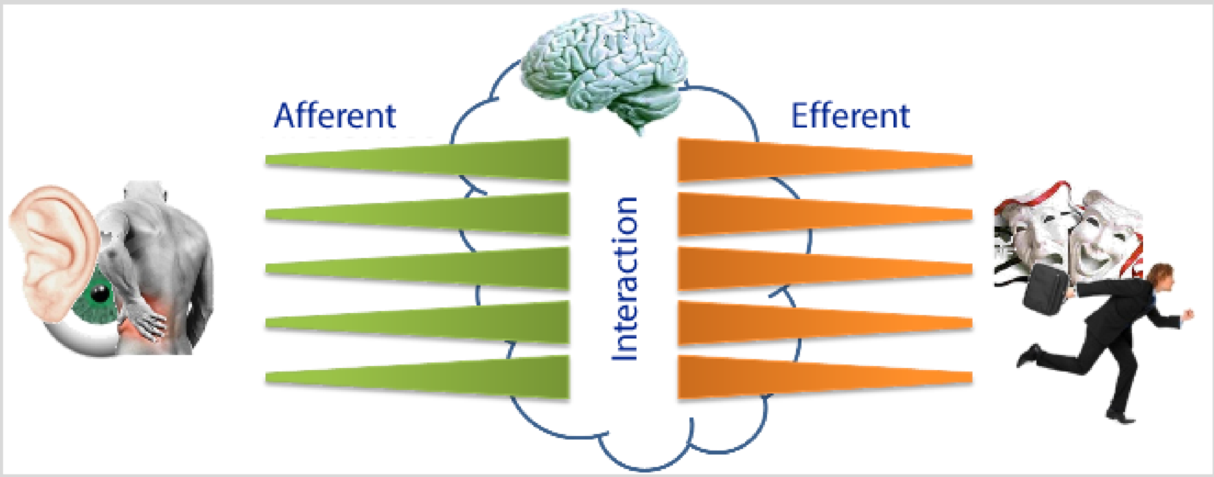
MODULE 4. Integrative Reading

One of the most important concepts of this course is the **neurocybernetic model of information processing**, which accounts for at least three main instances. We refer to these as:

1) **Afferent organization or *input*,** that's to say, everything that happens with the data collected from the environment outside the body, as well as from the internal environment, until it is processed in isolated areas of the cerebral cortex.
2) The second instance is **central processing**, which deals, fundamentally, with the inherent functions of motor logic, decision-making and neuromotor programming.
3) The final instance is what is known as **efferent organization or *output*.**

Figure 1: Feedback model of human movement



Source: [Untitled image showing feedback model of human movement]. (n.d.). Retrieved from https://goo.gl/mg5az4

Going into further detail, we recognize six main phenomena called **sequences,** so named because one triggers the next and the quality of the first determines the quality of the second. These movement sequences are studied and analyzed in order to then develop a special teaching method. They are:

1) Sensation.
2) Perception.
3) Representation.
4) Motor logic and decision-making.
5) Neuromotor programming.
6) Motor execution and control.

The **parallel** phenomena cannot be categorized at any given time, as their activity is determined via the processes as they are developed. Among these, we can mention the following:

- Feedback.
- Attention.
- Motor memory.
- Motivation.
- Emotional states and processes.

Emotions affect not only the regulation of muscle tone, but also the regulation of the motor act itself. Yet we try not to study *emotions emotionally*. On the contrary, we aim to avoid the romantic definition and study them as neurophysiological phenomena that have been depicted in evolutionary history as a survival advantage. Each emotion depends on a different neural correlate. Different neural populations process different emotional states, many of them in the limbic lobe, but many neural coalitions are generated from the participation of neural subpopulations in the frontal, parietal, temporal and occipital lobes. A common feature of all emotional states is that all the axons that process emotional states are supported by the basal ganglia. While we can disguise our emotions controlling our facial expressions and what we say, from an emotional point of view, we can't control muscle tone. There is no emotional dimension that does not provoke a change in muscle tone, fundamentally in the facial muscles. Emotions influence all of the processes of regulation of human movement with respect to sensation, perception, representation, motor logic, motor programming, execution and monitoring. Therefore, we study both the effect of emotions on motor acts, as well as strategies for controlling emotions. We have now reached a point in evolutionary history where the channels that communicate emotion to reason are more developed than the channels that communicate reason to emotion. This is why it is so easy to alter a rational process with an emotional process and it is so difficult to control an emotional process with a rational action.

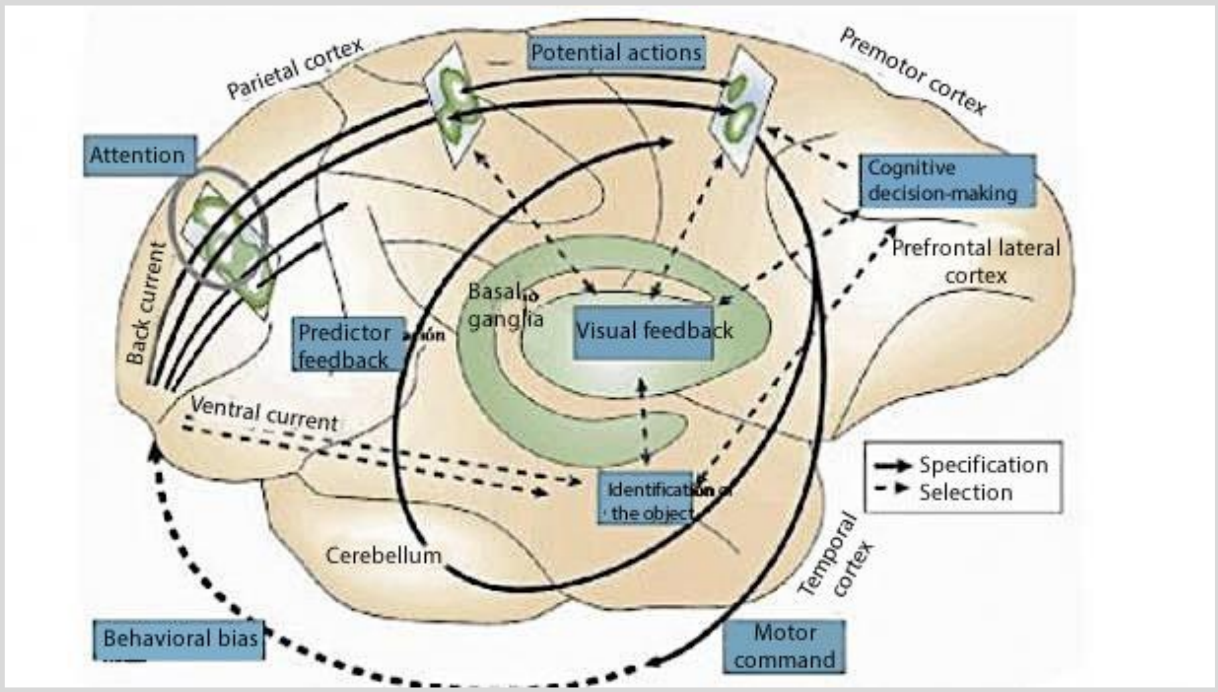
We could discuss whether the cause of this is a serial or a parallel phenomenon, from a fundamentally neurochemical (dopamine) point of view, and how it affects different areas of the cerebral cortex, especially in the supplementary motor area, facilitating these actions and preventing their obstruction. We study motivation more from the biological perspective than from the operative-teaching point of view.

The information processing theory emerged in response to behaviorism and Gestalt psychology. It is mainly concerned with the so-called "channel capacity", which is: how much information the nervous system can appropriately process when we execute an intelligent voluntary movement. With regard to this analysis, learning how we process information may change the way we choose to teach. This is especially significant when reflecting on the quantity of information a subject can be given in the different stages of motor learning and in skills training, as well as the quantity of information than can be produced in order to acquire, perfect or stabilize. Along with cybernetics, the theory has had a large impact on the theory and practice of correcting failures.

Essentially, the term cybernetic model refers to the information processing system carried out by an athlete when executing a motor praxis. In short, we are questioning what happens in a subject's brain and in the rest of their nervous system when they complete a movement. The term also implies a clear detection of differential stages that are often studied separately, bringing about interesting changes in the teaching methods in athletes and specific functional units. The study of neural correlates has to do with the trainability of the motor functions.

Cybernetics emerged from information processing theories. It is a branch of information processing concerned with feedback mechanisms as the main focus of analysis. In this context, it studies in detail the way in which returning information is processed in order to regulate movement and for the continuity of the motor learning process. Its objective is to make the subject able to properly address and capitalize on feedback, with the goal of progressively eliminating the need for outside monitoring.

Figure 2: Neurocybernetic model of information processing



Now that we have a clear understanding of the theoretical structure of information processing, we shall turn to the phenomenon of motor programming. Keep in mind that after the final decision that either prohibits or gives course to the motor program (pre-SMA), this motor program is distributed towards different sectors of the CNS. We include the following primary destinations, without discarding the possibility of others (their functions differ and all are important):

- Primary motor cortex.
- Cerebellum.
- Basal ganglia (Di Santo, 2015).

Primary motor cortex.

The **primary motor cortex** is responsible for executing movements, sending efferent signals to motor nuclei from the spinal cord. As will be explained in the next topic, the 1MC does not act alone, but rather it is the final stage before efferents reach the spine.

The primary motor cortex receives signals from the **pre-motor area**, which is responsible for storing motor programs that the individual has been creating throughout their entire motor function history.
The primary motor cortex cannot send the efferent motor signal if the supplementary motor area does not authorize the start of the action. There are other nervous system structures than send afferences to the 1MC.

Basal Ganglia

Physiologically, basal ganglia are considered to be made up of: the **caudate nucleus**, the **putamen**, the **globus pallidus**, the **substantia nigra** and the **sub-thalamus**. However, significant portions of the thalamus, reticular formation and red nucleus work closely with the aforementioned components.

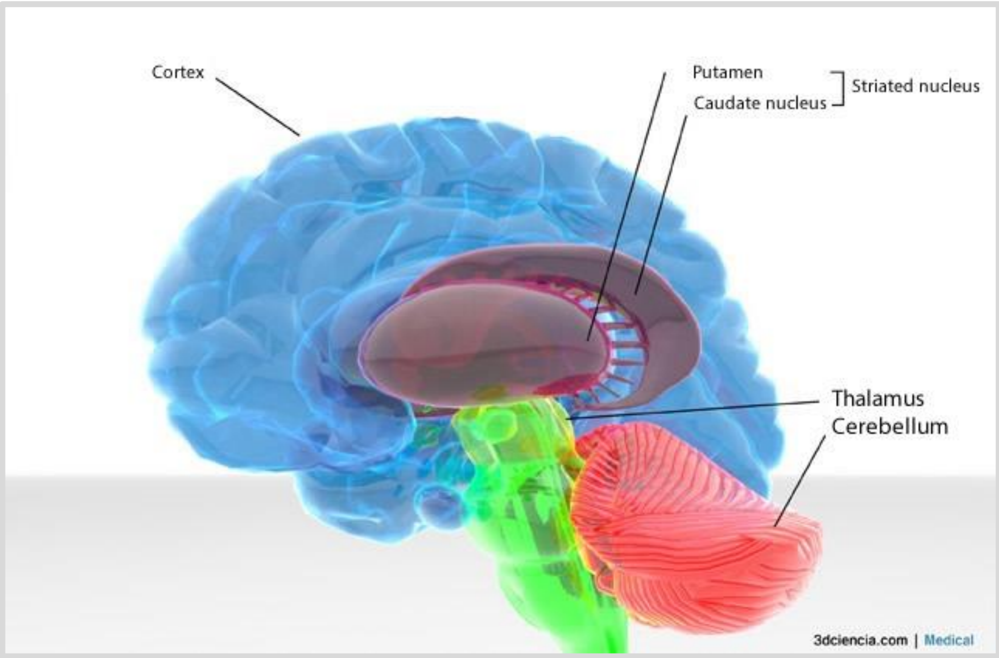
The basal ganglia have functions that have an impact on muscle actions. These "contain a repertoire of motor automatisms or engrams that, used in this context, would favor the intervention of relevant muscles" (Rigal, 1987, p.86).

Cerebellum

One of the organs that make up the encephalon. It is responsible for regulating muscle tone, balance (tonic), and facilitating movements through tonic pre-activation of the muscles (Rigal, 1987).

The cerebellum participates in **sensory-motor integration** and, by doing so, benefits motor control. The processes performed by this organ are, generally, not a target for consciousness, as they are actually subcortical actions.

Figure 3: Information processing sectors in the CNS



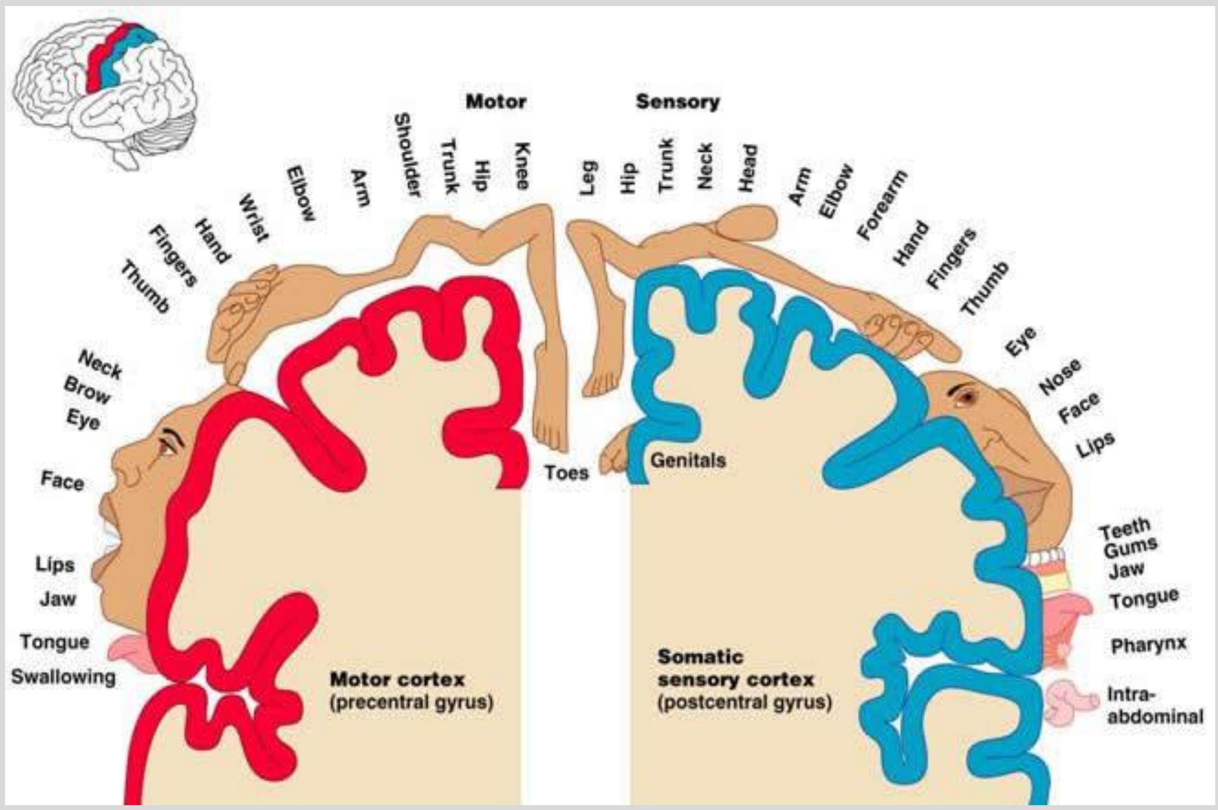
Source: [Untitled image showing information processing sectors in the CNS]. (n.d.). Retrieved from goo.gl/qCB9Uz

Prior to motor programming and execution, it is important to be aware that the cerebral cortex contains a representation of every part of the body. Information that was collected by the receptors and modified the status of the sensory neuron continues its journey to the control centers. It is then converted and accesses the cerebral cortex. This information finally reaches the cerebral cortex, to areas called **primary projection areas** which have become specialized to receive this information after being processed by different lateral geniculate nuclei of the thalamus.

Firstly, we can say that the size "assigned" to each part of the body in each of the primary projection areas depends on the density of the receptors belonging to that part of the body. Because of this, the idea of a small **sensory man or sensory "homunculus"** was created. Another reason that should be considered is that these areas map the distribution of receptors in the rest of our body, that is to say: to become aware of the inner and outer world and to build an object of perception, our brain has to map and/or organize the distribution of data collection systems that are on the periphery of our body. Our brain, somehow, is a small map that accounts for the distribution of receptors on the periphery and it is precisely this re-circulation of the information captured from the periphery by the structures of the CNS that allows us not only to be aware, of the outside world, but also to generate the phenomenon of **self-awareness**; in short, the ability to detect not only what we perceive but also what we do not perceive, that is, the inner world.

There are differences and similarities between the sensory homunculus and the motor homunculus: increased fine motor control and, therefore, more space to represent the motor homunculus, coincides with more space to represent the sensory cortical homunculus. In other words, wherever increased calibration and fine motor adjustment is needed, we also need a higher density of receptors, which is why we find a large similarity between the homunculi. The exception is the genital region, an area where we need a very high level of sensitivity. However, for reproduction functions, we don't need fine motor function (in this case there is no similarity between the sensory and motor homunculus). If we consider the functions of our hands, lips, tongue and even our eyes, the similarities between the homunculi are very significant.

Figure 4: Sensory and motor homunculus.

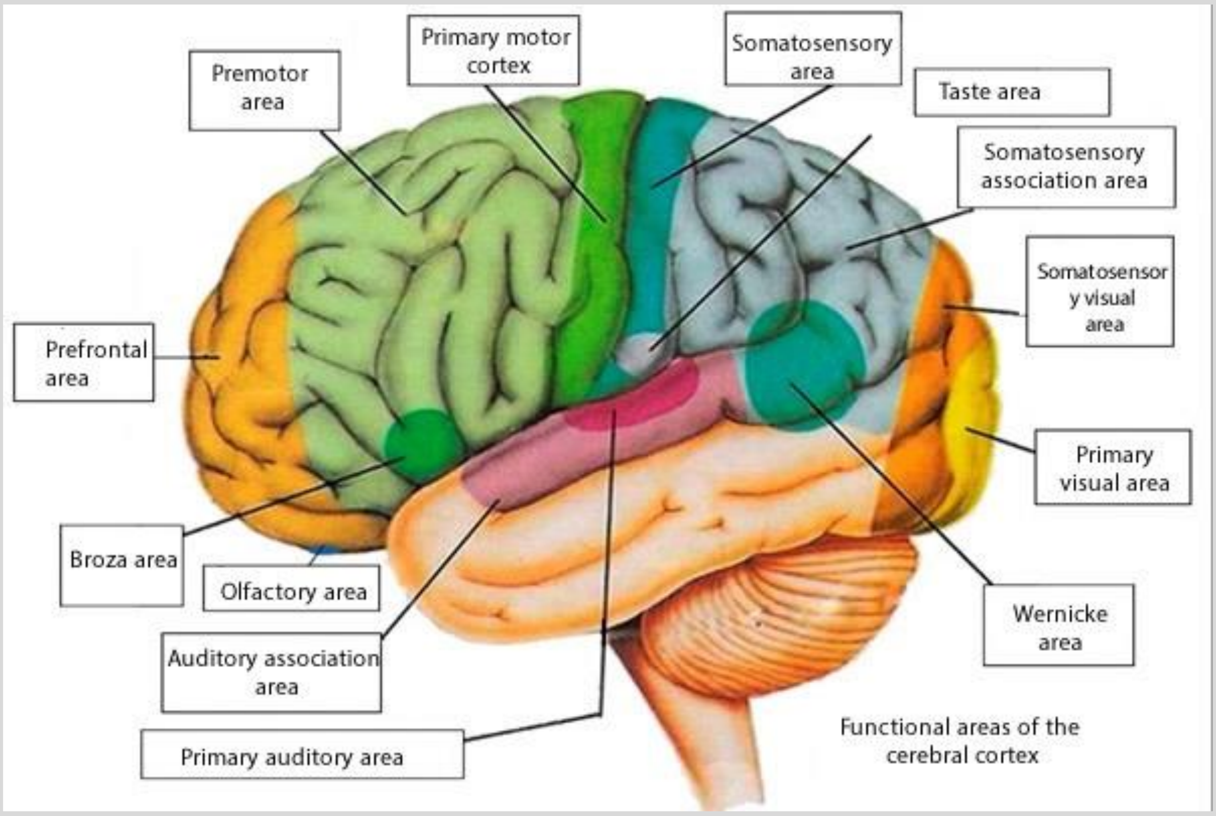


Source: [Untitled image showing the sensory and motor homunculus]. (n.d.). Retrieved from goo.gl/T48kzC

It is important to highlight the functions of two areas of the brain with an important role in neuromotor programming: one of which is the **pre-motor area or area 6**, and the other is **motor area or area 4.** It can be said that **area 4** is responsible for executing movements in different parts of the body. However, this doesn't mean under any circumstances that it acts alone. The primary motor cortex (1MC) "is the final station for converting the design into an executed movement" (Snell, 1999, p. 299). The 1MC does not create the movement's pattern, it executes it using the information it receives from structures such as basal ganglia, cerebellum, thalamus and the sensory cortex.

In order to explain the function of the 1MC, it can be compared to the keyboard of a piano. The keys represent the muscles and the movement of these depends on which keys the musician plays. Each muscle has a specific number of keys: the more motor units it has, the more keys it will have. The number of motor units that they innervate will depend on the precision of the movements to be performed (this will be seen in greater detail in the “motor homunculus” section). The **pre-motor area** does not have large Betz pyramidal cells, since it is not specifically responsible for executing movements. Instead, the pre-motor area stores motor programs that are produced from past motor experiences. The premotor cortex (PMC) receives multiple afferences from different nervous structures such as the thalamus and basal ganglia.

Figure 5: Brodmann areas in the motor cortex



Source: [Untitled image showing Brodmann areas in the motor cortex]. (n.d.). Retrieved from goo.gl/KEc0r9

Finally, with regards to the topic of **neuromotor programming**, because of its complexity, we suggest comparing it to a theater play. A **theater play** remains unchanged throughout the years. Its script, its scenes, the characters may change slightly. but if the main actors were essential, the play would not be able to continue when they grew old and died. It is exactly for this reason that the actors are changeable, they are temporary and it could be one or another. By contrast, the play itself, meaning the engram, is essential. In reality, the protagonists or actors are muscles and the act of programming decides which muscle performs in the play. If a muscle were vital and faced a problem such as an illness or a limitation, it would no longer be able to activate the engram. This would be a great disadvantage in evolutionary history. By contrast, it is an advantage that the muscle is changeable and the engram is not. **Programming** *refers to making decisions about featuring the invariant or the engram.* It is the composition of a sequence with specific actors who are the different muscles performing the movement. When the supplementary motor area gives the "go ahead" to start the action - that is to say, unblock or allow it to begin -, the motor program communicates or transmits to the primary motor cortex to begin executing sequential movements.

In this way, the excitatory information travels along the spine to different muscle groups so that the movement finally unfolds.

In the last stage of the motor act, when the motor program is ready, several copies are emitted to different sectors of the nervous system. This occurs even before the supplementary motor area stops prohibiting the movement and begins to unfold from the action of the primary motor cortex. The basal ganglia receive the information about the motor program before they start to execute the movement and our muscle tone starts to accumulate so that the quality of the movement can be sustained for an effective background (including the red nucleus that the gamma activity controls). In addition, the cerebellum receives a copy in order to regulate the motor act and compare the action in practice with the "ideal" model.

Figure 6: Motor programming as a theater play

Source: [Untitled image of motor programming as a theater play]. (n.d.). Retrieved from goo.gl/TK5nk7

After the action begins, the kinesthetic melody unfolds sequentially and its final manifestation is precisely the neuromuscular activation and the movement itself. In other words, the melody starts to play.

The deployment should include:

- Fluidity.
- Ensemble.
- Rhythm.
- Continuity.

Then we find that the prefrontal cortex (PFC) and other areas must take responsibility for the assemblage of the different components of the motor program. The deployment of the kinesthetic melody is supervised by the frontal cortex, which cannot be occupied with anything else. The more automatic we make the movement, the more the prefrontal cortex is free to make decisions regarding other programs (Di Santo, 2015).

Motor automatisms are what allow us to perform motor skills or actions effectively without having to think about them. This enables us to execute several motor skills simultaneously. A clear example is driving a car. When we have known how to drive for some time, we perform many of the motor actions, such as changing gears, using the clutch, looking in the mirror, etc., automatically and therefore subcortically.

There are voluntary movements which we don't have absolute control over that are inherent to the individual. Yet they have an impact, take for example, breathing or even a heartbeat. There is also a whole repertoire of movements called automatic or automatized movements that exist as a result of the repetition of voluntary movements. In this way, there is no need for attention or for the conscience to interfere.

The motor system can be divided into three levels:

1) **Upper level:** composed of areas of the motor cortex, areas 6-4-SMA.
2) **Intermediate level:** located at the brain stem; nerve tracts that innervate the spinal cord come from here.
3) **Lower level:** this is the spinal cord.

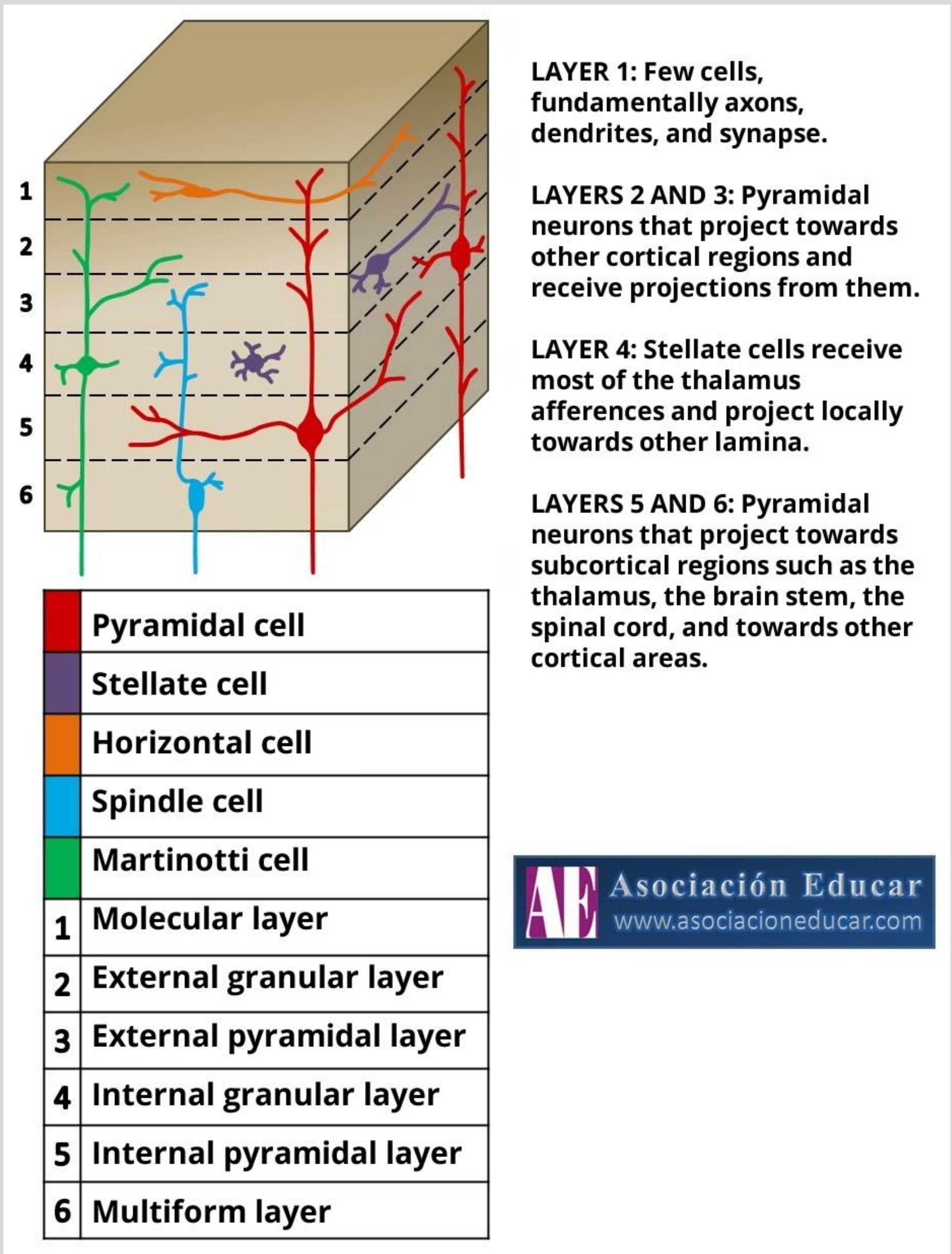
The first level is composed of the motor cortex and is responsible for planning movements and sending motor signals so that they may be executed in the motor neurons located in the spinal cord. It is also connected to the medulla oblongata in order to regulate control of head movements. The cortex can act on the spine directly or indirectly (corticospinal). After leaving the cortex, the corticospinal tract reaches the brain stem and, from here, the majority of fibers cross the mid line to the other side (lateral corticospinal tract). Only a small number of fibers that don't cross over go directly to the medulla. The majority of corticospinal fibers end up as interneurons, while a smaller number end up as motorneurons (Tamorri, 2004).

Going back to the cerebral cortex, which consists of a bundle of nervous fibers, neurons, neuroglia and blood vessels, we find the following types of nerve cells:

- **Pyramidal cells:** also called Betz cells, are the largest cells and can be found in the pre-central motor convolution. The vertices of these cells are oriented towards the cortex. From the apex of each cell, a dendrite extends towards the pia mater (internal layer of the meninges), where it emits collateral branches. The axon of these cells reaches the deeper cortical layers or enters the white matter of the brain as an association fiber.
- **Stellate cells:** a type of polygonal-shaped cell possessing multiple branching dendrites and a short axon. They communicate with neighboring neurons.
- **Fusiform cells:** found in the deepest layers of the cortex, these cells possess dendrites emerging from each of their poles. The inferior dendrite branches within the same cellular layer while the superior dendrite ascends towards the surface of the cerebral cortex. The axon reaches for the white matter, much like the pyramidal cells' axon.
- **Horizontal Cajal cells:** these are small, horizontally oriented cells found in the most superficial layers of the cortex. The axon of these cells runs parallel to the cerebral cortex, making contact with the dendrites of the large Betz cells. The dendrites arise from each end of this cell.

- **Martinotti cells:** these cells are present throughout all layers of the cortex and the axon is directed towards the pia mater of the cortex (Snell, 1999).

Figure 7: Layers and cells of the cerebral cortex



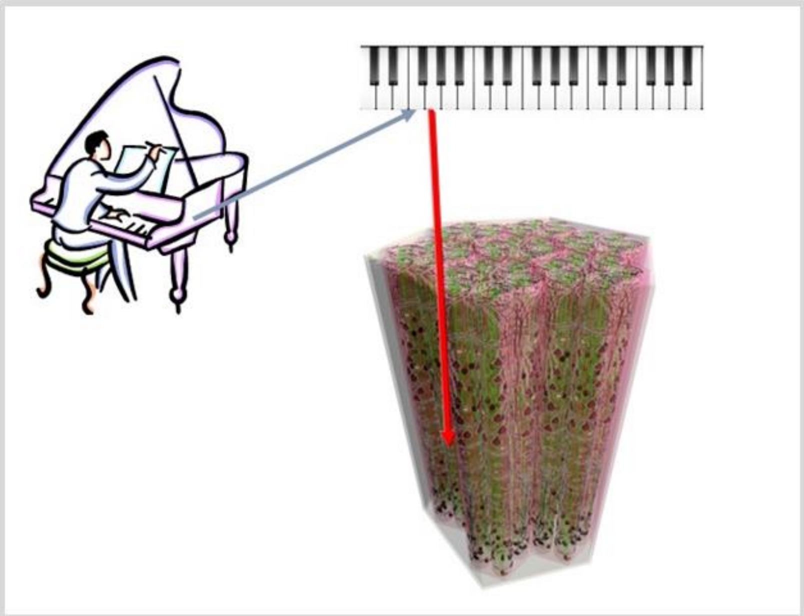
Source: [Untitled image showing layers and cells of the cerebral cortex]. (n.d.). Retrieved from https://goo.gl/hW2dHG

The kinesthetic melody was mentioned earlier as an example to understand the programming of the motor act and, among the musicians responsible for executing the melody, we referred to a particular pianist.

Taking this pianist as a reference, we can imagine that the keyboard is located in the 1MC, and that each one of its keys corresponds to a column. The motor act and, in particular, its harmonies are going to depend on the musician's continuity when hitting the right keys.

The number of columns of a muscle does not depend on its size, but rather on the quantity of motor units that neurally make it up and regulate it. Consequently, the greater the muscle's fine motor coordination, the greater the size in the 1MC and a greater number of columns (not to be confused with the aforementioned neuronal layers).

Figure 8: The pianist and motor execution



Source: Prepared by the author.

When discussing the quality or the harmony of the movement, these will depend on two aspects: **intramuscular coordination** and **intermuscular coordination.**

Following the example of the pianist, we can define these as:

- **Intramuscular coordination:** is the pianist's ability to play as many columns as possible that correspond to a muscle.

Considering the ideas of Tous Fajardo (1999), intramuscular coordination is the ability to **recruit motor units** of the same muscle, depending on the following characteristics:

    - *Spatial recruitment:* refers to the quantity of fibers recruited. This in turn can increase or decrease muscle tension, as required by the activity.

- *Temporal recruitment:* deals with the frequency with which the muscle fibers are active. Muscular tension can vary depending on how frequently fibers are recruited.
- *Motor unit synchronization:* "normally, motor units are activated asynchronously (so the movement is smooth), although it appears that (similar to what happens with weightlifters) when it comes to performing the maximum voluntary contraction, it is executed synchronously" (Fajardo, 1999, p.47).

- Intermuscular coordination: the pianist's ability to play the notes in perfect harmony while, at the same time, avoiding playing irrelevant columns.

From this we can understand that intermuscular coordination is our ability to **activate relevant muscle fibers,** not only in the agonist muscle, but also synergists. In turn, it is necessary for the pianist not to hit the columns corresponding to antagonist muscles, which limit the activity of the main column responsible for a movement.

It is vital that there be proper sequencing and synchronization in the different muscle groups, some of which are activated (agonist or synergist) and other inhibited (antagonist).

These coordination processes will depend on the capacity of inhibition or facilitation that the nervous system is able to exercise, which are related to different nerve reflexes (Di Santo, 2015).

Imagine that the pianist doesn't play the exact notes, but his finger reaches, not necessarily with skill, for keys corresponding to other muscles.

As a result, columns that do not correspond are activated. This phenomenon of irradiation and motor parasitosis accounts for a large part of motor performance failures.

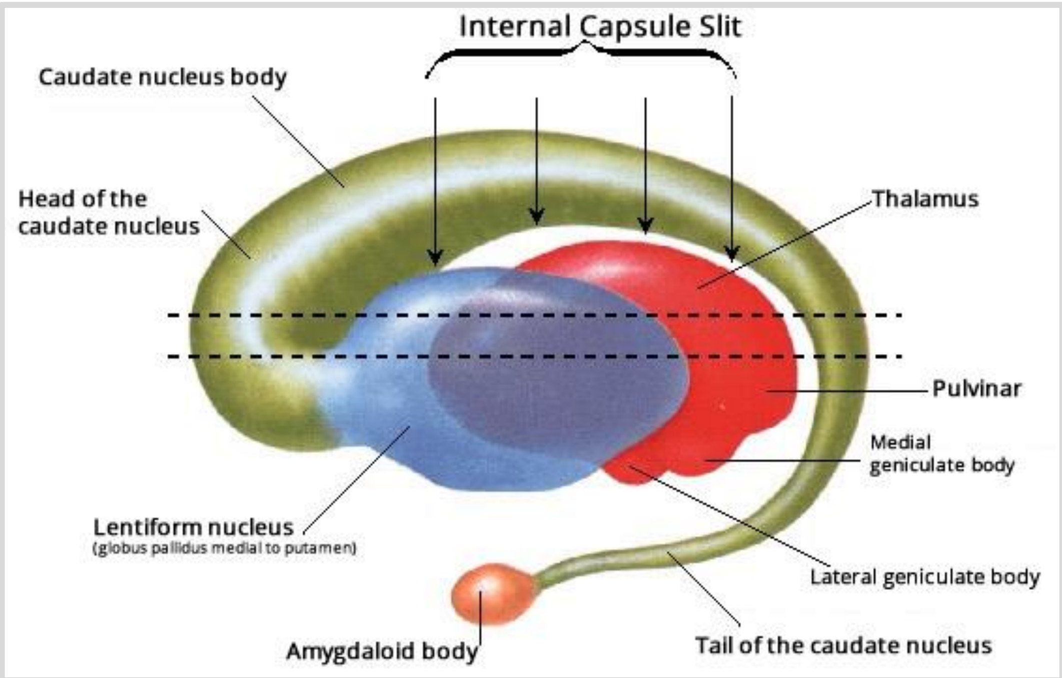
Figure 9: Parasitic activation

Source: [Untitled image of parasitic activation]. (n.d.). Retrieved from goo.gl/8mkCrd

Another important structure in the regulation of motor activity is **basal ganglia**, neural clusters located at the base of the brain (Rigal, 1987). These ganglia are comprised of the **dorsal striatum** (caudate nucleus and putamen), the **ventral striatum** (nucleus accumbens), the **globus pallidus,** the **subthalamic nucleus** and the **substantia nigra.** The red nucleus and the reticular formation are closely related to the ganglia. These are connected to various organs in the nervous system, and their function is centered around motor function regulation

Caudate nucleus: indirectly involved in modulating movement. It signals the frontal lobe when something is not going well and something must be done about it.
Putamen: in charge of precise voluntary movements. It also has an important role in operating conditioning.
Striate body: regulates instinctive movements, muscle tone and sexual nature and behavior. Inhibits the activity of the cerebral cortex and receives impulses from the thalamus.
Globus pallidus: transmits information from the putamen and the caudate to the thalamus.
Subthalamic nucleus: receives afferences from the caudate and putamen, participates in motor control regulation and is associated to the control of involuntary movement.
Substantia nigra: a micro regulator of the striate body via its neurotransmittor (dopamine) (Asociación Educar, 2015).

Figure 10: Basal Ganglia



Source: [Untitled image showing basal ganglia]. (n.d.). Retrieved from goo.gl/W1lmtO

If the ganglia are in fact closely related to motor functions, they have no direct connection with spinal cord motorneurons. Instead, they receive afferent information from the cerebral cortex and send information to the same cortex via afferent pathways. Prior to this, these efferences relay through the thalamus. The striatum is the entry point for information originating from the cerebral cortex towards the basal ganglia. The afferences will arrive in different sectors of the striatum, depending on the cortical sector from which they originated. For example: the motor cortex sends afferences to the putamen so that it can regulate movements and in turn, the caudate receives information about cognitive processes and ocular movements.

The signals coming from the motor cortex to the striate body belong to the corticostriatal pathway and arise from the motor cortex, premotor cortex and supplementary motor area.

Once the information enters the basal ganglia, it heads towards the thalamus via the substantia nigra and the inner side of the globus pallidus through two pathways. These two pathways are referred to as the **direct pathway** and the **indirect pathway.**

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