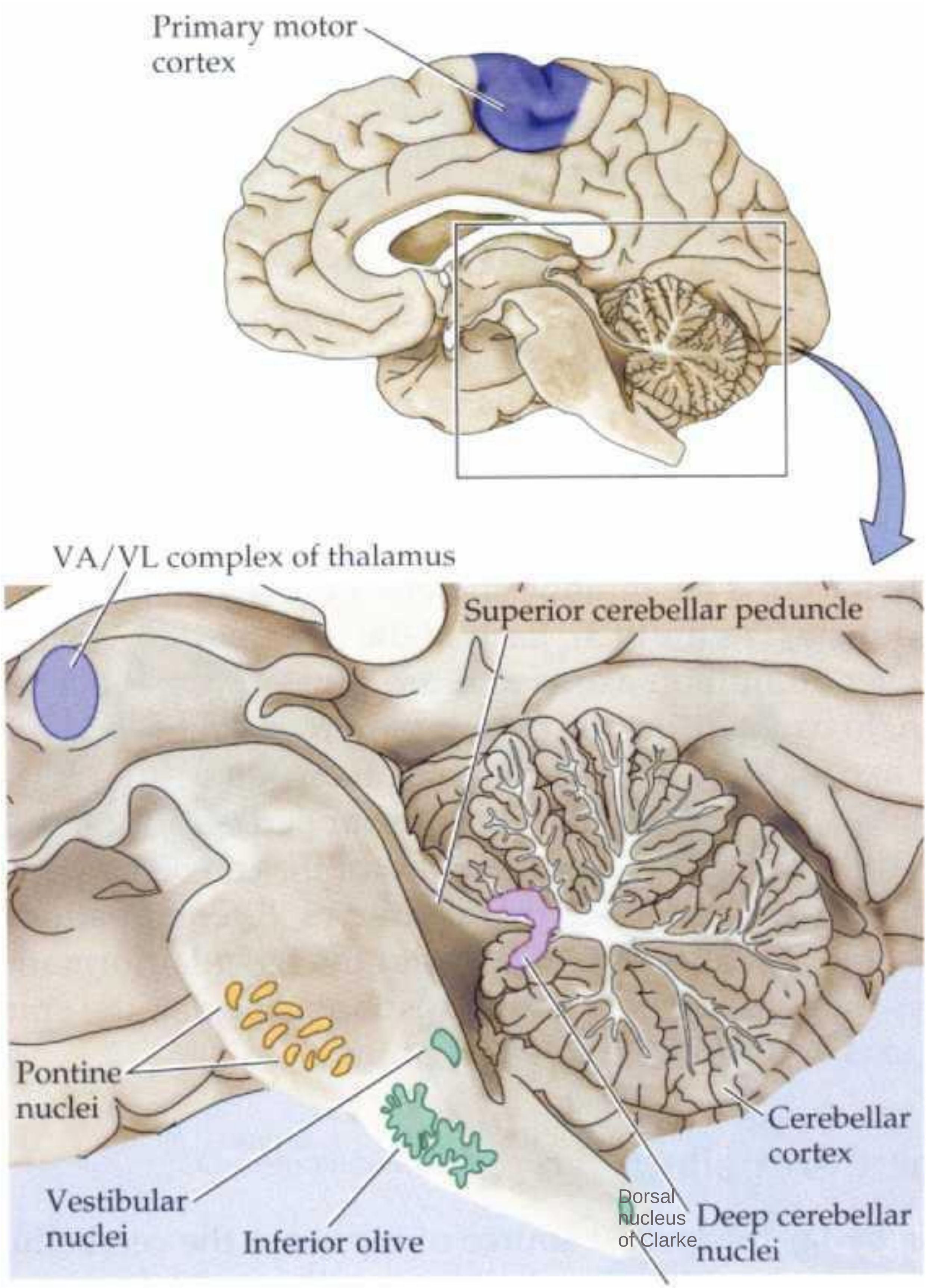
(A) Dorsal view of the left cerebellar hemisphere also illustrating the location of the deep cerebellar nuclei. The right hemisphere has been removed to show the cerebellar peduncles.

(B) Removal from the brainstem reveals the cerebellar peduncles on the anterior aspect of the inferior surface.

(C) Paramedian sagittal section through the left cerebellar hemisphere showing the highly convoluted cerebellar cortex. The small gyri in the cerebellum are called "folia."

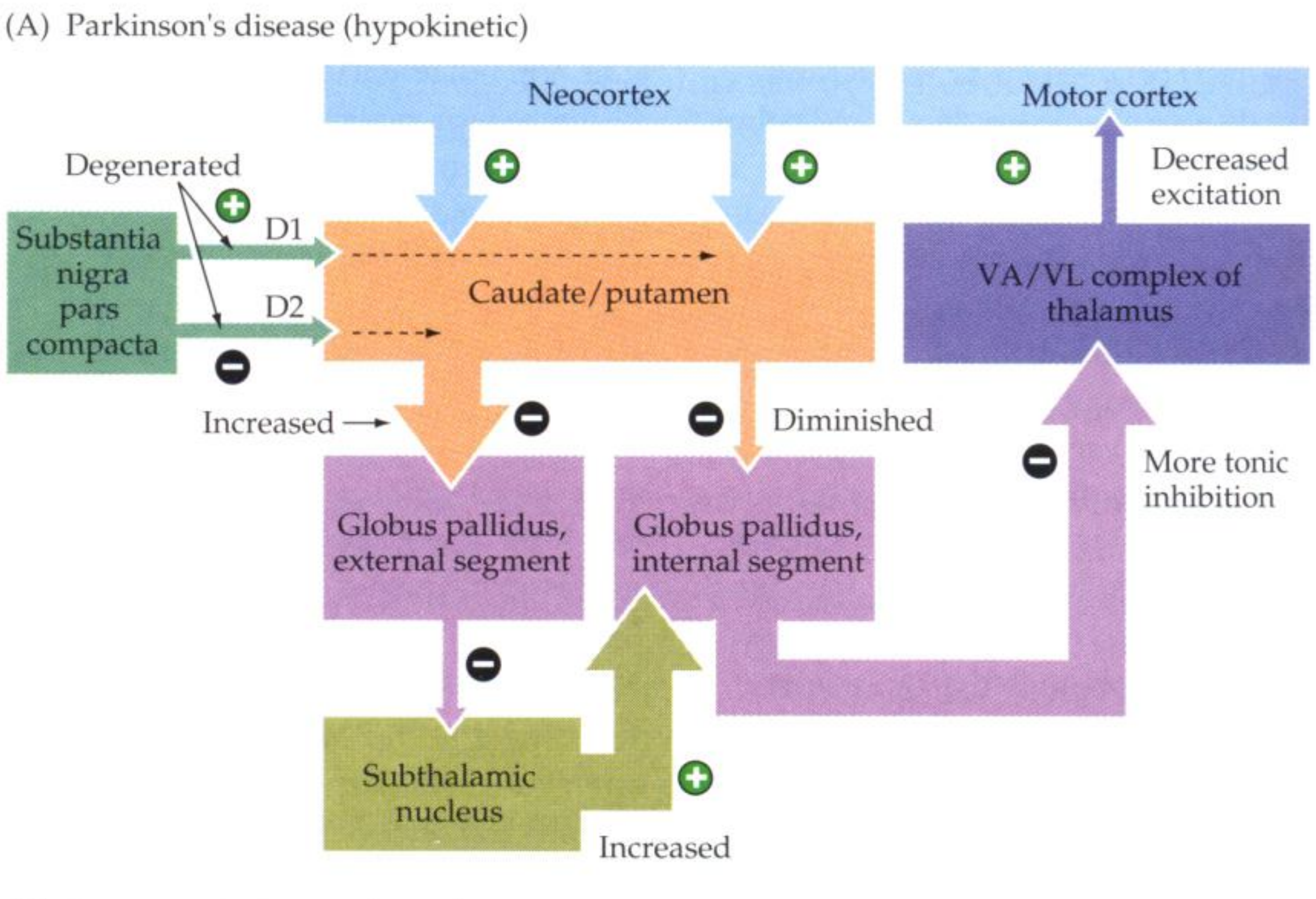
(D) Flattened view of the cerebellar surface illustrating the three major subdivisions.

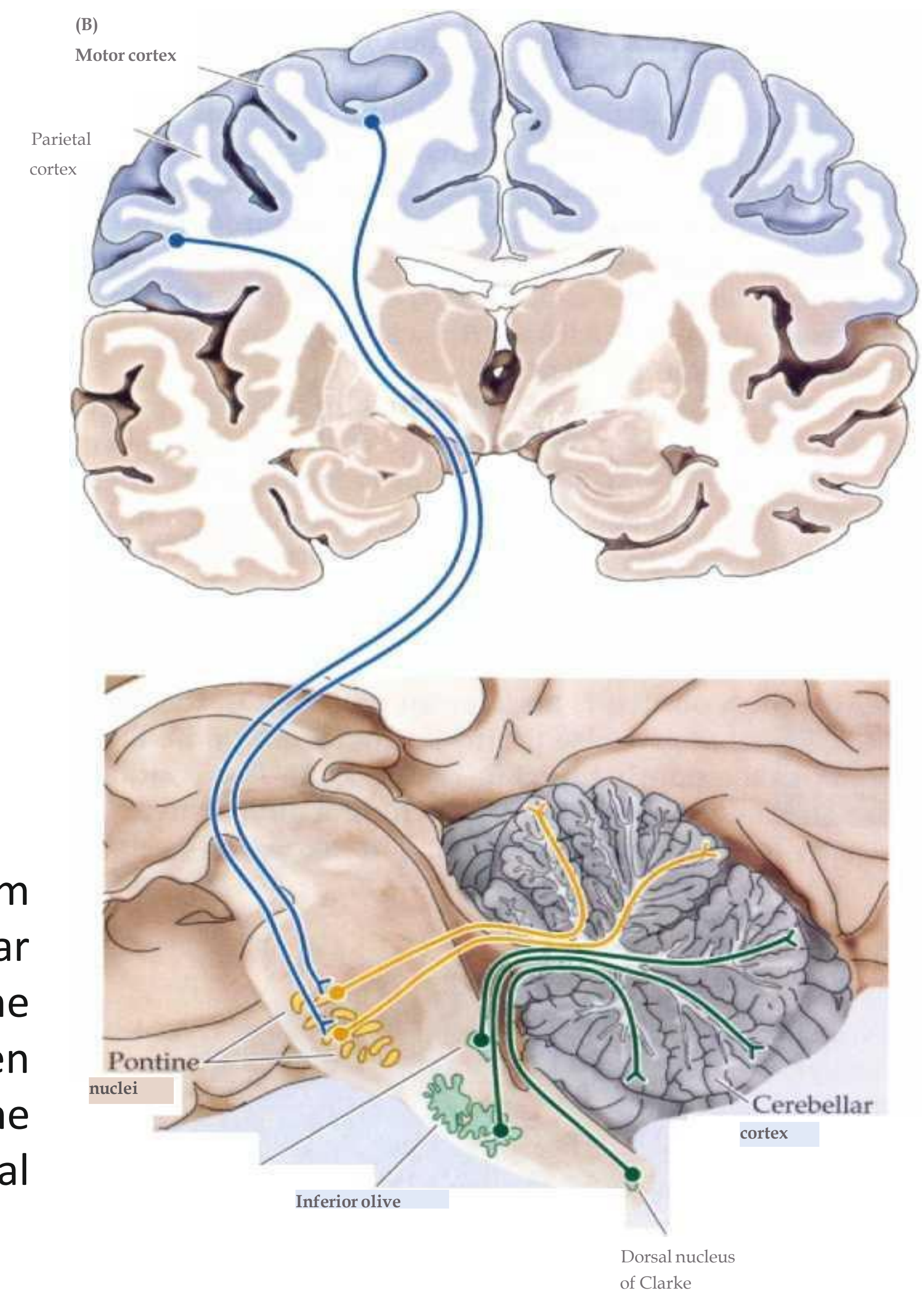
COMPONENTS OF THE BRAINSTEM AND DIENCEPHALON RELATED TO THE CEREBELLUM



This sagittal section shows the major structures of the cerebellar system, including the cerebellar cortex, the deep cerebellar nuclei, and the ventroanterior and ventrolateral (VA/VL) complex (which is the target of some of the deep cerebellar nuclei).

INPUTS TO THE CEREBELLUM

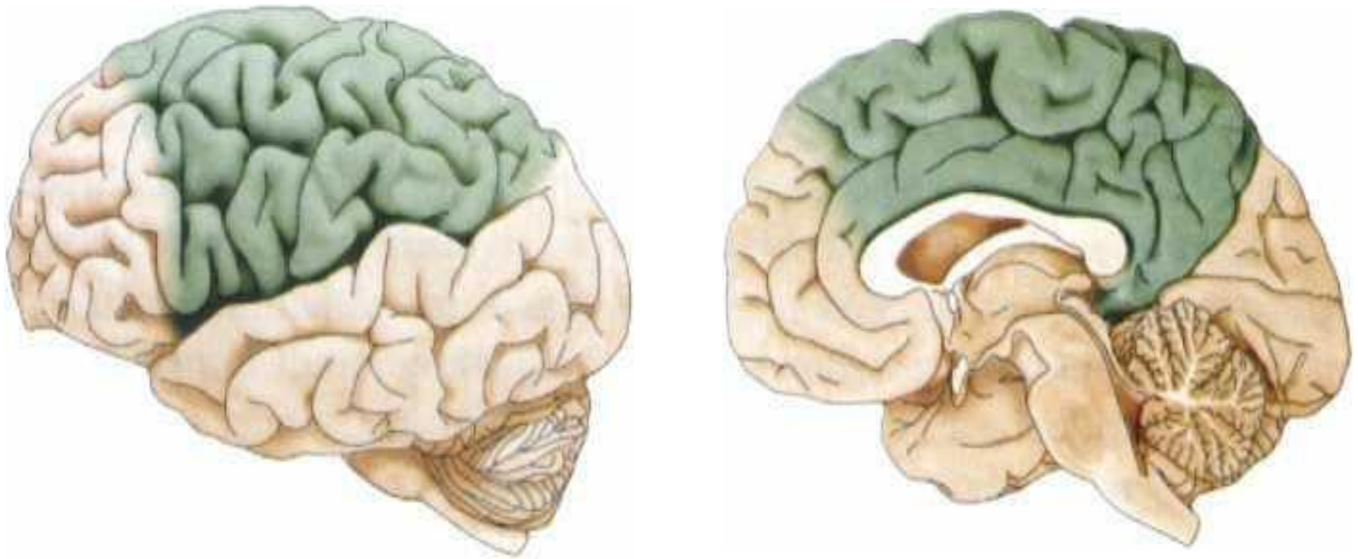




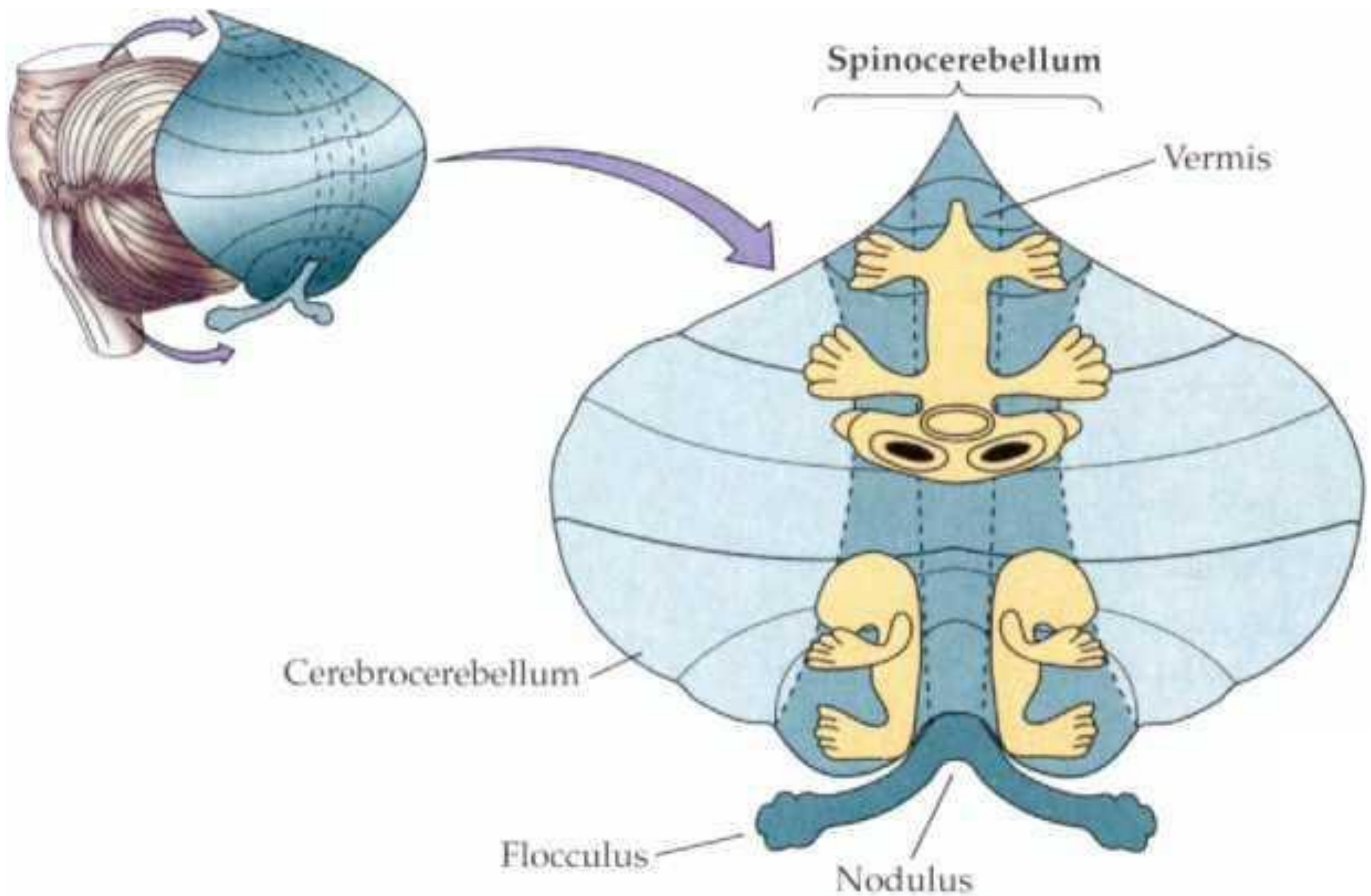
(A) Diagram of the major inputs.

(B) Idealized coronal and sagittal sections through the human brainstem and cerebrum, showing inputs to the cerebellum from the cortex, vestibular system, spinal cord, and brainstem. The cortical projections to the cerebellum are made via relay neurons in the pons. These axons then cross the midline within the pons and run to the cerebellum via the middle cerebellar Vestibular peduncle. Axons from the inferior olive, spinal cord, and vestibular nuclei enter via the inferior cerebellar peduncle.

SOMATOTOPIC MAPS OF THE BODY SURFACE IN THE CEREBELLUM.



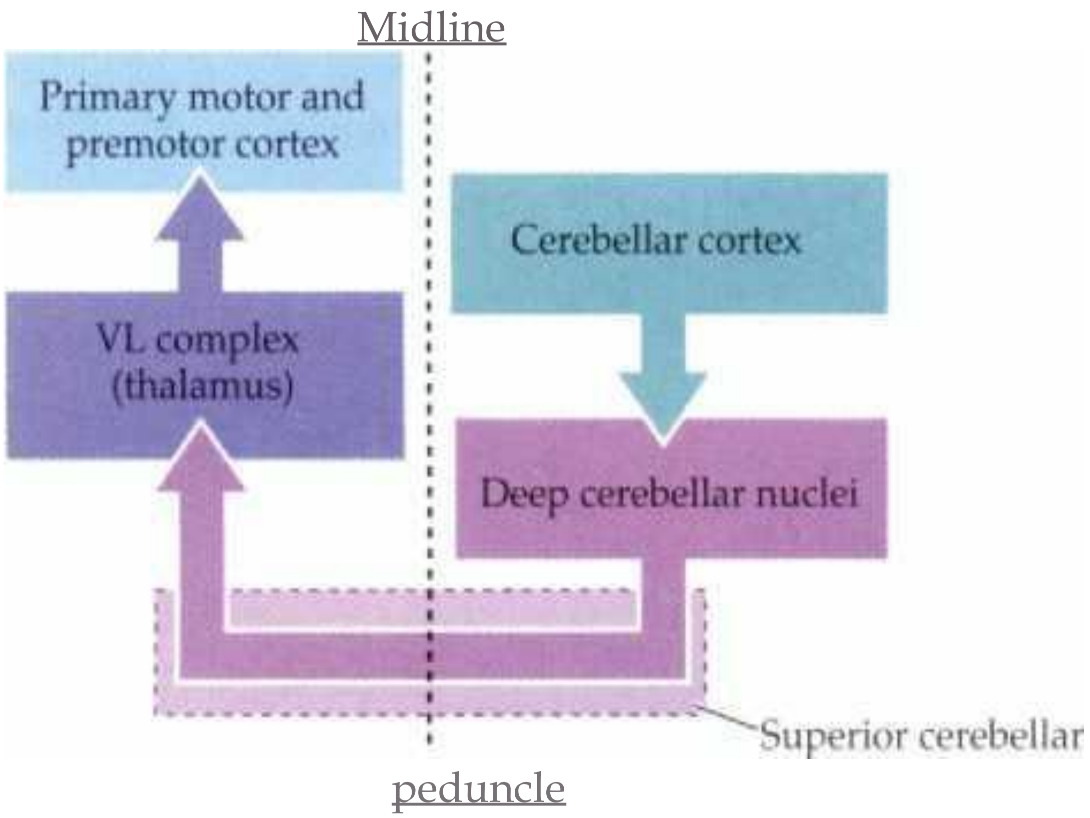
The spinocerebellum contains two maps of the body.



Regions of the cerebral cortex that project to the cerebellum (shown in green). The cortical projections to the cerebellum are mainly from the sensory association cortex of the parietal lobe and motor association areas of the frontal lobe

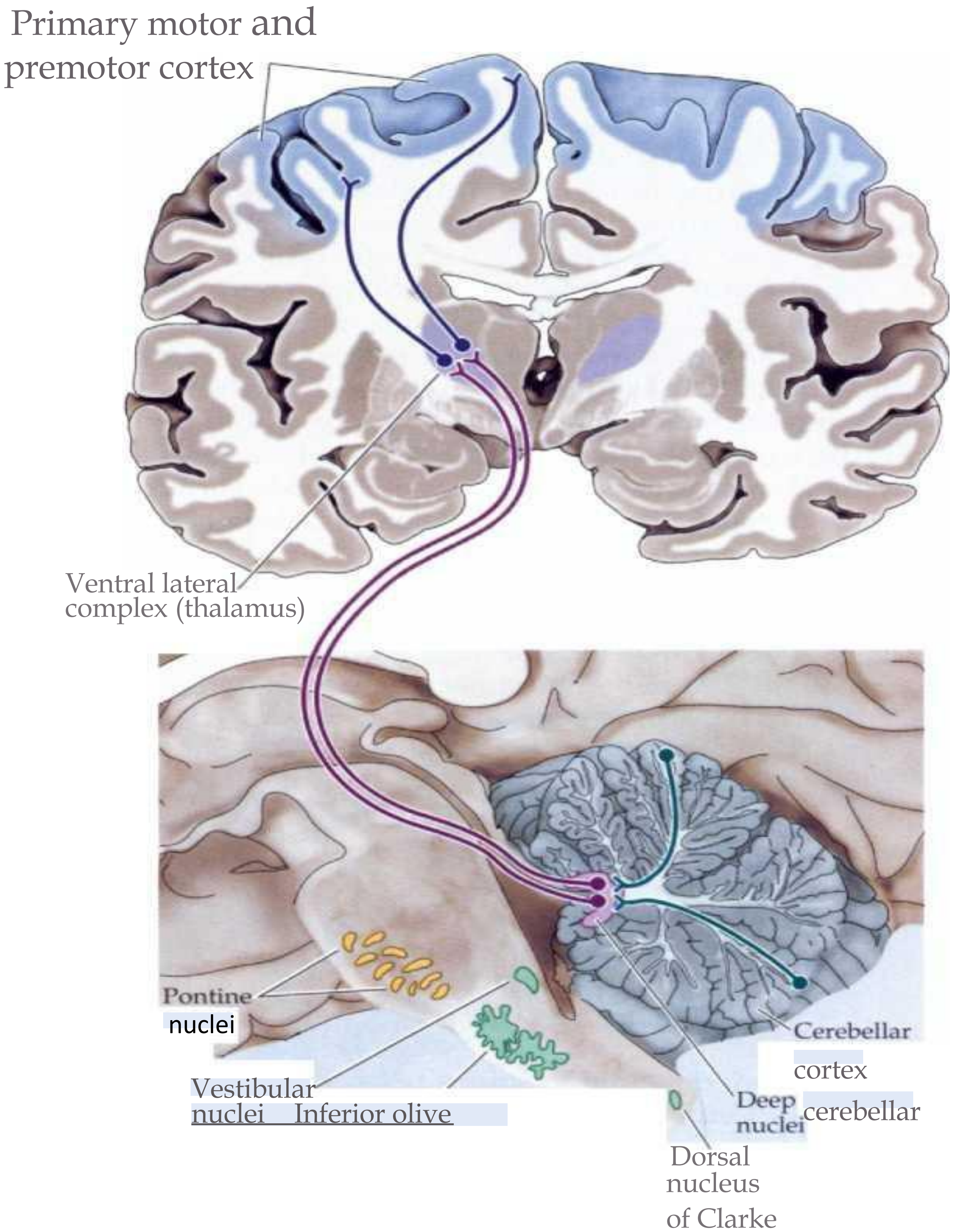
FUNCTIONAL ORGANIZATION OF THE OUTPUTS FROM THE CEREBELLUM TO THE CEREBRAL CORTEX

(A)

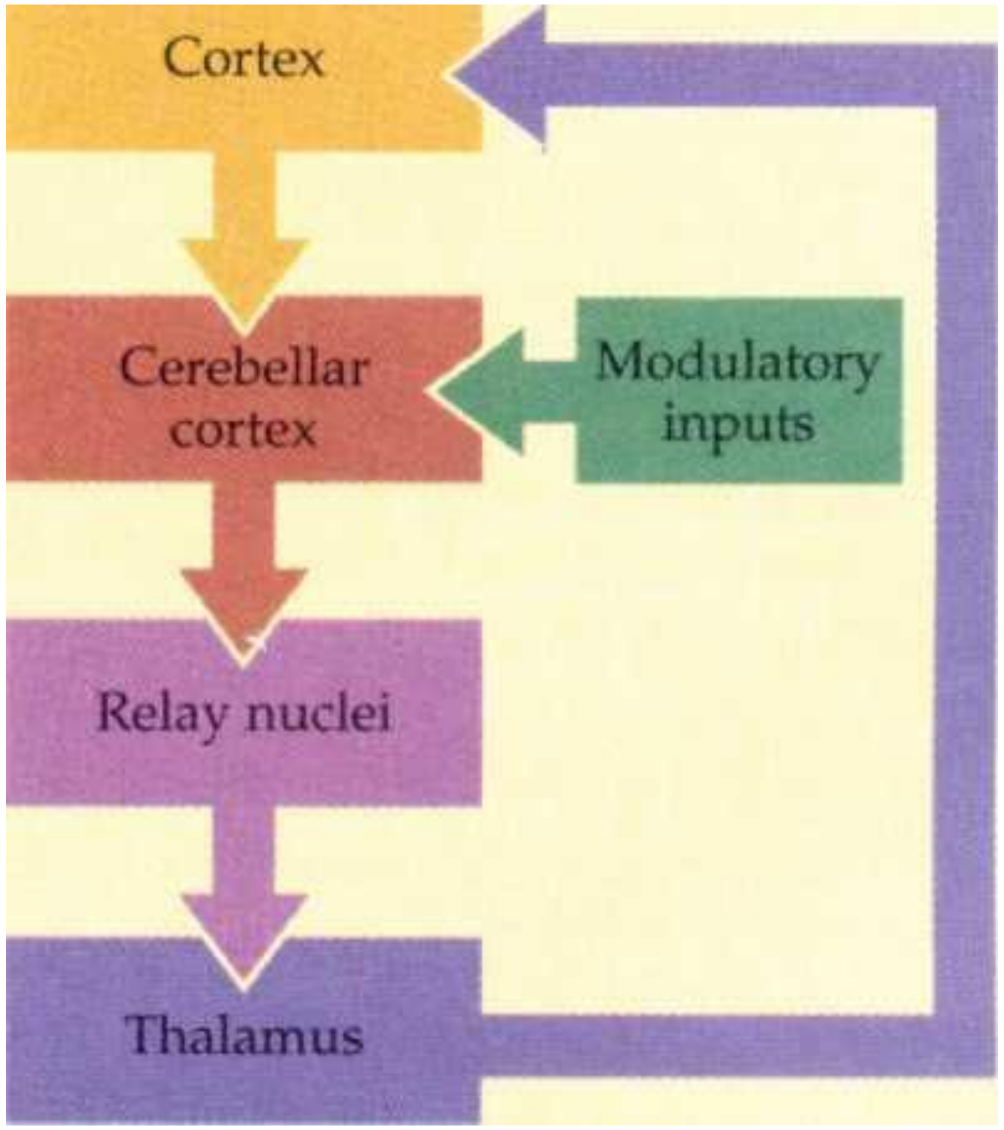


(A) Diagram of this aspect of the targets of the cerebellum. The axons of the deep cerebellar nuclei cross in the midbrain in the decussation of the superior cerebellar peduncle before reaching the thalamus. (B) Idealized coronal and sagittal sections through the human brainstem and cerebrum, showing the location of structures and pathways diagrammed in (A).

(B)

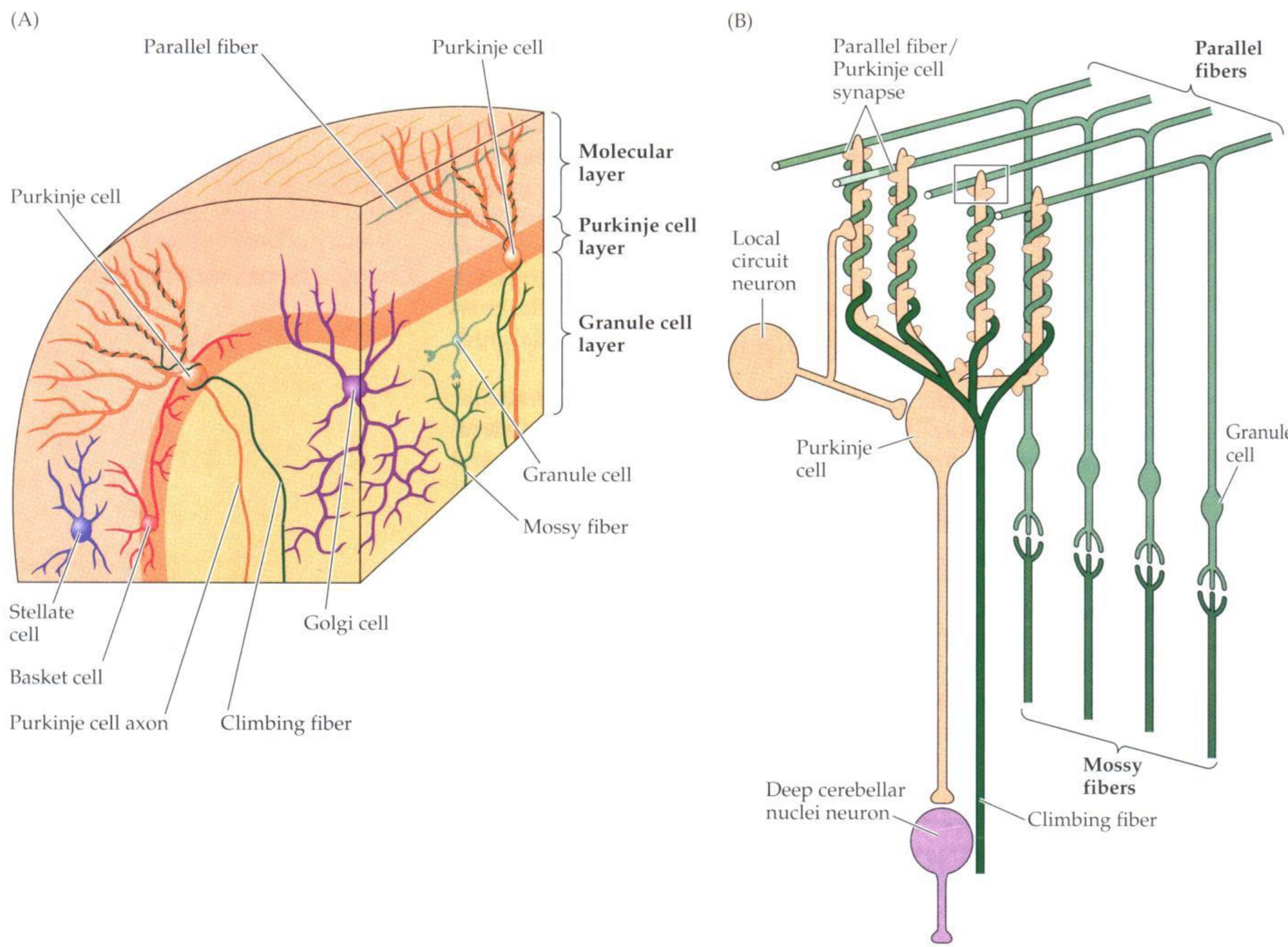


MOTOR MODULATION BY THE CEREBRO-CEREBELLUM



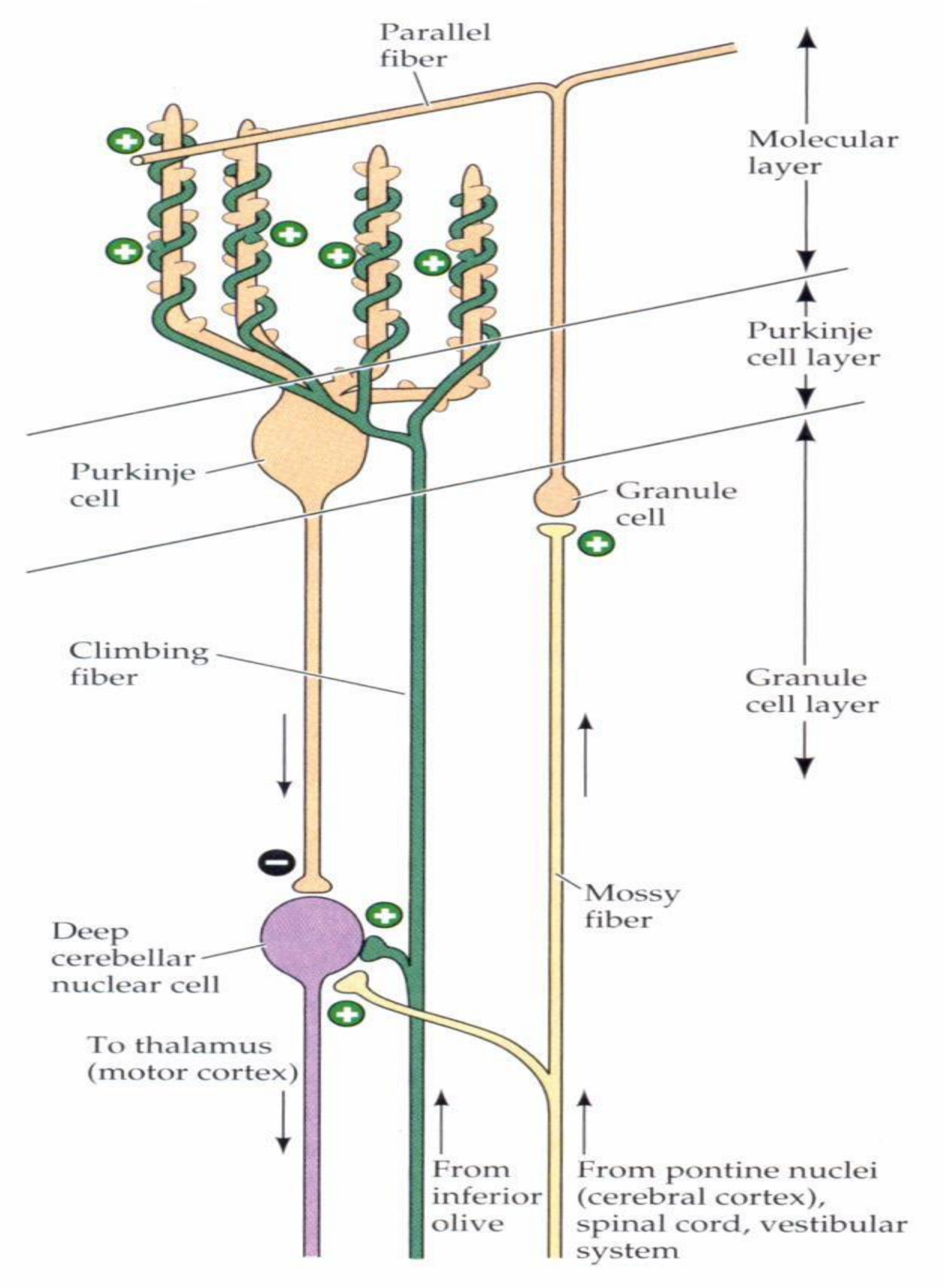
The central processing component, the cerebrocerebellar cortex, receives massive input from the cerebral cortex and generates signals that adjust the responses of upper motor neurons to regulate the course of a movement. Modulatory inputs also influence the processing of information within the cerebellar cortex. The output signals from the cerebellar cortex are relayed indirectly to the thalamus and then back to the motor cortex, where they modulate the motor commands.

NEURONS AND CIRCUITS OF THE CEREBELLUM



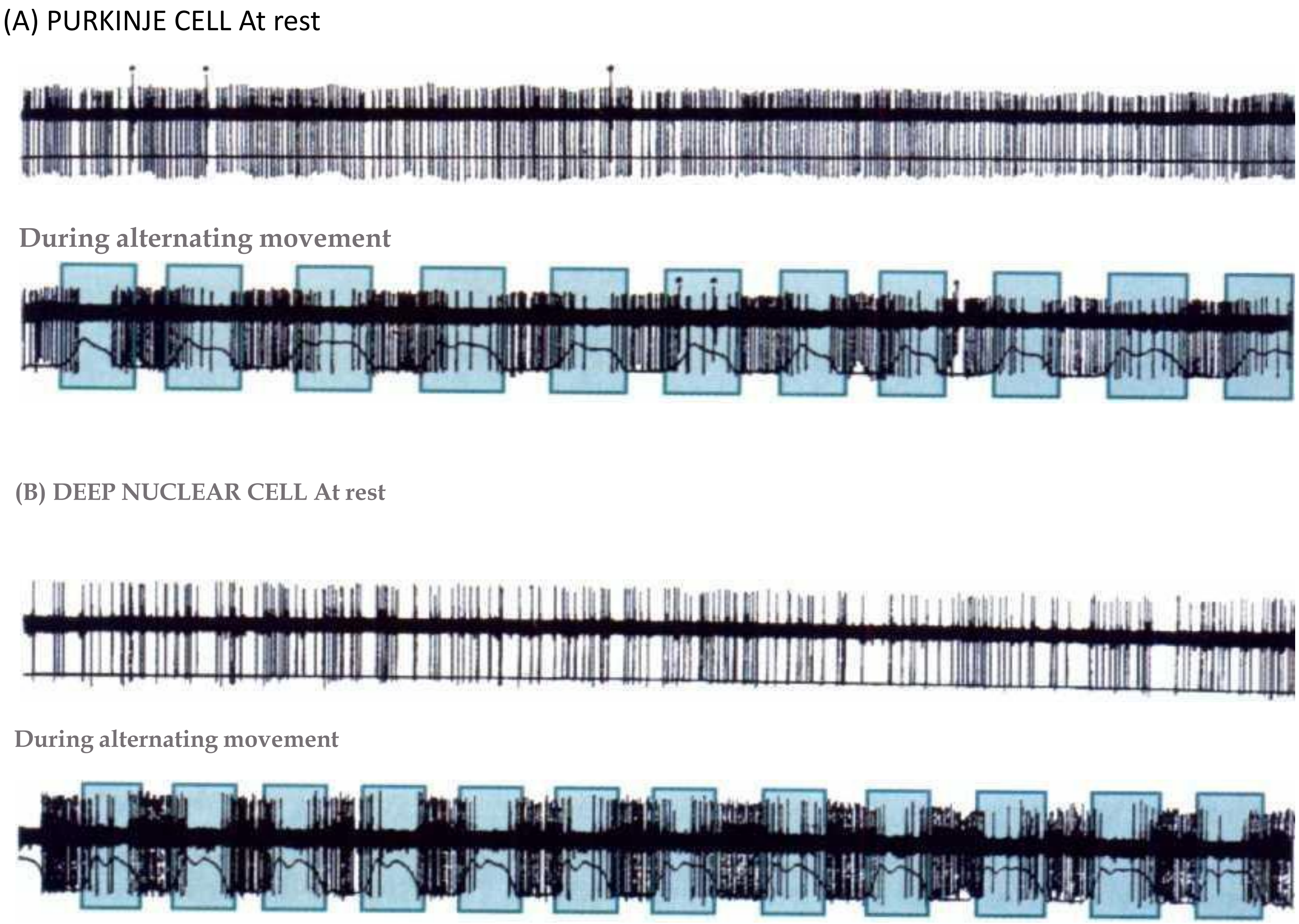
(A) Neuronal types in the cerebellar cortex. Note that the various neuron classes are found in distinct layers. (B) Diagram showing convergent inputs onto the Purkinje cell from parallel fibers and local circuit neurons [boxed region shown at higher magnification in (C)]. The output of the Purkinje cells is to the deep cerebellar nuclei.

EXCITATORY AND INHIBITORY CONNECTIONS IN THE CEREBELLAR CORTEX AND DEEP CEREBELLAR NUCLEI



The excitatory input from mossy fibers and climbing fibers to Purkinje cells and deep nuclear cells is basically the same. Additional convergent input onto the Purkinje cell from local circuit neurons (basket and stellate cells) and other Purkinje cells establishes a basis for the comparison of ongoing movement and sensory feedback derived from it. The Purkinje cell output to the deep cerebellar nuclear cell thus generates an error correction signal that can modify movements already begun. The climbing fibers modify the efficacy of the parallel fiber-Purkinje cell connection, producing longterm changes in cerebellar output.

ACTIVITY OF PURKINJE CELLS AND DEEP CEREBELLAR NUCLEAR CELLS



Activity of Purkinje cells (A) and deep cerebellar nuclear cells (B) at rest (upper traces) and during movement of the wrist (lower traces). The lines below the action potential records show changes in muscle tension, recorded by electromyography. The durations of the wrist movements are indicated by the colored blocks. Both classes of cells are tonically active at rest. Rapid alternating movements result in the transient inhibition of the tonic activity of both cell types.

REVIEW QUESTIONS

- List the basic circuits of the basal ganglia pathway with denoting the excitatory and inhibitory connections.
- What is a role of Purkinje cells in providing ongoing movements?
- Explain functional organization of the inputs to the cerebellum.
- What is a role of basal ganglia in generation of saccadic eye movements?
- Explain organization of the ascending and discending pathways from the cerebellum.
- Explain principles of the motor modulation by the cerebro-cerebellum system.