Module 3. Neuromotor Programming

Unit 3.1 Programming

3.1.1 Introduction and historical background

When considering the Soviet line of research, the presence of **Nikolai Bernstein** casts a long shadow. We are greatly indebted to his research on human movement, from which we now have such notions as redundancy and everything related to the degrees of freedom problem.

In the mid-20th century, Bernstein took part in the debate around repetition in human movement and the discussion as to whether human volition surrenders control during repetitive movements. At that time, it was debated whether in the act of marching (military) volition surrendered all motor control. From these debates arose, for example, the goose step, the march wherein the pendulum or recovery phase has voluntary control in order to increase hip flexion.

The goose step, which was later adopted by the German military, was a march that at all times ensured that control or volition was regulating human movement and, for the same reason, soldiers were unable to relinquish control over any aspect of motor functioning. Thus it was incorporated into the military and the parades of the time.

Mark Latash, the translator of Bernstein's work from Russian to English, concentrated the larger part of his research on the issue of repetition in human movement. He believed that no matter whether a movement is repeated an infinite number of times, no single movement is the same; there is always intrinsic variability and that variability brings with it consequences for teaching methods.

Vladimir Lenin, philosopher and political statesman, was the first to establish under his direction in 1922 Europe's very first center for the study of human movement (also where Bernstein studied). Lenin believed that a large part of the economy depended on the analysis of workers' movements in order to save energy and avoid injury from overuse. Thus he proposed a program that would offset the consequences of anti-ergonomic, asymmetrical and unbalanced movements in favor of more economical movements. In that way, for Lenin, the more efficiently and safely workers could perform their jobs without suffering adverse health effects, the more productive and economically prosperous the nation would be.

We cite the aforementioned example because we feel that it would be an excellent idea to implement today, where a large part of the population's problems, creating additional costs for the State, are due to a lack of movement or poor movement among the population. We are currently living in a time when human movement needs to be extensively studied again. This is the case not just in sports, but also in order to design strategies and policies in order to avoid negative consequences stemming from lack of movement or improper movement. Likewise, the study of movement would contribute to designing objectives for improving quality of life as well as economic growth.

In the mid-19th century, John Hughlings Jackson also contributed his own studies to the research on the functional character of human movement. He is known for his famous phrase: "the central nervous system knows nothing of muscles, it only knows about movements".

Figure 1: Landmark Figures in the Study of Human Movement in the 19th, 20th and 21st Centuries

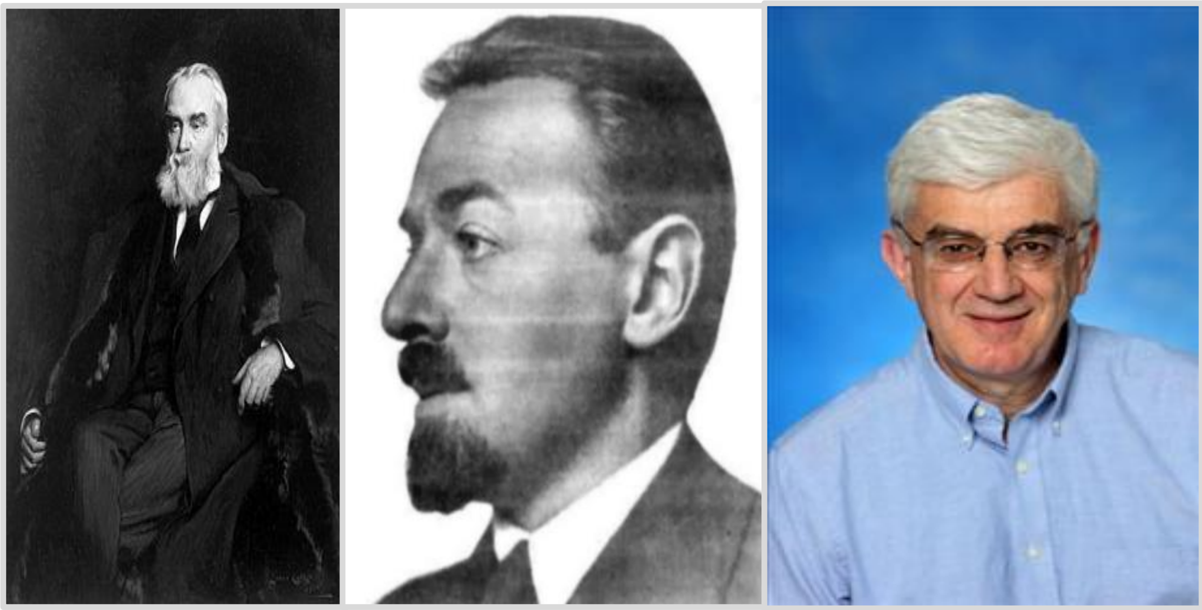


Fig. 1. Above: John Hughlings Jackson. Taken from https://goo.gl/1a0OJt
Bottom left: Nikolai Bernstein. Taken from http://goo.gl/lfcXLT
Bottom right: Mark Latash. Taken from http://goo.gl/9QYYyV

This concept was very important for understanding that, through the articulation of movements, humans develop adaptive solutions to complex environments wherein the muscle is contingent on movement and not movement on the muscle.

This functional aspect of human movement was very important since it marked a trend at the time.

Having completed this quick historical overview, we will now analyze how a specific "nerve-muscle" sequence is constructed, the same sequence that makes movement possible.

Movement, in the end, is a sequence of muscular actions; in brief, it is the grouping of sub-groups of muscular actions occurring so that bone segments will move.

This ties back in to some very interesting contemporary discussions and allows us to see how scholars of physiological movement have fiercely debated these topics. As previously mentioned, it was Nikolai Bernstein who raised the issues we are discussing here. Bernstein was later sent into exile by Stalin, leaving a Russia then dominated by **Pavlov's paradigm**, a more convenient model for the time since the concept of "man" was reduced to the idea of a being only capable of producing and consuming. **Nikolai Bernstein** understood that by researching movement one could gain insight into the human brain, and that when the neuroscience of volition is studied, the neuroscience of motor action is also implicated. Among other things, Bernstein espoused that movement was the means for understanding mankind. The aforementioned argument leads us directly to the issue of neuromotor programming.

Do we have movements stored in our brain, or do we have to construct them? Is each movement stored in the brain or is there only partial storage, presupposing a later decision-making and fine-tuning task? In Russia, the two paradigms competed against each other for dominance. On the one side, the traditional Pavlovian position supported the idea that movements are symmetrical and are repeated as such; on the other side, Bernstein disagreed, arguing that repetition belonged to lower-level organizing, and that if the physiological complexity were greater, repetition of the movements would prove impossible.

In that sense, Bernstein maintained that the physiological complexity of the human body did not allow for movements to be repeated. He argued that only basic organisms repeated actions and that *non-repetition* was, in fact, a highly important strategy for survival. For the sake of survival, these strategies relate directly to motor variability. Who repeats movements? Predators show the highest degree of motor variability, while prey represent organisms with the lowest level of variability.

Human beings do not repeat movements. Unicellular, basic, low-complexity organisms repeat movements. The greater the complexity, the less possibility there is for repetition; therefore, non-repetition is a biological advantage for survival. Each movement in human beings varies, and the more subtle the variation, the greater the chance of survival.

On the other hand, Pavlovian thought maintained that movement was repeatable. In this respect, Pavlov's concept was perfectly aligned with the dominant political ideology in

Russia at the time. That is, this idea was completely in line with the aspirations of Lenin and Stalin.

In our own case, we are more inclined to accept Bernstein's theory. The underlying question is: What would be necessary in order to not rely on repetition? We are specifically wondering here about the biological conditions allowing for unlimited variability. Bernstein justified the concept of variability based on the invariance of some other aspect. In order for variation to take place, something should remain unchanged: in short, there must be something stable that enables said variation.

3.1.2 The concept of programming

As mentioned before, Nikolai Alexandrovich Bernstein performed his first scientific study in 1922, when he and other researchers were first invited to study movement at the Central Institute of Labor in Moscow. The purpose of the study was to optimize productivity, basing their analysis on observations of the act of cutting metal with a chisel. The **cyclographic techniques** used in the study for tracking human movement would later be used for many of his other experiments. His research found that the majority of movements, such as hitting a chisel with a hammer, could be broken down into smaller movements. If any of the smaller movements changed, it would affect the movement as a whole (Di Santo, 2014).

Bernstein viewed movement as the door to understanding the human brain, where his major line of inquiry was whether movements are repeated or not. To review, the traditional position (Pavlovian) held that two movements could be identical. However, Bernstein was opposed to this idea. His theory emphasizes that human beings do not repeat movements like unicellular, basic, low-complexity organisms. The greater the complexity, the less possibility there is for repetition, thus each human movement is different.

This is where we get the concept of **motor programming**, which consists in outlining a sequence of actions before they occur, establishing beforehand a sequence of muscle activations in a precise order. In neural terms, it loads a pattern of specific connections between the nervous and muscular system, whose deployment, organized in time, is the said movement.

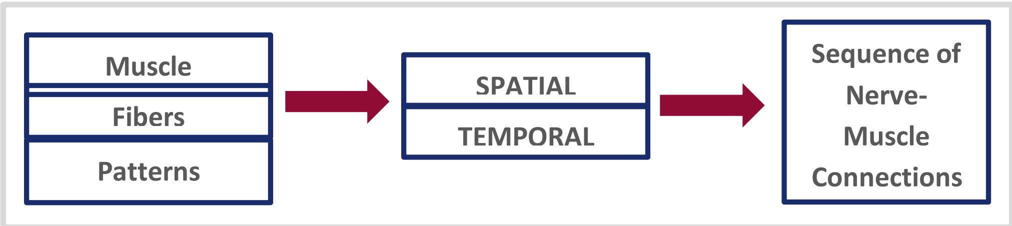
We can divide the action of programming into two separate dimensions:

On the one hand, there are **invariants or engrams**. These neural connection and motor memory patterns are stored in order to be used for movement. On the other hand, there are **parameters**: these are the protagonists of action that do not form a part of motor memory, but are nevertheless required for programming.

Programming a movement is an action, so that what is at issue is not an anatomical structure but a function that requires anatomical correlates. The **act of parameterizing an invariant** consists of: choosing the most appropriate protagonists, so that the deployment of the engram is successful in terms of obtaining the best possible environmental adaptation, for survival as much as reproduction. Therefore, it includes the task of making a decision between alternative protagonists for the best possible choice.

The parameterization of an invariant thus generates a series or sequence of muscular activations that, as they unfold, create the movement. Below is an image that will hopefully clarify the foregoing explanation.

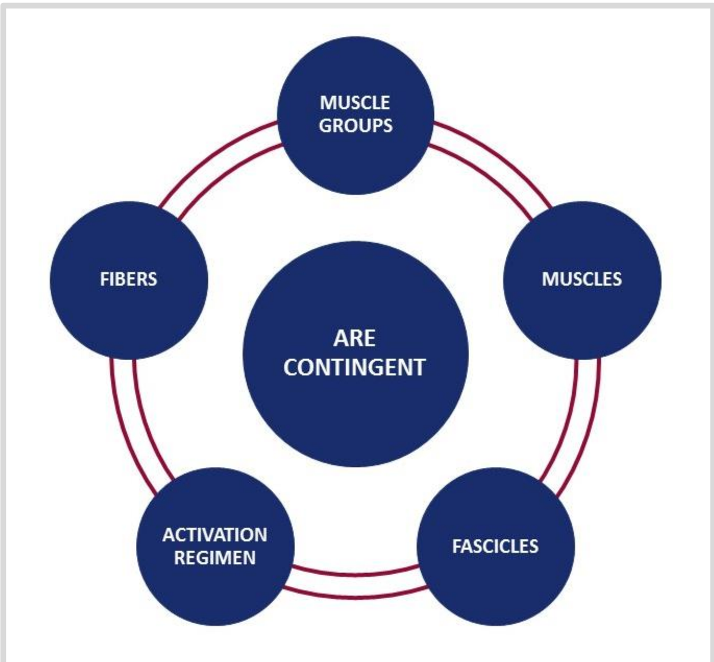
Figure 2: Motor Programs Parameters



Source: Prepared by the author.

Parameters do not form part of the trace or motor "engram", it would be a disadvantage if they did.

Figure 3: Contingency



Source: Prepared by the author.

There exist other components for parametrization, but none of them form part of the engram.

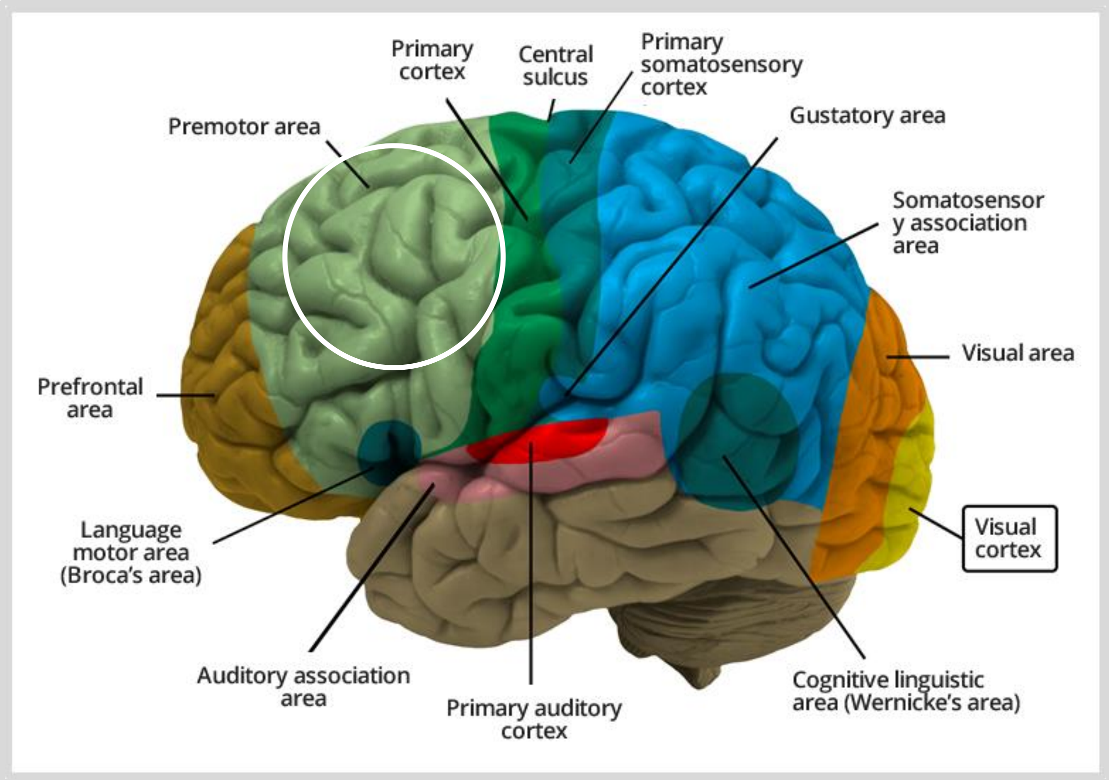
The parametrization components are the following:

- Frequency.
- Synchronization.
- Recruitment.
- Intramuscular stability.
- Muscle tone.
- Inhibition.
- Synergies.

Nevertheless, multiple adjustments arise during a movement that depend on feedback.

When we train, we choose the best protagonists for a determinate scenario. If those protagonists are unavailable or fatigued, we resort to the next best possibilities. To begin, we always tend to choose the best version, later resorting to the alternatives, and only last do we choose from among what is available at the time. Thus the concept of **always training the best version** is key; that is, to always have available the most efficient protagonists. This is why it is advantageous to change the engram, activating other protagonists or parameters (again, the most efficient) before fatigue from overuse of the protagonist takes hold, forcing the use less ideal actors. To this end, motor alternation and variation are important for avoiding and evading fatigue, and for finding our best versions (Di Santo, 2015).

Figure 4: Where Does Programming Take Place?



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

Where Does Programming Take Place? Everything indicates that it takes place in the **premotor area** or Brodman 6 area, a very important area for planning motor actions. To understand programming as a function, as an action, it is important to understand that it is contingent and does not form part of the trace or motor engram.

3.1.3 Stage production and orchestra performance as similes for neuromotor programming

Stage Production

The metaphor of a stage production will help us to better understand motor programming. It contains a script, an outline and acts. There are all different types of actors: leads, supporting and extras, even understudies for the lead roles. There is also a director and a stage that must be maintained. There is a context and an audience. The correlation between the two could be expressed as follows:

The script: the play itself, it does not change over time and yet, it can be slightly corrected or adjusted.
The actors: are contingent, that is, they are the muscles that, just like actors, play leading, secondary and supporting roles, among others.

The director: the correlation would be with some sub-system responsible for choosing the correct actors so that the production is a success.
The stage: without a doubt, muscle tone is a kind of backdrop providing support for the main act and stability for the actors.

In this simile of a stage production, the representation of the play is the program, likewise the play itself. The actors are the programs, that is, they would be the action through which this play (invariant) is performed. The programs are closely related with decision-making about who the protagonists of the play will be.

If the play depended on a protagonist, if the parameter were more important than the invariant, if there were a fixed option, the play would never be able to move forward. It would be a terrible biological disadvantage if the muscle stored in the memory were unchangeable, since, for example, if some sort of problem or injury were to occur in that muscle, the program could not unfold; nonetheless, it is a biological advantage that the authors are in fact contingent.

It is very interesting to grasp this idea, especially for detecting and determining whether the error is in the engram or the parameter, where each would require very different corrective methodologies. A parameter problem can be detected when spatial or temporal distribution of the movement is correct but the wrong protagonists are selected. If this happens, the movement is not executed as expected.

It could also be inferred that there is a deficit in the engram itself, in which the where and when of the movement are unknown. If you change the engram, the play also changes and the movement becomes different. If you make corrective adjustments to the same movement, you are affecting the parameter.

The stage production serves as an analogy, where we have a script and actors of all types: main, supporting extras. The intelligent choice is to use the best actors, or, put differently, to use a brain subsystem that programs without ever using bad options. This is, without a doubt, what distinguishes high performance athletes from amateurs; those athletes that do not become professional athletes always use bad versions or bad protagonists.

Although the best actors cannot always be used, we can obtain alternates: if something happens to them, there are others to take their place. As an example: if the supraspinatus muscle is an abductor and gets injured, this movement would no longer be performable, and yet it has supporting actors that can cover for the main actor and perform the movement in any case.

We find that subsystems are strongly involved in this process. Following the metaphor, the director could not be in charge of everything, such as the stage and backdrop. Other subsystems are directly responsible for the backdrop supporting the action.

Who is the Director?

To say that the brain is the director would be superficial. Saying that the brain in its entirety is in charge of programming would be a kind of holism, an assertion that any small injury to any part of the brain would alter the programming for every movement. For example, if you had a stroke in a small part of your brain, you would lose your whole motor repertoire. On the other hand, to say that a single neuron is responsible would be to attribute that neuron with a great deal of power. Santiago Ramón and Cajal, did just that, attributing a single neuron with all the power. A more coherent statement would be that **subsystems of a neural population** are responsible for the neuron.

Likewise, it makes more sense to say that certain cerebral subsystems are in charge of assembling the entire play: not only the casting and final choice, but also possible subsystem candidates. The possible directors for the motor programming process are: the prefrontal cortex, the frontal cortex, the basal ganglia and the brainstem.

Producing a movement is so complicated and variable that it is hard to believe that only one subsystem would be responsible for every detail. It is, however, difficult to let go of this idea, the one that insists that you are the one deciding not only the motor program, but its execution. The concept that a director or some similar entity is inhabiting your brain revives a certain dualist nostalgia.

Musical Orchestra

The musical score, the piece of music itself, this does not vary. At most, it can be adjusted through small changes. There may be multiple versions and various interpretations. The symphony itself, the **"kinesthetic melody"**, is necessary and irreplaceable (Luria, 1973); the rest is contingent.

3.1.4 Neural correlates of motor programming

Where Does Motor Programming Take Place? It takes place in two areas: in **area 6 of the premotor cortex**, where there is a higher level of activity when constructing or planning a movement; the **supplementary motor area** is also being discovered to play a role. Following that, the pre-SMA plays a fundamental role in deciding and activating programs. Therefore, who constructs the program is not the same as who decides its execution or who executes the program. You may be brilliant at constructing programs but then make poor choices when it comes time to implement that program.

Programming depends on the intervention of other sectors, namely, the **premotor cortex,** the **motor cortex**, the **ascending frontal convolution** and, slightly higher and turning inward, towards the corpus callosum, the **supplementary motor area** participates in movements which are more complex than habitual movements. Of course, depending on the experience of neuromotor programming, more complex programming actions require more or less help from the SMA.s

John Eccles (1994) thought that the seat of the soul was the supplementary motor area because, in the end, the soul is manifested through movement. He maintained the hypothesis that this sector was the seat of soul-brain interaction.

This sequence, while possible, is by no means necessary. It is not necessary because a program of action could be triggered without the mediation of voluntary action. If there is an immediate response to a stimulus, we do not find mediation of the SMA or the pre-SMA, but instead the mediation from the premotor cortex. If you decide to take a penalty shot, then the SMA will mediate without a stimulus response; or if the stimulus and the start of the action is separated by any length of time, as for example, when the referee blows the whistle to indicate the start of an action.

It follows: **The premotor area for programming** and **the pre-SMA to initiate and execute an action.** There are other sectors of the frontal cortex that also activate the corticospinal tract (Not only the MP1), although without the protagonism of the MP1. This would be an interesting basis for further study and research: If not from the MP1, where does the data allowing for the activation of the corticospinal tracts and the motor system come from?

The SMA can intervene when the decision to begin a movement is not crucial; when the response to a movement is immediate and there is no decision to put it in practice. The cerebellum can act with the objective of activating new motor programs beyond the initial program, for example, creating a particular action to remain standing. This organ can correct the program or, if necessary, change it. Changing the parametrization of the engram takes anywhere from 400 to 600 milliseconds; changing the initial program takes more time, surveyed to be more than 800 milliseconds.

Once an engram is parametrized and the movement is constructed, then the MP1 comes into play. The **cerebellum** is also involved, which we know will make all necessary adjustments before, during and after the movement. The **basal ganglia** receives a copy of the program and activates the gamma motor system in order to create the optimal setting to support the action. The accumbens center reinforces the circuit with dopamine, that is, it sensitizes the post-synaptic membrane and facilitates activation, should the movement need to be repeated.

What Does this Program Activate?

This program activates two subsystems: one involves the SMA, pre-SMA and the basal ganglia, and the other is a direct connection between the parietal lobe and the premotor cortex. This topic merits attention, given it is of great anthropological importance.

How Is the Program Communicated? This is a different problem. Once the SMA decides to put the motor program into motion, there must be a connection between area 6 and area 4 in order for the selected program to be deployed. There must be a connection between areas 6 and 4 through the **plexus** in order for the pre-established sequence in area 6 to activate the pyramidals in area 4.

- **Area 6:** is programmatic.
- **Area 4:** deploys the program.
- **Supplementary motor area:** vetoes or allows the program to be deployed (depending on the hormonal secretion affected by the nucleus accumbens). The cerebellum, basal ganglia and accumbens regulate the process.

Reflexive action does not show cortical participation (although all reflexive actions can become an object of knowledge for consciousness), rather demonstrating a circuit where decision-making cortical structures do not interfere; nonetheless, it does include a complex synergy, reason enough for us to oppose the concept of reflex as a simple response to a stimulus that proves, by way of example, the inhibition of an antagonist.

We consider a reflex to be much more complex than simply pulling your hand back when it is burning. A reflex action, in the end, allows for a final calibration of the movement production; it is the final adjustment or tuning.

The micro-movements that are produced during **unstable training** continuously adjust the parametrization of the program. In the case of having to change the program due to a fall, upon falling, another action needs to occur that supposes some change. While this is happening, there is a permanent recalibration of the program parametrization on the basis of the proprioceptive information received during the action. If we continue with the same protagonists as we are falling and do employ some other, we fall to the ground. The cerebellum can act in order to achieve the objective, that is, to not fall; in short, it can act in order to activate new programs. Thus, based on the initial program, the cerebellum can generate a particular program to remain standing.

The methodological repercussions of this premise is related to the concept *quality over quantity.* This means that an activity will not simply be completed despite the presence of fatigue; instead, the best version will be attempted several times over. When a given version begins to fail for whatever reason, it should be terminated. In endurance training, the intermittent method attempts to avoid fatigue with pauses so that the best version may be performed several times. This implies change, since avoiding fatigue is simply a question of training the parametrization of motor movements in a variety of ways with distinct protagonists; thus, when one fatigues, other protagonists are activated to complete the objective.

Unit 3.2 Engrams

3.2.1 What is an engram?

Taken from the Greeks, it is the idea of a **trace or line** drawn onto the brain, a structure of stable neuronal connections and a specific circuit of associated, involved neurons in a concrete spatial arrangement. Engrams configure the deep architecture of our brains. It is a specific circuit and it creates a network of neuronal connections that generate movement. The name "engram" comes from their interrelation for the purpose of determining specific responses; in this sense they are comparable to gears.

This presupposes the activation of a system of neurons, itself produced by an efferent effect with the excitation of either internal or external nerve endings. Thus, the activation of efferent, stable, neuronal structures is stimulated, where the structures are in turn responsible for the movement itself.

There are some movements which do not depend on the conscious participation of the subject while others do require it (Di Santo, 2014). As we have mentioned, the engram is made up of neurons that are connected by nerve impulses transmitted through synaptic connections. They form a complex network with a well-defined internal order that allows for coordinated activation. The engrams produced register in an orderly fashion in specific modules, that is to say, responding to a "mapped" order in which engrams are connected so as to transmit activation in a logical manner, taking into account other engrams.

These are also called **loops**, or **patters of action or movement**. There are loops of greater and lesser complexity, namely, short and long loops (Di Santo, 2014). According to the number of neurons within a circuit and the levels of the NS involved, we can distinguish between:

- **Short loops:** possibly involving the cortical tract, in charge of simple movements.
- **Long loops:** in charge of complex, compound movements that involve more than the cortex.

It is important to mention **motor memory**, of which engrams are substrates. Memory is based on the reactivation of engrams, as traces that mark us as individuals and identify us. Based on this perspective, we can also define engrams as the neurophysiological footprint on the brain and as the base where memories are stored. In short, they are a circuit made up of neurons that, when requested, recruit muscle fibers in order to form a specific motor activation pattern.

In order to form a circuit, it is necessary for the repetition to form a reaction pattern between neurons and that this take place at the exact point when a determinate stimulus is capable of activating that circuit (Jacques, 1988).

Traditionally, engrams are recognized as having two basic components: spatial and temporal structures. The **spatial structure** refers to the location or the topographical relation of the different connecting nuclei involved (contingent), while the **temporal structure** alludes to the specific sequences of actions and, above all, there temporal proportion. Spatial structure refers to location, which distinguishes a given particular movement from others, whereas the temporal structure refers to the time or the sequential deployment of the movement, also called **phasin**g (Jacques, 1988).

In summary, engrams are:

- Stable structures of neural interconnections.
- A specific circuit with related, involved neurons in a concrete spatial arrangement.
- Ultimately, they make up the deep architecture of our brains.
- They form a complex network with a well-defined internal order that allows for coordinated activation.
- They are registered in specific modules, in an ordered sequence.
- They can also be called "loops".
- They are considered patterns of action or movement.
- There are both high and low complexity engrams: short & long loops.
- They consist of neurophysiological traces within the brain, and serve as the basis of memory.
- They are circuits made up of neurons that, when requested, recruit muscle fibers in order to form specific motor activity patterns.
- They consist of trails or traces of memory: the neurophysiological substrate of memory.
- Neuromuscular engrams are memorized patterns of muscle response with respect to specific proprioceptive information. It is a component of unconscious programming created in the CNS in order to be able to control the muscular system.
- They are a data set that represents a movement.

In order to form a circuit, it is necessary for the repetition to form a relationship pattern between neurons and that they react exactly when a particular stimulus is capable of activating that circuit, which includes:

- Changes of neural chemical nature.
- Ability to identify and sound out.
- New sequences of amino acids.

- Changes in the concentration of RNA inside and outside a neuron.

3.2.2 Components of the Engram

Traditionally engrams have two basic parts: a spatial and a temporal structure.

- **Spatial structure:** refers to the location or topographical relation of the different connected nuclei involved (contingent).
- **Temporal structure:** alludes to the specific sequence of actions and, above all, to its temporal proportion (also known as phasing).

Temporal Organization of Sequences

Movement can be envisioned as a set of motor elements of a determinate amount of time, triggered one after the other in a temporal order. If the duration of each element is programmed, it is enough to know the order of the sequence in order to develop a program. Thus, the issue has been raised whether temporal organization is coded and at what level of generality. On various occasions it is has been determined that the invariant is not absolute time, but rather the relative duration of the sequences; the speed of a movement can vary but the relative proportion of time between them remains unchanged. This is also known as **"phasing"** (Corraze, 1998).

By associating this phasing with the balance of forces needed for each motor element, a particular notion of invariant has been proposed that says that the first moment occurs contrary to that occurring on the basis of location (Corraze, 1988).

Schmidt et al. (1998) had considered not introducing a space between invariants of motor programming or, at least, not directly. Their study regarded the essential invariants as the balance of power involved in each muscle contraction and the relationships of each movement's duration (Corraze, 1998).

Movement is the result of the forces that make muscles contract and the amount of time each movement takes. Programs can be conceived as ordering a series of muscle contractions with a certain force and a certain duration in a particular order. (Corraze, 1998).

3.2.3 Uses of the engrammic Copy

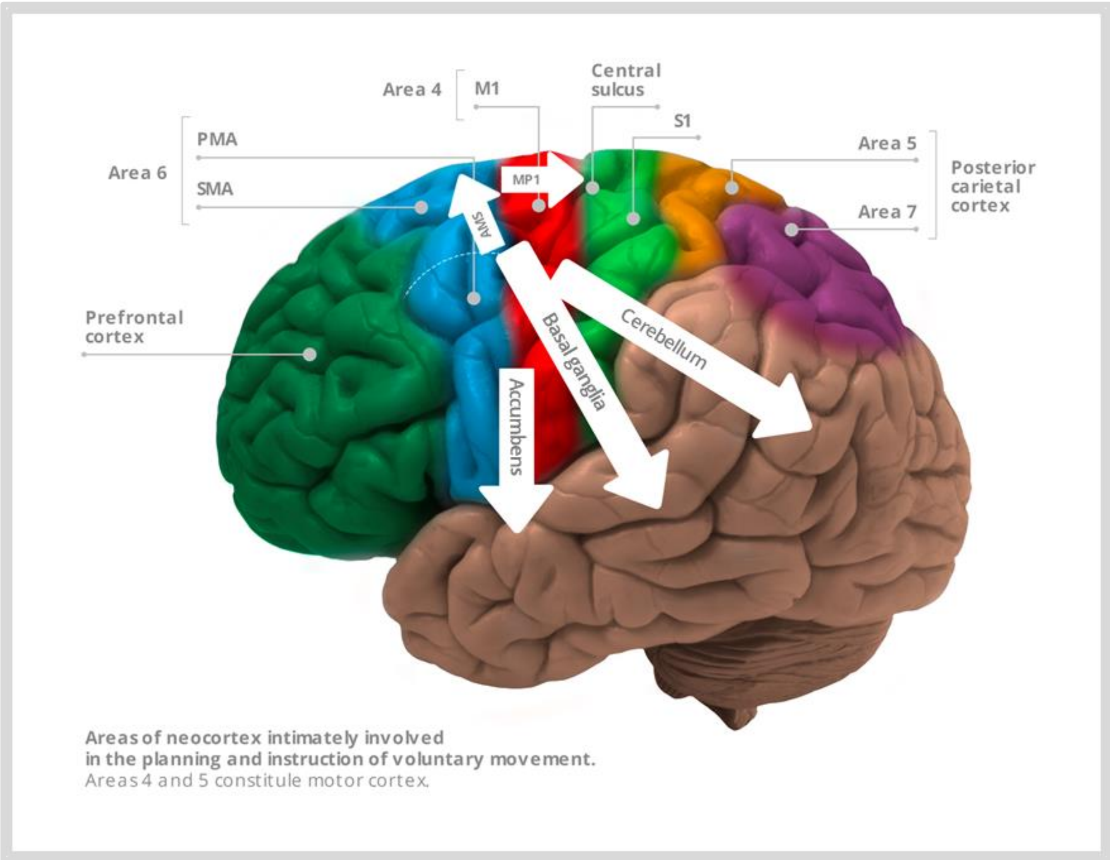
This is also known as a **preview value**, where various programmed copies are distributed before the actual movement takes place. All of these destinations have neurophysiological relevance.

They are:

- SMA and pre-SMA.
- Cerebellum.
- MP1.
- Basal Ganglia.
- Nucleus Accumbens.

Engram copies are sent to the cerebellum in order to control movement coordination, where its task is to evaluate and compare the previewed value with the result. Engram copies are sent to the basal ganglia in order to make the appropriate tonic adjustments, and thus leading the motor gamma system's activity (red nucleus). The MP1, which directly controls alpha activity, is also involved in order to activate specific muscles via the cortico-spinal tract. Finally, the copy is sent to the Accumbens center where a replacement is produced to reinforce the motivational circuit or dopamine pathways.

Figure 5: Destinations of Engram Copies



Source: Adapted from Cram. Retrieved on 7/21/2016 from http://goo.gl/AWvy8U

3.2.4 What put an Engram in Motion? Voluntary Movement

The majority of human adults have a strong sense of control over their actions. They are able to choose their actions, and it would be interesting to know more about the topic. The capacity for voluntary actions is so fundamental to our social existence that limits and prohibitions are carefully justified and regulated. Voluntary action may evidence different character disorders, as in those pathological states that are produced by ingesting foreign substances. Other states and mental processes, especially deeper emotional states, can alter the normal inherent functions of voluntary action.

If we had to define a voluntary action, we would fall back on a dualism and would likely establish that there is an "I" that consciously chooses actions; "I" am the one who chooses actions and "I" am in control of "my choices". This dualist language involves a mental "I" that is different from the brain and the rest of the body. As such, it can trigger cerebral events such as images, memories and, of course, movements (mental object dualisms are related to this objection). Nonetheless, contemporary science does not hold this view and proposes a different approach to the phenomenon.

We approach **voluntary movement** based on the contemporary scientific perspective, which defines it as the final point on a continuum initiated with a reflex. We will now discuss the differences between voluntary movements and reflex movements.

Reflexive movements include the following characteristics:

- Immediacy.
- Required external stimulus.
- Its form, occurrence and timing are all determined by the stimulus.
- Spinal level.
- Lacking the possibility of veto.
- Lacking the possibility of prospective memory.
- Lacking decisions.

Voluntary movements on the other hand are characterized by:

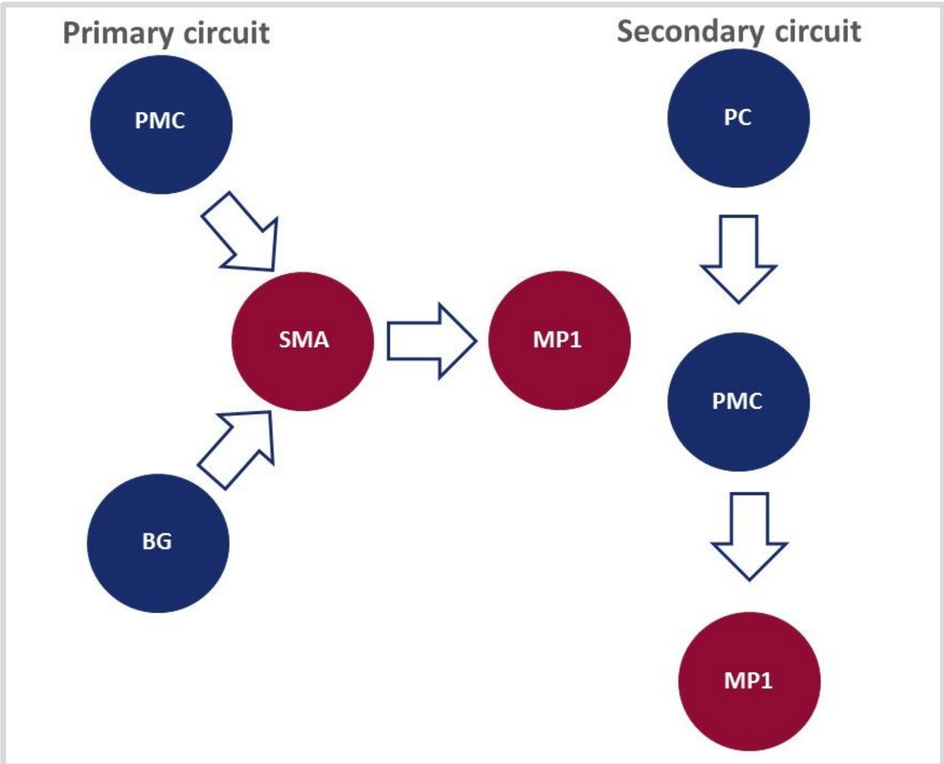
- Mediation.
- An external stimulus is not required.
- It does not depend on stimulus.
- Cortical level.
- The possibility to veto or continue the action.
- The possibility of prospective memory.
- The possibility to decide objectives, actions, programs and to veto or not.

For a long time these movements were distinguished as being automatic or voluntary. This opposition has been weakened to the extent that the following was written in a neurophysiological discourse: "The distinction between reflexes, instincts and voluntary actions has vanished" (Kandel and Schwartz, 1982, p. 273).

Cortical circuits for voluntary movement: these circuits converge in the MP1. MP1 executes motor commands, transferring them to the spinal medulla and muscles. MP1 is the shared final pathway of the cerebral cortex; the motor neuron of the spinal medulla. It receives inputs from two circuits: one specific to voluntary movement and the other specific to reflex movement, although there are other areas that project to the medulla, which receive inputs from the same circuits. At the level of the cortex, there are two clear alternative itineraries and two cortical circuits, namely:

On the one hand, the **pre-motor cortex circuit (PMCC) and basal ganglia (BG) with pre-SMA**, which connects the basal ganglia to the cortex (pre-SMA) and the PMCC with the pre-SMA, and lastly, to the MP1, the shared final pathway. On the other hand, there is the **PMC-parietal circuit**, which also converges at the MP1 and connects the sensory sectors of the parietal cortex to the pre-motor cortex, and lastly, to the MP1.

Figure 6: First and Second Circuit

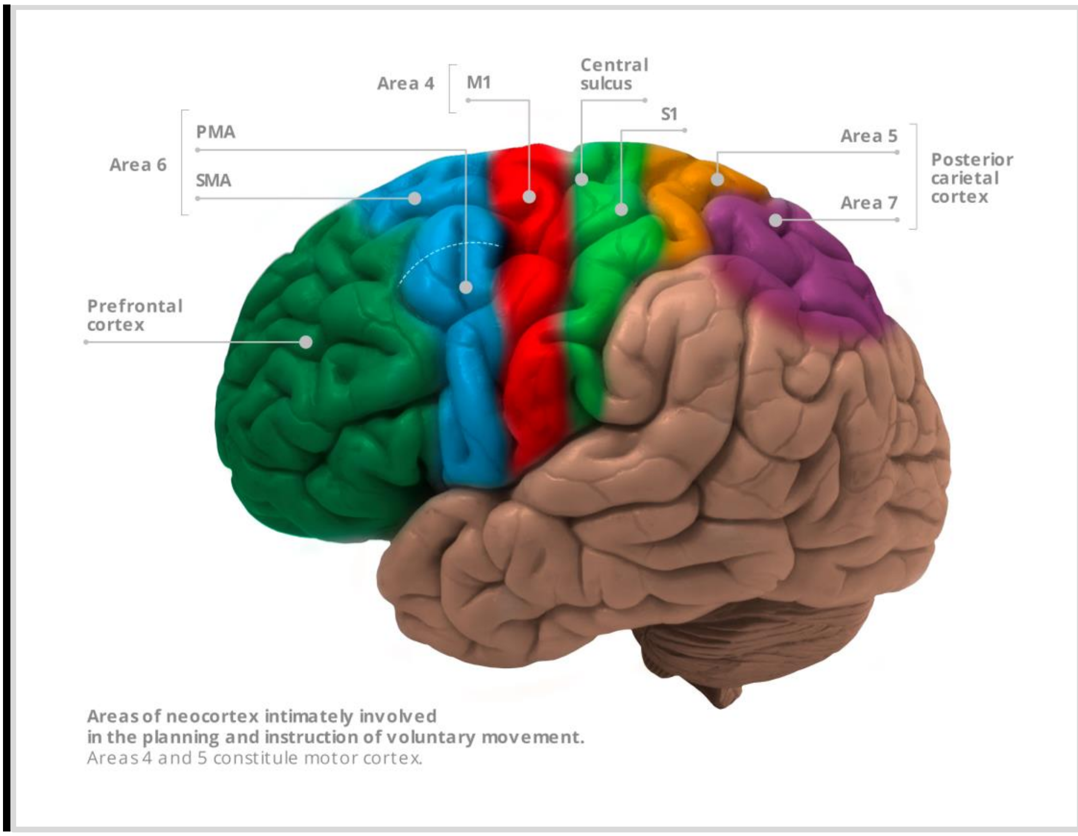


Source: Prepared by the author.

First Circuit

We employ this circuit the most in the absence of external stimulus: the pre-SMA activates when there are no external stimulus, together with cognitive motor circuits, the PMCC, the cingulate cortex and the frontal pole cortex. The pre-SMA either denies or prolongs an action's beginning; however, when it is triggered, the pre-SMA connects with the SMA and from there on to the MP1. In order to start an action, input from the basal ganglia is essential. The pre-SMA BG circuit plays a fundamental role at the start of an action: the pre-SMA inhibits the action and the BG inhibits the inhibition. Parkinson disease is such a terrible disease because the BG do not inhibit the inhibition of the pre-SMA and thus less actions are initiated.

Figure 7: Motor Areas



Source: Adapted from Cram. Retrieved on 7/21/2016 from http://goo.gl/AWvy8U

Second Circuit

We use this second circuit for actions such as holding or gripping. It promotes actions that are oriented towards objects and it also participates in voluntary movement, although it is more immediate than the former, and as such, it promotes immediate actions.

There are two circuits according to immediacy:

- The ventral involves the pre-SMA and BG, making it more mediate (it is not used in sudden movements).
- The second is used when time is a factor: it is **immediate**.

In voluntary movement there is a moment where a decision is made; perceptual decisions also exist, which differ from intrinsic actions. We find:

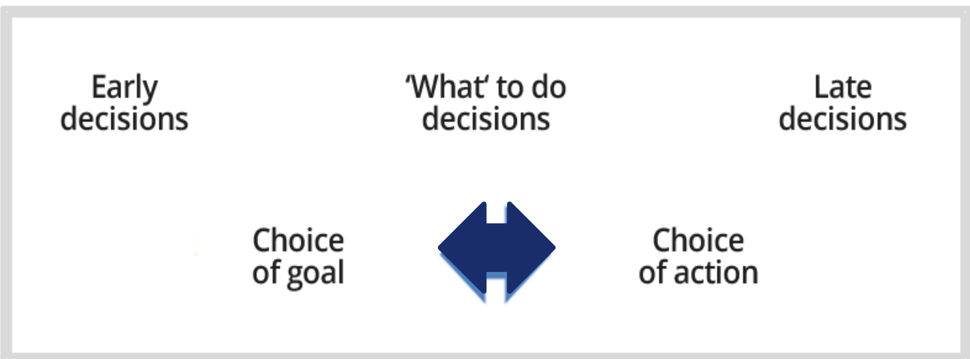
- **Early decisions:** First, there is an early decision regarding performance or not of a given action. This decision is based on three types of motivations:

- Necessity.
- Wants.
- Other reasons.

- **Decisions regarding "the what":** This refers to which voluntary action will be done, based on the two following possibilities:
  - Choosing the goal.
  - Choosing the voluntary action to achieve this goal.

- **Decision regarding the goal:** Goals can be varied; nonetheless, they are ordered in time, although there are some disorders that disturb the order. Having a set goal, the FC and the pre-SMA play a vital role, which consists in keeping the volition focused on a purpose or connected to intentions and action. The pre-SMA represses the automatic beginning of an action triggered by environmental stimulus: if there is an injury, there is also hyper-reactivity. Deciding between goals involves the FC, and the pre-SMA also plays a role.
- **Decisions Regarding the Choice of Movement:** The majority of objectives can be achieved through different movements.
- **Late decisions:** This decision involves the dichotomy of "to do or not to do".
  - *Check:* Decisions regarding the "what" activate specific motor circuits; in this case, it involves the predictive or veto check.
  - *Assessment:* This involves assessing the cost of a chosen action. This is when the final check happens, before the action is issued or triggered.
  - *Action*: As a result of the check, the action can be promoted (and the movement triggered) or vetoed (and thus, the action is not generated).
  - *Restraint*: canceling an action may prove wise, but it can also be the exact opposite.

Figure 8: Choice of Goals and Action



Source: Prepared by the author.

Neural Substrates of Cancellation

This takes place before the pre-SMA and its specific role is related to vetoing actions. The frontal-medial anterior cortex, rostral or anterior to the pre-SMA and the insular cortex are key to self-control. These processes are all closely related to restraint.

Let's consider the two extremes of decisions:

1) **Early:** The decision consists in doing or not doing.
2) **Late:** The decision consists in a final check and an action veto.

Both account for individual responsibility. The others (the what, how and when) are less important. Responsibility can depend on the reason that triggered the neural process, which culminated in the action and the final check, that is, if one should veto or let the action continue. Both have a strong normative element. Despite the fact that an individual's brain decides the actions to take, culture and education teach a person acceptable reasons for taking action, and when a predictive final check recommends holding back on an action.

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