Module 1. The Logic of Motor Functions and Decision-Making

Unit 1.1 Thinking about movement

1.1.1 Introductory concepts

The first aspect of the central processing of information is what we call motor logic and decision-making. Does motor logic exist? Do athletes think before taking action? And if they do, what kind of thought process takes place, compared with the normal thought processes we carry out in other situations?

We understand that if thought occurs, it is in the form of **probabilistic inductive inferences,** where we do not have time to translate perceptual information into words; that is to say, perceptual data forms the basis for reasoning without the possibility of being translated into words. But these elements form part of an inference process that allows us to select between the different motor programs available to us. If athletes had to transform all of their perceptual information into words in the midst of a fast game-situation, they would lose (for reasons of time) the possibility of selecting the correct motor program. We reason based on perceptual information that we do not have time to translate into words, but this reasoning determines the quality of the motor program that we select in different game situations, as can be found in any kind of sport, even in those that are based on times or records. This dimension of motor logic mainly activates our **frontal lobe**, and above all the anterior sections that permit decision-making processes. Motor logic and decision-making are some of the most important aspects around which we should center our teaching methods. Human movement and motor learning are a tool to improve the quality of general thinking processes, in particular motor logic and decision-making.

We can make a distinction between what we call "physical education through movement" and "physical education for movement".

When we refer to **education through movement**, we want our students or athletes to reason through alternative motor skills to resolve situations. The cybernetic model dealing with education through movement dispenses with this reasoning step, simply emphasizing the reproduction of what was demonstrated and leaving as the only decision-making point the choice to initiate or not initiate the movement in question.

When the movement is reproduced in the temporal, occipital and parietal areas, the

information passes to the premotor cortex area, or area 6 in order to prepare for the movement. This is where the leading elements of the movement are decided, but this is not a selection between alternative motor programs, since the only motor program that should be carried out is the same one I am being shown.

When we talk about **education for movement,** the idea is that we have alternative motor programs that we can choose between. To perform correctly, I should use reason, and we take this to be the most illuminating point, the heart of what education for movement means, when I am training my capacity to choose between alternative motor programs and not solely the capacity to plan and make a decision.

The frontal superior motor areas make demands of us that imply the need for motor reasoning and decision-making. Not all of the areas of the cerebral cortex participate equally with respect to the objective.

There are four large neural correlates in the process of decision-making: an **anterior pre-frontal** sector, fundamentally ventromedial and orbitofrontal, which is related to decisions of the large neural pathways; a **dorsolateral** sector that is associated with the means of transit along these pathways that we have chosen; finally, there are two very important sectors that act as protagonists of the action: the **psycho-motor area** (area 6) and the **pre-motor area**, which together decide if the action will be carried out or not.

1.1.2 Representing and thinking. Differences

While the neural correlates of the **decision-making process** are fairly well identified, in the human universe it is not so easy to determine if we are dealing with a **serial or parallel phenomenon**, as it could just as easily be either one (whether it is serial, parallel or both does not imply any special consequence for teaching methods). We understand that decisions are implicit in every instant, not only in sports but in our daily life: even the most basic organisms make decisions. At the level of motor skills, the phenomenon can be witnessed at every moment, only second in prevalence to that of perception. The temporal processes can be varied: they can span from seconds to months and even years and that imply, inevitably, the intervention of other processes, above all emotional ones.

Let's take the example of daily decisions: How many of these are rational? If they are rational, are they the best ones? Reason and emotion don't always seem to operate in the same manner in every case; nevertheless, while evaluating seems to depend on different correlates, triggering the decision seems to have similar correlates.

Representing and Thinking

These two actions are not the same thing. We use representations throughout the day. Often, the images are unceasing, they flow beyond our control; all the same, this does not imply thought. Thinking is something more profound and complex, although it can also be supported by images. **Representing** implies simply generating and sustaining an image, which is something we do regularly throughout our lives and that, applied to movement, we can train like a skill. **Thinking**, on the other hand, implies a higher level of processing, implying the creation of a strategy that can do without images. In short, making detours without trying to reach a particular end.

With respect to human movement, representing and thinking are two distinct things.

Representing in human movement implies generating and sustaining images without weighing alternatives and consequences. **Thinking in human movement** implies, with or without clear images, considering and weighing options and their effects. Often, the majority of movements are so rapid that we cannot generate or sustain clear images, much less enumerate, classify and evaluate options. Nor is it correct to think during the execution of movement, because this can produce the phenomenon of **analysis paralysis**: when we attempt to generate and sustain images or weigh options at the same time that we should be controlling rapid and complex movements. Thus the problem is not imagining or thinking, but when and how to do it.

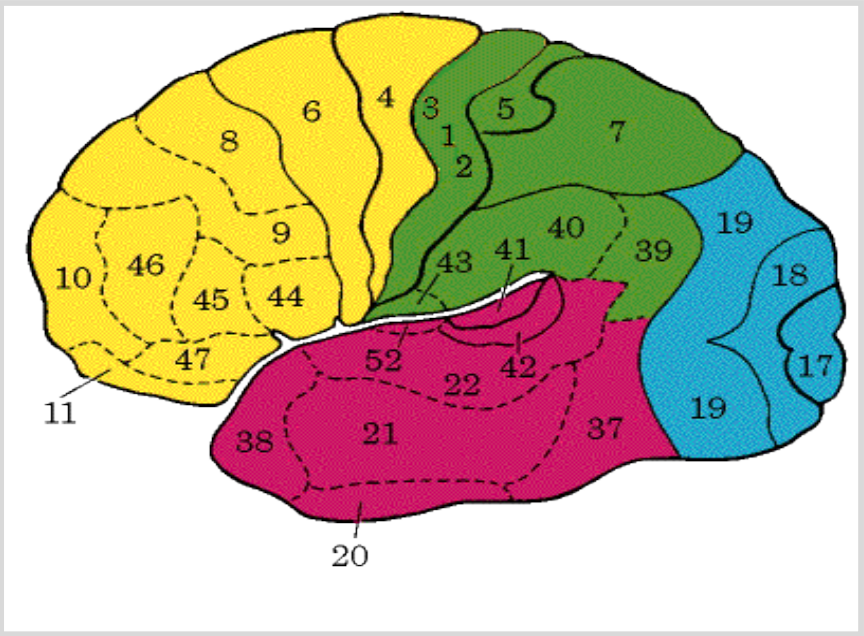
1.1.3 The three most common dimensions of decision-making

These three dimensions are:

- Technique.
- Tactics.
- Strategy.

When we speak of decisions inherent to **technique**, these are fundamentally based on the action of the pre-motor cortex. The decision on the technique to be applied corresponds to area 6 which determines what muscle and fascicle groups are appropriate for a given movement. This moment is crucial for subsequent success in sports. If the athlete is not correctly trained and incapable of correctly deciding which muscles to use for a given action, no matter how correct we are with our tactical intentions, the whole process runs the risk of failure or of poor execution.

Figure 1: Brodman Areas



Source: University of Michigan (n.d.) accessed from http://goo.gl/z5075d

The more efficient the choice of the correct muscle groups to employ, that is to say, the more careful this choice is, the better the entire tactical development process (which is strictly pre-frontal) is bound to be.

When we speak of **tactics,** we are referring to the performance all of those physical processes previously selected by the pre-frontal cortex when faced with a more or less fluctuating context, varying according to the obstacles that might arise. At this point, athletes should choose the most appropriate tactical intentions that will help themselves or their team to accomplish the goals outlined in the strategies. Here, not only is our capacity to call on motor units or specific muscle groups important, but also the actions being taken by our opponents to achieve their own objectives. In many cases, tactical decisions are immediate in nature.

To discuss **strategy**, we have to understand it as a plan to achieve an objective. We need to address the various aspects that will influence the pursuit of said plan. In the case of athletic activities, each member of a basketball team will, for example, come up with their own strategies towards achieving a common objective.

To make the best possible decisions, every member should be aware of all the aspects of the competition as a whole, and on this basis develop a strategic plan to contribute to the group, or to themselves, in order to achieve the objective established at the beginning. This kind of planning, in general, is not urgent in nature.

It is not only the athlete who should be making decisions about the competition, but also the coaching staff and physical trainers. For example, take the case of a tennis coach who detects an error in his players forehand drive, thus weakening his performance.

The coach may decide to automatically begin an adjustment process targeting the error. But to do this, he should consider:

- Whether the error represents a risk of injury for the competitor and whether there are no upcoming game dates, as the very adjustment process itself could affect the player's performance.
- Whether the athlete can maintain the same wrong motor pattern until a competition-free period allows them time to work on it.

Is the same neural correlate operating in all of these cases? Or should we assume different areas and functions? What is the real difference between technique, tactics and strategy? Are there similar approaches to each? Does it depend on age? Does context or genetics have an influence? How can we train them?

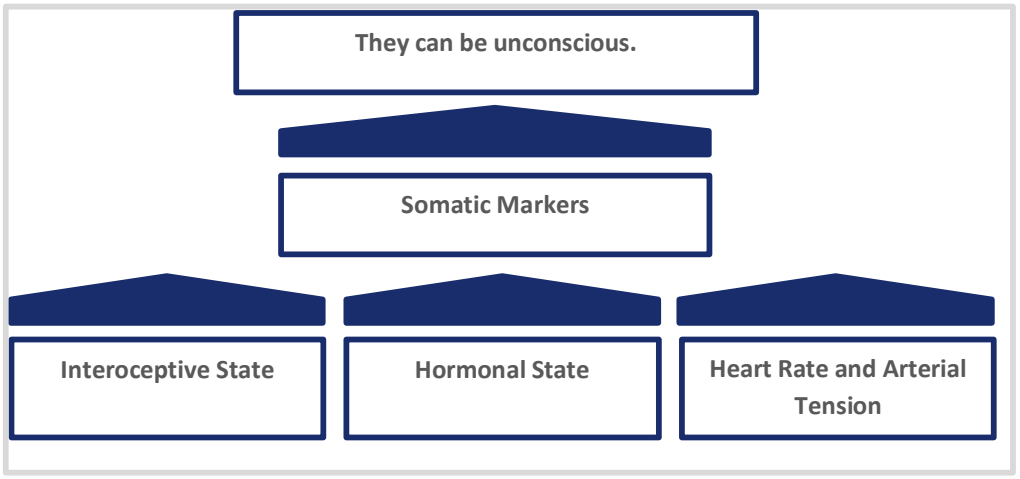
1.1.4 The influence of Antonio Damasio

Given his approach to understanding the neurobiology of the human decision-making process, Antonio Damasio is among the most trusted sources on the subject. In his book *Descartes' Error,* Damasio formulates the **somatic marker hypothesis.**

The somatic marker hypothesis is, among other things, a neurological theory of decision-making that details the neural processes in the brain when faced with a decision, highlighting the key role of peripheral body signals in decision-making.

Proprioceptive and visceroceptive body mapping not only contribute to our emotions, but also to the performance of complex social behaviors. Visceral responses "mark" potential choices as advantageous or disadvantageous (Damasio, 2006, pág. 191).

Figure 2: Decisions and Somatic Markers. They condition cognitive processes during decision-making



Source: prepared by the author.

Visceral decisions are those decisions that we make based on our first impression of a given object or situation. They are not rational and are generated by the impact of a particular phenomenon.

Sensing a stimulus's effect on us (a given emotion) triggers a process of active interoception that can lead us to make a decision. Visceral responses mark or anticipate the advantages or disadvantages of possible decisions. The brain possesses a system that transforms external stimuli into visceral internal changes that perceive their own relevance. Here we find evidence of the relationship between interoception and the ventromedial cortex.

One way or another, emotions modify the interoceptive state of hormones and physiological values. Albeit unconsciously, these markers condition decision-making processes (Di Santo, 2015).

In his book, Damasio mentions the case of Phineas Gage, a railway worker in Vermont, in the United States. After a workplace accident (an explosion) an iron bar passed through the base of his skull, entering through the left cheek and reaching the frontal lobe of his brain. The injury did not produce a loss of consciousness or problems with motor skills. In approximately two months he had almost completely recovered. His speech was also unaffected, but he suffered behavioral changes, becoming emotionally unstable where he was once a responsible person (Damasio, 2006, pág. 41).

Figure 3: Representation of Phineas Gage's Accident

Source: Escuela con cerebro (n.d.). Accessed from https://goo.gl/ShqkUG

The author examines other cases of pre-frontal cortex injuries resulting in similar behavior. Based on the analysis of these cases, Damasio connects this kind of injury with difficulties in decision-making processes connected with emotions and feelings. The author explains that human reason does not depend on a single brain center, but rather on various systems in continuous cooperation (Damasio, 2006).

The author further explains that in one single area of the brain, there are nerves responsible for disparate functions, such as decision-making, emotional processing and holding a mental image. Mental phenomena can be understood by first looking at the interaction of man with his environment. All individuals who interact with their environment have the ability to sense, and with these sensations they create images, process those images and have their behavior influenced within their environment (Damasio, 2006).

Unit 1.2 The neurobiology of decisions

1.2.1 Key cerebral regions and their interrelations

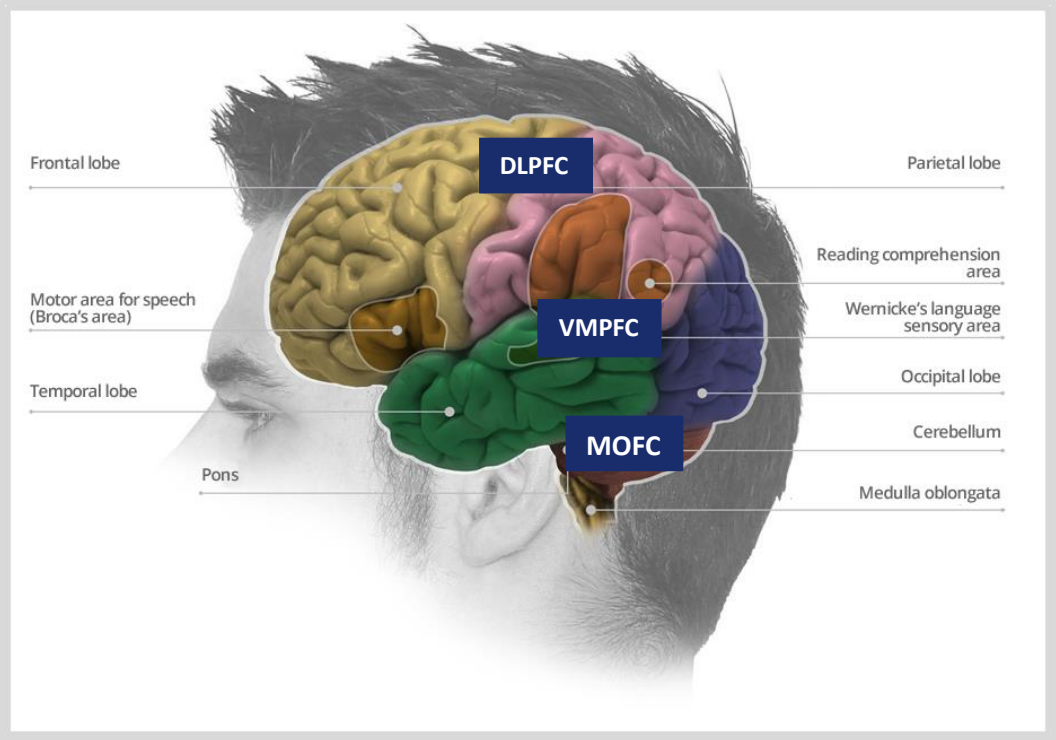
Any neurological model of decision-making needs to answer three crucial questions:

- How are subjective assessments of options learned, stored and represented?
- How is the decision implemented in the motor circuit?
- How is the action later selected from among the options?

We will attempt to answer these questions, but first it is crucial to clarify which regions are involved in decision-making. Each region carries out different roles, and not only in the three big moments of the decision-making process, but also in cases of health and illness, because a healthy person doesn't use the same systems as someone who suffers from an illness. These five regions are:

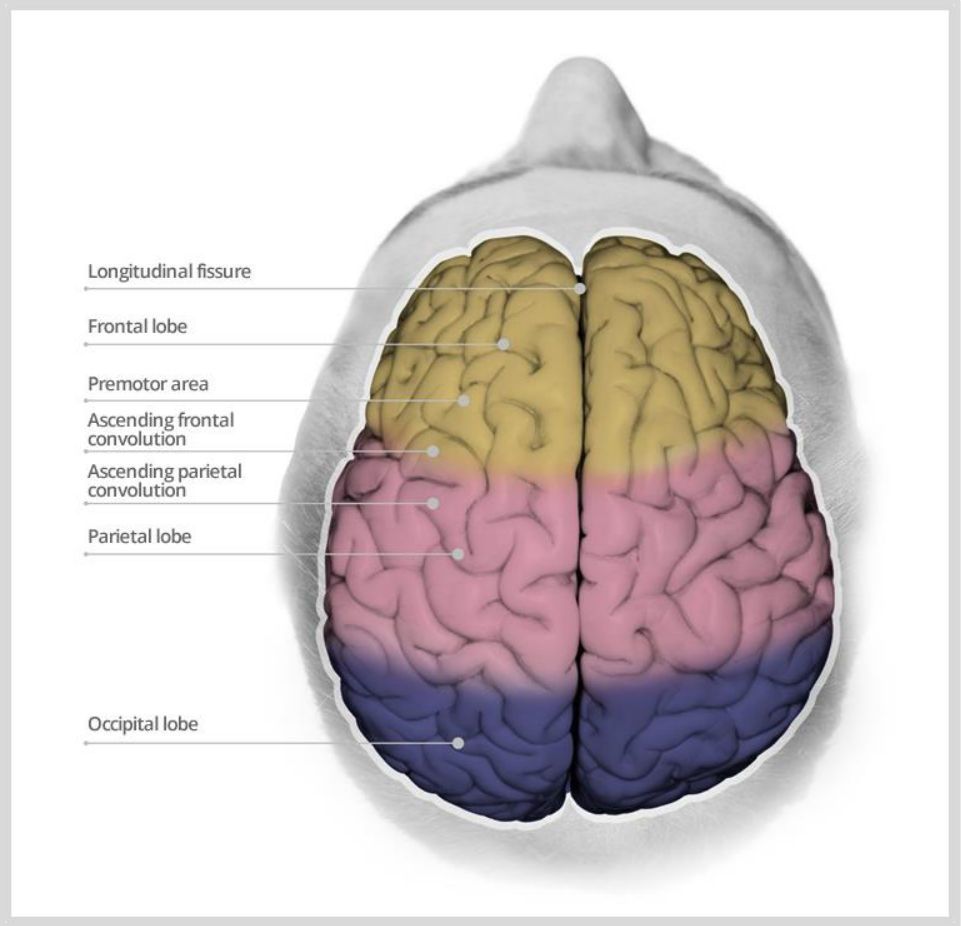
- VMPFC (ventromedial prefrontal cortex).
- MOFC (medial orbitofrontal cortex).
- DLPFC (dorsolateral prefrontal cortex).
- AN (amygdalar nucleus).
- CS (Corpus striatum).

Figure 4: General Location



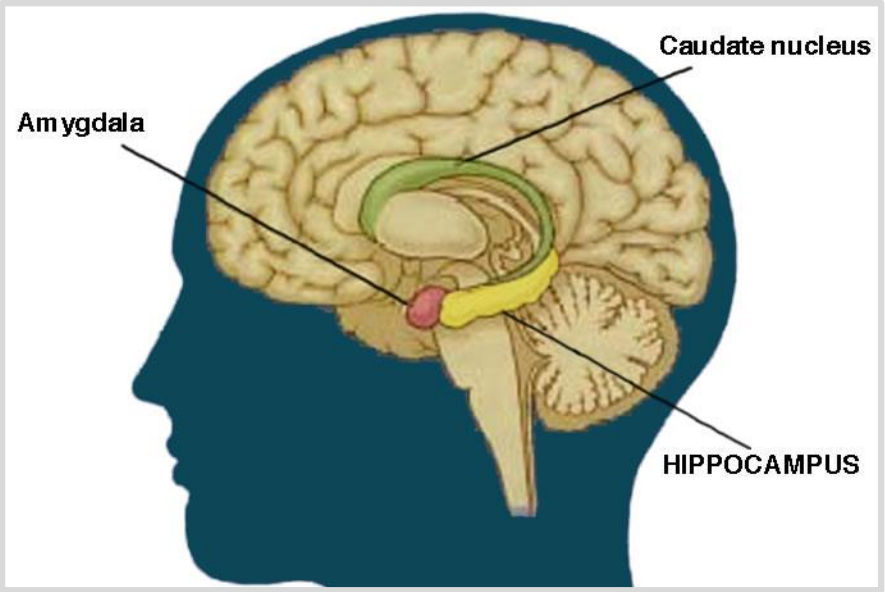
Source: [Untitled image on deformation] 2010. Adapted from Investigacion de alzheimer, Accessed from http://goo.gl/B3iCpp

Figure 5: General Location



Source: [Untitled image on deformation] 2010. Adapted from Investigacion de alzheimer. Accessed from http://goo.gl/B3iCpp

Figure 6: Hippocampus



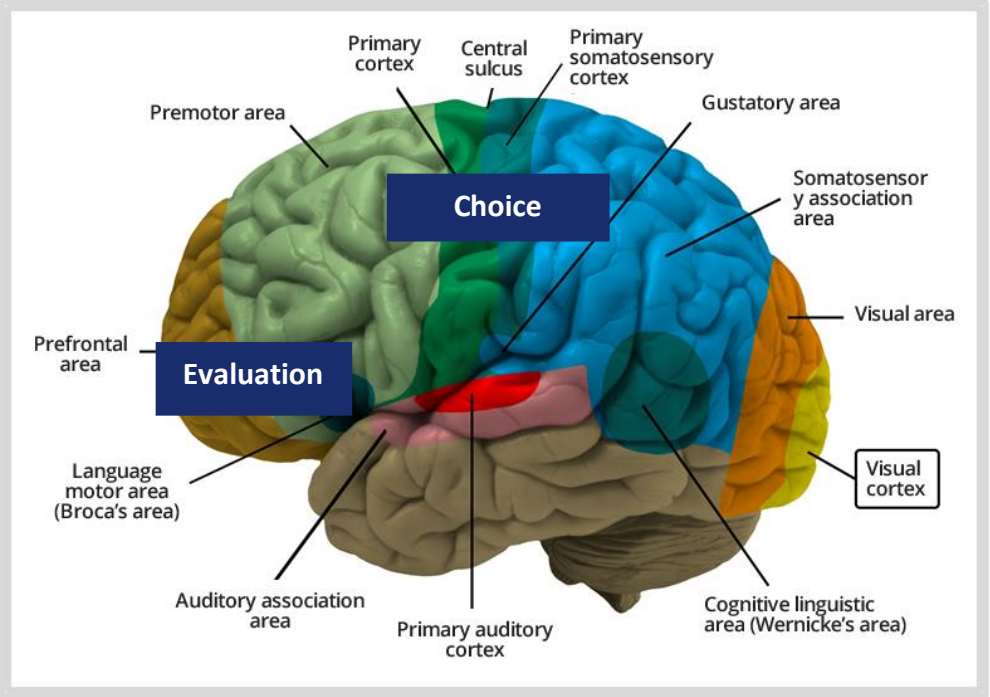
Source: Neuropsiques (n.d.). Taken from http://goo.gl/Q3Rkb6

Decision-making has three clear moments. It involves three sequential steps that happen not only in sports, but in everyday life:

- **Evaluation**: also known as multi-behavioral assessment, this is implemented by the **ventromedial prefrontal cortex** in association with the striatum.
- **Choice:** this is implemented in the **prefrontal lateral cortex** and the **parietal areas** and implies the same option.
- **Action:** this is the final implementation that triggers the movement. Its correlates are the least known.

The **amygdalar nucleus** processes somatic states based on emotional events and processes fear.

Figure 7: Parts of the Cortex Involved in Evaluation and Choice



Source: Adapted from Psicobiología del género homo, 2015. Taken from http://goo.gl/qfMwss

The neuro-physiological model hopes to explain how alternatives are generated and how we ultimately make choices. This process is made up of the following steps:

- **Generate and evaluate options:** these actions are conditioned by the action of the **ventromedial cortex**.
- **The act of choosing:** the **lateral and parietal prefrontal cortex** are responsible for carrying out this action.
- **Implementation of the option.**
- **Analysis of the process**: there is no single processing center for this step, depending instead on multiple areas.

1.2.2 Stages of decision-making and their neural correlates

Stage I: Evaluation or Assessment

Decision-making markers integrate the various dimensions of an option into a single subjective value and then the best option is chosen: this is the **subjective consideration of value.** The VMPFC (ventromedial prefrontal cortex) and the striatum participate in this process.

VMPFC (ventromedial prefrontal cortex)

It has been observed that in primates the differential neurons fire in three different situations. The correlates in human beings are not exactly the same as in monkeys, although they are very similar. These three situations are:

1) ***Subjective evaluation:*** this acts to decide the usefulness of different offers.
2) ***Testing****:* the differential neurons activate when testing options.
3) ***Choice:*** these nerve cells are stimulated when a decision is being made.

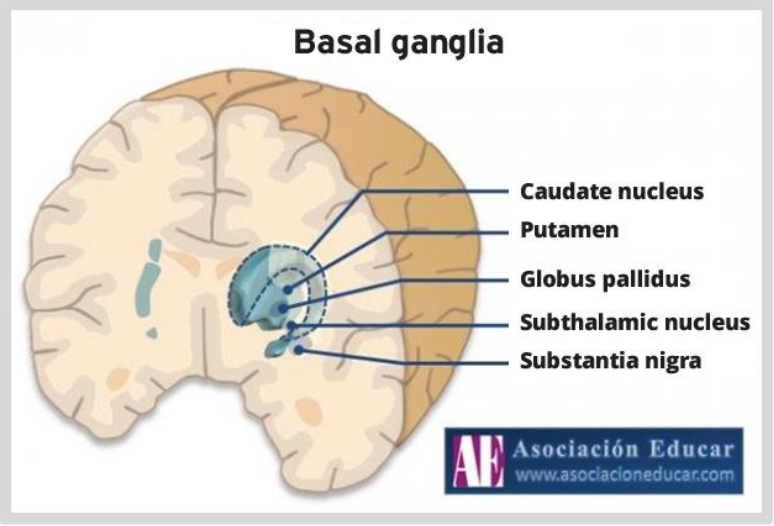
The Importance of the VMPFC

Injuries to the ventromedial prefrontal cortex can cause profound changes in the capacity to make decisions in the following contexts:

- Personal.
- Social.
- Emotional.
- Athletic.
- Financial.

The essential function of the VMPFC is to link the control of the visceral and proprioceptive state with decision-making and emotional processes (operating as a nexus). Injuries to the VMPFC profoundly alter the general mechanism for decision-making and practically all aspects involving decisions. The ventromedial prefrontal cortex and the medial orbitofrontal cortex promote somatic states based on internal emotional events, like memories and cognition. The act of weighing the consequences of possible decisions depends on the prefrontal cortex, but considering the possible options depends on the amygdala.

Figure 8: Striatum or Corpus Striatum



Source: Asociación Educar (n.d.). Accessed from http://goo.gl/gExW3M

Striatum or Corpus Striatum

The striatum shares key functions in the processing of automatic movements, that is, those decisions that we do not think through or evaluate. It also represents the subjective values of options. We find here three categories of neurons that act in sequence:

1) **Neurons that assess action.**
2) **Neurons that choose.**
3) **Neurons that execute the choice**, which produce a categorical response when a particular action is selected.

The latter types are activated later, at the moment of reward. The number of functions carried out by the corpus striatum and its key role in automatic motions are noteworthy. One common mechanism that underlies both the VMPFC and the striatum is the action of **dopamine**. The dopaminergic neurons in the midbrain project both to the VMPFC and the striatum. Past experience is the most important source of information for subjective assessment, and this information has direct repercussions on the assessment of options, influencing similar future situations. In practical terms, the striatum plays a crucial role as a connector: it connects the peripheral somatic signals with cells that produce peptides such as dopamine, serotonin, noradrenaline and acetylcholine. The connection is: **periphery-thalamus-striatum-peptide producing cells.** We should remember that dopamine is a principal actor in reward mechanisms and is a hormone that directly affects the desire for repetition.

Stage II: Choice

This stage implies choosing an option based on a particular value, later to pass on to the motor cortex for implementation. This stage involves: the parietal frontal cortex, the lateral parietal cortex, the premotor cortex, the supplementary motor area and the motor cortex, thus indicating a strategy based on numerous actors.

Each system enjoys **exclusive evaluation**; in that way, the different systems code the same value for the same actions in different ways. If they code different values for the same actions, these differences can lead to diverging conclusions about what action should be followed, above all at the level of relative consequences, if there are injuries or brain dysfunctions.

If one of the areas responsible for selecting the best option is injured, this affects the possibility of coding values of the options that are being weighed. Though it may seem odd, drug-users and non drug-users, for example, do not use the same neural correlates. Non drug-users tend to use two cortices: the VMPFC and the DLPFC (above all the VM); by

contrast, drug-users principally employ the right MOFC, while people with bipolar disorder tend to activate the temporal and occipital lobe.

A key study (Ernst, 2002) on correlates in the decision-making process shows the differences between people who are addicts and those who are not.
Non-addicts activate:

1) Medial orbitofrontal cortex.
2) Ventromedial prefrontal cortex.
3) Anterior cingulate cortex.
4) Dorsolateral prefrontal cortex.
5) Insular lobe.
6) Inferior parietal cortex.

Meanwhile, people affected by the use of drugs, in contrast, employ different areas:

1) Less activity in the right medial orbitofrontal cortex.
2) Less activity in the right dorsolateral prefrontal cortex.
3) Less activity in the ventromedial prefrontal cortex.
4) Less frontal superior activity, which forms part of the dorsolateral cortex.

1.2.3 Decisions and emotional states

Damasio cites three theories (Damasio, 2006) about the role of emotions in the decision-making process:

- **Risk as an emotion:**
  - The cortex does not intervene in situations where risk is involved.
  - Fear, threats or anxiety influence decisions.
  - Assessment is emotional.

- **Anticipatory emotion:**
  - The emotion occurs when we anticipate something, not during the decision itself.
  - When we anticipate responses, we experience emotions.

- **Strength of the emotional network:**
  - The network of emotional responses predicts when a consumer will select a product.

1.2.4 Three system dimensions according to decisions

Three clear and distinct possibilities emerge:

- **Pavlovian systems**: these systems include the study of simple alignments between stimuli and responses.
- **Habituation systems**: these assume relations between stimuli and responses that do not adapt rapidly to changes, to contingencies or to diminished rewards.
- **Goal directed systems:** the relations between stimuli and responses adapt rapidly to contingencies and to diminished rewards.

Faced with these three possibilities, we can ask ourselves: Is there any possibility beyond this last model? Can the theory of dynamic systems contribute any distinguishing aspects?

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