1.1 Sensesations and human movement

This course aims to apply neurobiology to sports practices and also to the motor practices related to health. We develop a general and comprehensive introductory framework regarding neuroscience as it relates to human movement. The purpose is to provide a means for physical exercise professionals to approach a subject that tends to be neglected on account of its complexity. However, its application can contribute to training technique, motor learning and athletic performance, as well as interventions in health through adapted exercises. This introductory class intends to facilitate a global understanding of concepts, tempt those interested to further deepen their studies and venture to implement specific applications.

Let's recall that, in fact, what exists is neurobiology. Today we talk of neurosciences as a set of disciplines whose target is to study the human brain and its applications to different dimensions and disciplines (such as marketing, decision-making in the business environment, among others). What really exists, therefore, is neurobiology. From it we will explore some elements that help us understand the reasons not only for some extraordinary performances, but also for sporting failures, errors, the failure to achieve certain objectives; we will also study existing methodologies, as well as propose new possibilities.

1.1.1 Definitions and components of sensory systems

Specifically, the quantity and quality of information that our different receptors can collect is the basis on which any further processing of information depends. Perception can hardly be of a higher quality than that provided by the sensory information. Likewise, the ideomotor representation is unlikely to be better than perception. Following the same reasoning, our motor logic, our motor decision-making and programming will not improve upon the previous steps, let alone motor control, once the efferent or even motor discharge leaves the cerebral cortex. That is why, in the process of acquiring, improving, stabilizing and varying the availability of a voluntary practice, we depend heavily on the amount and quality of information that our sensory systems can provide. We thus see that it is the topic with which we should start studying our subject.

Among the most important functions of the nervous system is that of obtaining information on the physical and chemical conditions of the inner and outer medium of the body and the variances that this presents. Such information is crucial to maintain homeostasis, counter heterostasis, and adapt to the conditions of the medium. There are common features to all sensory systems, regarding both anatomy and the basic functions of its components.

One of the most outstanding features of our nervous system is that of collecting information from the environment, both external and internal, precisely because the generation of behaviors that allow us to adapt to the environment (and also to avoid problems that may leave us no chance of survival), as well as transform the context and improve current living conditions, depends on the quality and relevance of this information and its subsequent interpretation.

We shall start by defining a **sensory system** as a set of organs, pathways and neural processing centers specialized in collecting information from the environment, both external and internal, the integration of which triggers further steps relating to motor programming and its actual execution. In fact, the contributions of sensory systems are crucial to motor adjustments once the movement is triggered from the cerebral cortex. It involves a set of structures that have developed throughout our evolutionary history to collect relevant information needed for the further development of adaptive behaviors.

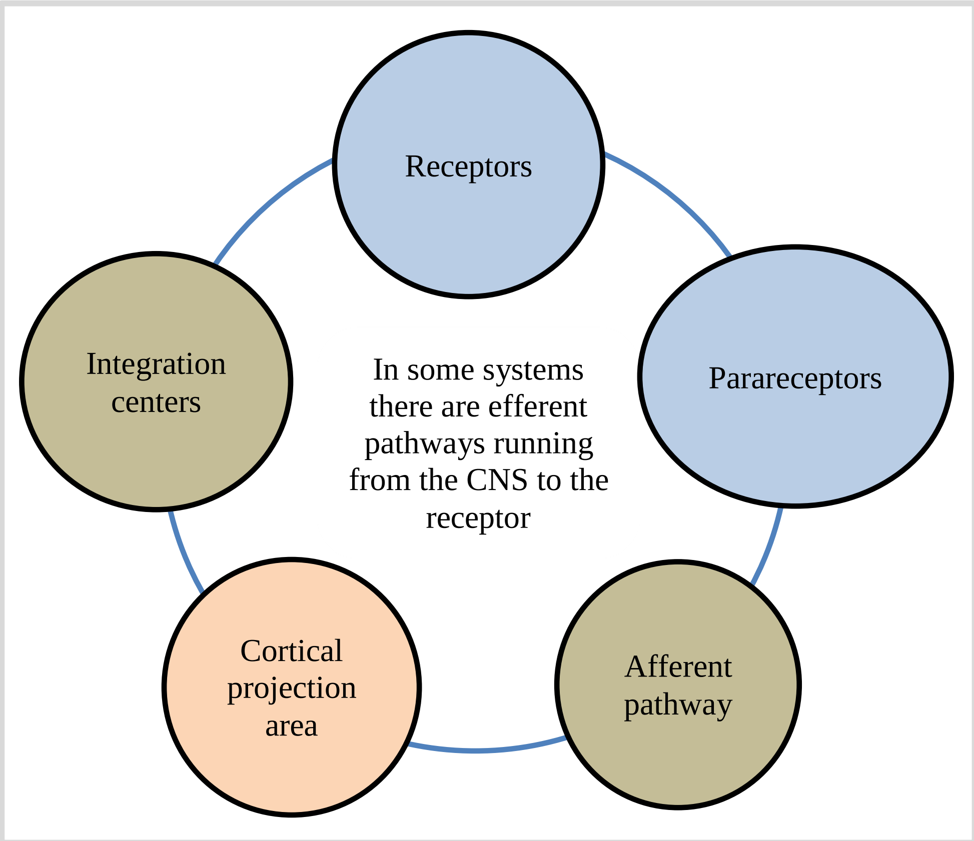
Components of a Sensory System

A sensory system is not made up only of receivers, but also of a series of structures that complement their work. Among the different components of a sensory system are the receptors. We also have afferents or transmission routes of the information captured by them, called sensory pathways. In addition, there are survey centers or synaptic switching, both pre-medullary and pre-cortical. These information processing centers modify the information substantially before it has access to the primary cortex.

We also have primary projection areas in the cerebral cortex where that information is initially received and continues with further processing. We add other structures, such as annexes or parareceptors, which protect and assist in capturing and amplifying the stimulus. We shall begin with an analysis of the components of a sensory system and how useful information is collected to configure programs, in addition to the phenomenon of motor learning. We can distinguish five, namely:

- **Receptors:** Histological anatomical structures specialized in the reception and transduction of a particular sensory stimulus.
- **Parareceptors:** Histological anatomical structures associated with the receptor, which protect, assist and amplify the capture of information.
- **Afferent pathways:** formed by a set of sensory neurons that convey information to higher centers.
- **Integration centers:** these are anatomical centers within the central and peripheral nervous system that serve as information relays and switches (spinal cord, dorsal root ganglion, thalamus).
- **Cortical projection areas:** these are specific areas of the cerebral cortex where sensory information is first received for its further analysis (17, 42, 3, 1, 5, 7).

Figure 1: Sensory System Components



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We will focus on those sensory systems that provide valuable information for motor learning, such as proprioceptive information, tactile and haptic sensitivity, vestibular sensation, vision and hearing, as well as those that contribute more to solving motor problems, in both sports and daily life.

The first elements that make up sensory systems are receptors and we will begin our analysis with them. **Receptors** are non-neural cells or nerve terminals adapted and specialized for the initial collection of information, from both the external environment and the internal environment. Environmental information is transmitted in the form of undulating or analog messages, such as sound or light waves, and one of the most important functions of these specialized cells is to encode this information digitally. The way our nervous system decodes these stimuli is precisely digital. What circulates in our nervous system is not analog, but digital information. In a manner very similar to Morse code, our neurons transmit action potentials at different frequencies, that is to say, neural messages formed from a modification of the information from nature into a kind of information circulating specifically in our nervous system, both central and peripheral.

Classification

The criteria for proposing a taxonomy are varied, as they depend on the point of view considered initially. One of these criteria is precisely the source of the stimulus or the origin of said source. Following this point of view, one of the most traditional forms of classification is the distinction between **interoceptors** and **exteroceptors.** When we talk about interoceptors, we refer to those receptors that have specialized in gathering information from our internal environment. Some claim there are two types of interoceptors: *visceroceptors* and *proprioceptors;* included within the proprioceptors are not only those that provide information from the tendons, muscles and joints, but also those that provide information from the vestibular apparatus, which senses the position of our head, its acceleration, deceleration and rotations. Some even choose to include touch and nociception as an interoception mode. Within exteroceptors (distance receptors), we have receptors where information does not make direct contact with our structures (such as sight and hearing) and others, such as contact receptors (taste, smell, or touch) where impact is necessary. Touch is a sense that not everyone agrees to include, either as part of the interoceptors or exteroceptors. Perhaps, ultimately, all the senses are forms of touch.

- **Interoceptors**
    - **Visceroceptors:** report on the state of our bodies not directly linked to posture and movement (among which we can include the systems that provide vascular, cardiac, and respiratory information; also from the gastrointestinal tract, and even the endocrine and immune systems, including nociceptors).

- **Proprioceptors:** we include not only those that provide information from tendons, muscles, and joints, but also to the receptors that provide information from the vestibular apparatus. Especially, fasciae (i.e., different systems specialized in controlling posture and movement).

- **Exteroceptors:**
  - Vision.
  - Hearing.
  - Touch.
  - Taste.
  - Smell.

Another form of classification is based on the consideration of the type of stimulus. From this perspective we can list **photoreceptors** (specialized in capturing light stimulation), **mechanoreceptors** (responsible for capturing contact stimuli produced by an immediate deformability), **thermoceptors** (which obtain temperature information, both internal and external), **chemoreceptor**s (which capture the state of concentrations of different chemical components in our body), and **electroceptors** (which capture signals of the changes in our electric fields).

- **Photoreceptors:** are sensitive to light stimulus.
- **Mechanoreceptors:** are sensitive to mechanical deformation stimuli.
- **Thermoceptors:** are sensitive to (internal and external) thermal stimuli.
- **Chemoreceptors:** are sensitive to the state of the internal environment.
- **Electroceptors:** are sensitive to natural electrical stimuli.

There are several classifications for receptors, but they all serve the purpose of collecting information and transforming it into a type of data capable of being processed by our (peripheral and central) nervous system.

1.1.2 Sensory physiology

Principles of Sensory Physiology

Here we describe some functions inherent to sensory systems that serve to understand aspects that influence our bodily practices. Knowledge of these aspects allows us to understand some phenomena such as nonfunctional hypertonia, PNF (Proprioceptive Neuromuscular Facilitation) techniques, difficulties in gathering information and motor learning, among others. The study of these concepts provides immediate educational opportunities for our training practices.

All sensory systems have an **afferent neuron,** an **integration or switching center,** as well as an **area of primary projection** and an **efferent pathway** to motor modulate the activity. An afferent neuron is one that transmits information from the receptor to the integration centers and our PNS (Peripheral Nervous System). Some of these sensory neurons are of particular interest, such as the IA, IB and the IIA type. These provide proprioceptive information to the central nervous system. The quality of information they transmit (without neglecting the task of the receptor itself) conditions the possibility of recognizing our positions and finally regulate the control of movement.

Precortical integration centers are switching points of the stimulus, where much of it is filtered or mixed, before continuing its journey to the cerebral cortex. For example, the information captured from our body by proprioceptors (intrafusals, Golgi bodies) is modulated in premedullary switching centers located in the dorsal root ganglia. The **spinal cord,** meanwhile, is a small brain that integrates information and is able to modify it before its journey towards the upper structures. The **thalamus** is another center where information is switched before continuing its journey to the cerebral cortex. We observe that the information that finally reaches the cerebral cortex and the areas of primary projection is far from that which initially changed the resting potential of our receptors.

Elements of sensory physiology

To better understand the bases of sensory physiology, it is necessary to consider the following aspects:

- **Adequate stimulus:** It is the kind of information that makes it possible to change the resting potential of a given receptor. For example: the adequate stimulus of the muscle proprioceptors is the longitudinal deformation of the intrafusal fibers, specifically in its central portion. This does not mean that, in certain situations, they may respond to other stimuli. The adequate stimulus to activate joint receptors is, among others, compression, which makes it possible to modify the state in which these receptors are found. The adequate stimulus to activate the auditory system are vibrations of the air medium at a particular frequency, which are captured by the eardrum and transmitted to the middle and inner ear. All the sensory systems respond to adequate stimuli that promote the sensory modality for which they have specialized.

- **Sensory Unit and Receptive Field:** refers to all receptors that are innervated by the same sensory neuron. We have sectors in our body where a sensory neuron takes a small number of receptors, therefore, we need a greater number of sensory neurons to cover the entire sector. In these sectors, precisely because of the greater receptive density, we are able to access far greater discrimination in tactile information. In the case of touch, for example, we have a lot of receptors in the skin that are innervated by a single sensory neuron. We can conduct a small experiment, for example, with two toothpicks: if you place them a certain distance apart and press, you will probably feel two stimuli; however, if you bring them closer together, you begin to feel a single stimulus instead of two and this is because the stimulus shares the same sensory field, so one pricking sensation is generated instead of two. The receptive fields are much smaller in places of our body where we need much finer information processing (e.g., in the hand, lips, fingers) and are much larger in places where we need to collect less information of a tactile nature (calves, thighs, back).
- **Transduction and Analog-Digital Conversion:** These are the two most interesting phenomena to explain. We have our receptor in a condition called resting potential (chemical state of receptor) and which corresponds to a specific ion concentration, some with positive charges (cations), others negatively charged (anions), all within the receptor. When an energy source that is transmitted (by nature) in an undulating or analog manner makes contact with the receptor, the first thing it generates is a change in its chemical status. This promotes a phenomenon called receptor potential, which is nothing more than a modification of its resting potential. This simple event is what we call transduction.
  For this receptor potential to generate a change in the nature of the message transmitted by the sensory neuron, it must exceed a certain threshold. When it does this and it generates a modification in the pattern of discharge per time unit, the phenomenon of analog digital conversion is added to the phenomenon of transduction. This can result in the production of a sensory message that will transit to the relay systems in our CNS (Central Nervous System). It

is interesting to note that there is a lot of information that comes to our receptors and produces modifications in the resting potential, but does not possess sufficient intensity to change the resting potential of the sensory neuron and, for this reason, fails to generate a digital analog conversion. Therefore, we have no cognitive access to such information (ultraviolet, infrared, infrasound and magnetic waves). This is the same information that other species *can* capture producing recognition, knowledge, and behavior in response to these stimuli.

One case is worth citing and explaining: our proprioceptors are constantly emitting information to the CNS. When there is a change in specific action potential of the proprioceptors, the nature of the message changes by increasing or decreasing the frequency per time unit. This contrast between rest (where the proprioceptor emits information) and motion (where proprioceptor modification changes the neural message) is what makes us aware of the movement. The fact that proprioceptors permanently generate information that is sent to the CNS accounts for a sense called **statesthesia** or position sense. The fact that the same proprioceptors generate changes in the action potentials of sensory neurons allows them to become aware of the change of position. This accounts for what is called the kinesthetic sense or **synesthesia.** Both statesthesia as synesthesia depend on information originally collected by proprioceptors; therefore, both at rest and in motion we have a permanent discharge of information to the CNS. To put it another way, our proprioceptors never rest and this is a biological evolutionary survival advantage. In the case of our auditory system, if there is no stimulus, no action potential is generated to the CNS.

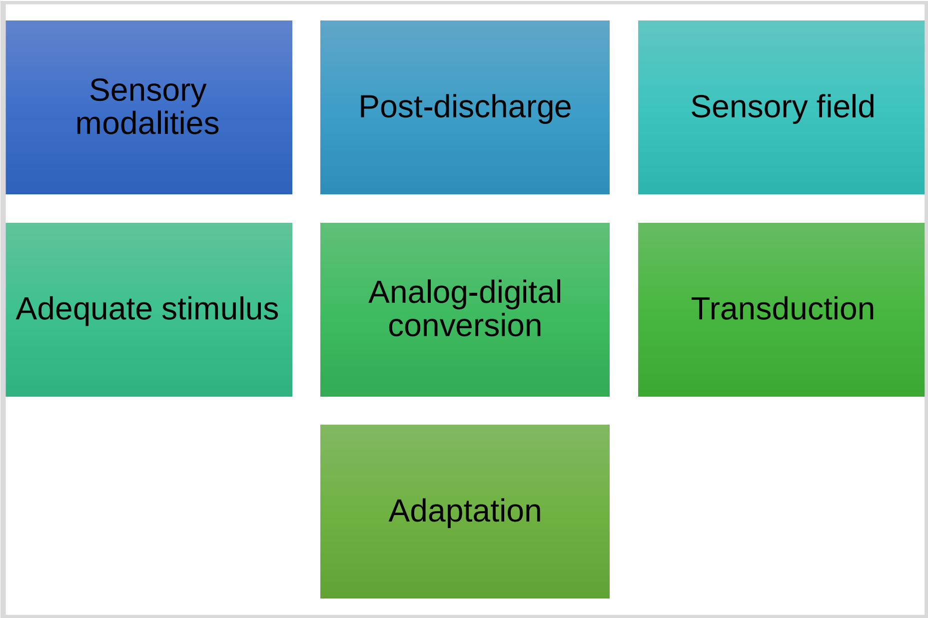
The same applies to the case of vision: if there is no stimulation of photoreceptors (by photons) to change the state of the rods and cones, we have no visual information. But in the case of proprioception, both at rest and in motion, we have a constant discharge of information to the CNS, which distinguishes rest from movement and positions, as well as pressures, compressions, and tensions, which are contrasts between the action potentials emanating from the proprioceptors and moving along the sensory pathways.

- **Post-Discharge:** another interesting phenomenon in sensory physiology is what is known as post-discharge. After a receptor has been modified in its resting potential, it can recover that same state relatively quickly. When it takes longer to return to its resting potential, despite the absence of the stimulus that generated the receptor potential, we still feel the presence of that stimulus, though it no longer has this contact with the receptor. For example, when one wears a hat for many hours, when the hat is removed one has the feeling that it is still on one's head. This is because those receptors are still discharging information related to the deformation of the skin's mechanoreceptors.

- **Adaptation:** is another significant property, with important consequences for training. It occurs when the neural message, generated by the presence of a stimulus, does not continue, even when the same stimulus continues to modify the status of the receptor. This adaptation of receptors to the presence of a stimulus is one of the major risks we have to try to avoid in motor learning and technique training. Adaptation of (mainly proprioceptive) receptors is a tremendous danger for progress in motor performance and the variable availability of gestures. Due to a lack of variation of stimuli, receptors no longer provide differential information to the CNS and this can cause what is known as stereotyping. This phenomenon, which induces undesired effects (such as the inability to break the speed barrier, difficulty in changing speeds, blockages in motor learning, stagnation in technique training, difficulties in capturing new types of information) hinders sports performance. In short, it causes major problems for the evolution of motor learning. Stimulating receptors in general (and particularly proprioceptors) in multiple or varied ways to avoid adaptation is one of the most important tasks of educational intervention in any physical practice. In other cases, such as in neurological rehabilitation, adaptation of receptors can be an advantage.
- **Neural Message Parameter:** another interesting element to study in sensory physiology is what we call the neural message parameter. Information in our afferent and efferent pathways circulates as action potentials. It is an immense wiring network; and thanks to its connectivity on a synaptic level, data is transmitted digitally. The neural messages have different components: frequency code, time code, spatial code and phase code. Like the Morse code which, with its temporal variability, silences and interruptions, varies the kind of information it contains. This enables us to perceive the world, both internally and externally.

  What circulates in our nervous system are action potentials, not meanings or images. One of the great mysteries of neurobiology and the philosophy of mind is to understand how we come to extract meanings that are relevant to molding our conduct from the movement of such action potentials, and how we come to generate reactions or emotional responses to these meanings. Saying that our nervous system is a huge network of cables, where bursts of action potentials or digital messages circulate, is not simple reductionism. We are not trying to say that humans are only that, we simply admit this reality and wonder about the immense mystery of meaning: how is it that we extract meaning from this kind of information processing in our brain?

Figure 2: Basic Elements of Sensory Physiology



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Conclusions and Perspectives

To conclude, we dare say that understanding the phenomena of sensory systems and studying them in depth is very important when it comes to administering decisions related to human movement. A number of interesting consequences can be derived from these inquiries:

- The construction of future learning will depend on how well we are able to train these channels of access to information.
- The phenomenon of sensation is as trainable as the phenomenon of perception.
- Therefore, everything we can offer regarding training and activating sensory-perceptual channels through the stimulation of the afferent information pathways to the CNS improves the quality of motor learning further, especially in the early stages of a person's psychomotor training (not just in sports).
- This discriminative sensory-perceptual training then favors all processes that have to do with the consolidation of the beneficial aspects of movement and the progressive elimination of errors based on a pertinent interpretation of the corrections.
- There are a great deal of educational consequences that flow from this knowledge and have to do with the need to construct special

strategies for the training of sensory function and perceptual function.

1.1.3 The itinerary of information processing in sensory systems

The time-line that follows the stimulus when it makes contact with a receptor involves modifying its resting potential or status and changing its action potentials or status, thus stimulating sensory neurons. Then, these modifications go through a switching center and follow their path to the primary cortex, where the information is distributed among different neurons specialized in reacting to very particular features of the object.

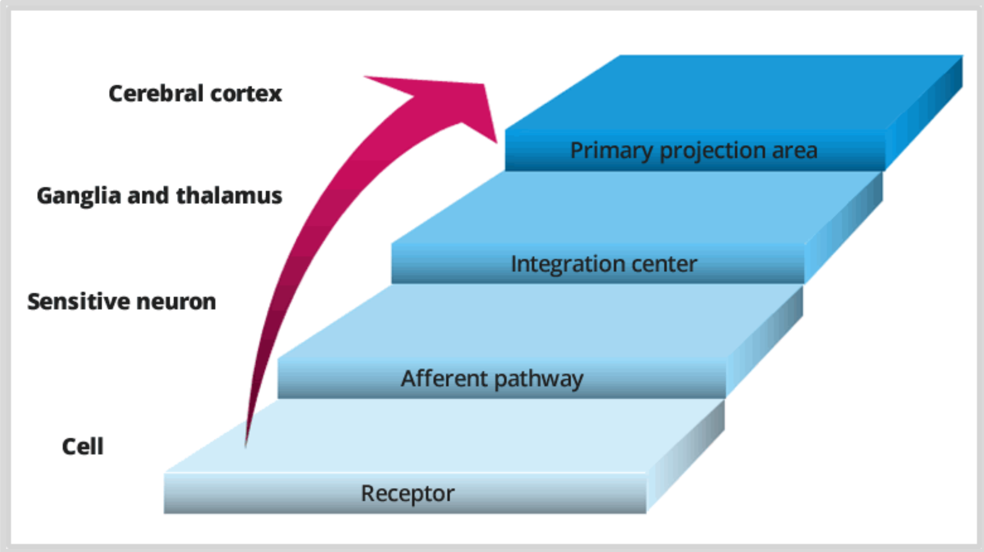
Remember also that motor functions are involved in all sensoperceptual acts; there is a specific motor action for improving the quality of data collection. Sensory systems have motor neurons which are fundamental components that modulate the activity of receptors, which allows for an increase or restriction of data input, in order to avoid damage to these cells specialized in reception. In connection with this, we want to reinforce this idea: all sensory systems have inherent motor functions, i.e., there are specific motor skills involved in the modulation of sensory systems to improve the quality of how the information is collected from both the internal and the external environment. For example, for receptors called intrafusals to capture information about the state of muscle length we also have motor systems (gamma motor system) that adjust or calibrate the state of the receptor to more accurately collect information on muscle length. The visual function also involves motor tasks that modulate the activity of the iris, opening or closing the pupil, which allows more or less light to enter. In turn, again in the visual function, we have motor neurons that modulate the activity of the extrinsic eye muscles to continually capture, with different cones or rods, the same object and, thus, allow those that initially did it to re-synthesize their neurotransmitters and be available to be used to process new information. These are micro-movements generated to improve the quality of how the information is collected. The reception of information is not a passive phenomenon, but rather an active motor skill.

These ways of processing information, or these pre medullary commutations and subsequent post-medullary commutations, have an obligatory relay in different nuclei of the thalamus where the information, before reaching the cerebral cortex, is again switched, integrated, and also often altered. The information is cross-processed, i.e., when we use one hemibody's set of sensory systems, almost all of it is processed by the opposite sensory hemisphere. For example, our right side sensory systems provide information to the left cerebral hemisphere and, similarly, all sensory systems on the left side provide information to the right brain hemisphere. With regard to the above, in recent years subjects have been classified as either homogeneous or heterogeneous: homogeneous are those that capture information predominantly from a single hemibody and heterogeneous are those who do so from both hemibodies in a balanced manner. This classification is not only for the capture information but also for motor actions. Homogeneous, in this case, are those that predominantly use a single hemibody in actions implicating fine and coarse coordination, while the heterogeneous employ both hemibodies proportionately for these actions.

There are also evaluations to detect this dominance, whether for athletes or otherwise. The usefulness of these tests varies. From them one can enhance educational results to activate the side that is less used or optimize the skills of the dominant side. In our practice, when we use these evaluations it is primarily to try to balance the quality of how information is collected by sensory systems distributed in either of the two hemibodies. This occurs especially where the subject tends to under-utilize one of them, because we understand that the greater the amount of information collected from the sensory system that is less employed, the greater our ability to make good decisions and improve motor programming. From these fundamentals, the underlying question becomes obvious, namely: Is it more advantageous to be heterogeneous than homogeneous? This is a question we cannot answer and something that future scientific research will be responsible for revealing. We can, however, make reference to cases of sports stars with both characteristics. There are almost as many that are homogeneous as heterogeneous.

The information is crossed before it is processed in the thalamus. To illustrate the function of the thalamus, we can use the analogy of an international airport that receives flights from around the world and from which depart domestic flights within the country. Similarly, all sensory information (except smell) reaches the thalamus before moving on to the primary cortex for its detailed analysis.

Figure 3: Itinerary of the Information



Source: prepared by the author.

It is precisely through the quantity and quality of information that our receptors can collect that the quality of the entire data processing activity depends. Perception will never be better, in quality, than what the sensory systems are able to provide; therefore, representation will never be better than perception and motor logic, just as decision-making and motor programming will not be better than the previous steps. That is why in the process of acquiring improvement, stabilization, and varying availability of voluntary practice, we have a very large dependence on the information our sensory systems are able to incorporate or provide. One of the great features of our nervous system is to collect information from the external and internal environment, because the generation of behaviors that allow adapt to the environment depends on the quality of this information and its interpretation. Thus all the problems that could leave us with no chance of survival from an evolutionary point of view are avoided. Sensory systems are highly trainable, and their importance lies in that the subsequent psychomotor process depends on this step of acquiring information. Such systems are the access channels to crucial data. The rest of the psychomotor process will depend on the ability that they have to collect and transmit the information.

It is also important to consider what these sensory systems are and what their importance for different sports is, know how to evaluate them, know the basic educational approach for training them, stimulate them in children from an early age, and counteract their involution in the elderly.

The consequences of training them is rooted in the importance of preventing injury based on their stabilizing effect on the joint system, the final modulation of sensorimotor references that give precision to the gesture, the dosage of the levels for the application of strength in all their expressions and magnitudes, and self-detection of functional abnormalities and their subsequent regulation of effort.

1.1.4 The importance of afferent processes for the correct neuromotor programming, execution, and control of movements

The information that was collected by the receptors and modified the status of the sensory neuron continues its journey to the control centers. It is switched and finally reaches the cerebral cortex, to areas which we call primary projection or striated areas, which have become specialized to receive this information after being processed by different lateral geniculate nuclei of the thalamus and other previous instances. Among the areas of primary projection that we are interested in for processing the information and that we need for neuromotor programming, we can cite: in the occipital lobe, **area 17 of Brodmann;** in the temporal lobe, **area 41;** in the parietal lobe (ascending parietal gyrus), **areas 3, 1 and 2** for processing mechanical, thermal and pain information; **area 5** for proprioceptive information, and **area 7** for vestibular information.
What particular features are present in these areas of primary projection? There are several interesting points to consider:

- First, the size assigned to each part of the body in every area of primary projection depends on the density of receptors in that sector of the body. That is the reason for inventing the concept of a small man or sensory homunculus, to account for the fact that the density and size in that area of primary projection correlates to the number of receptors in that part of the body.
- Another reason 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 organize the distribution of data collection systems that are on the periphery of our body. Our brain, somehow, is also a small map that accounts for the distribution of receptors on the periphery and this re-circulation of the information captured from the periphery by the structures of the CNS is what 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 the outer world and the inner world.

The cerebral cortex has **6 neuronal layers** (nodal, external granular, external pyramidal, internal granular, internal pyramidal, and multiform). In turn, in the areas of primary sensory projection (listed above), the two initial paired layers (layers 2 and 4 that are called granular) have a significant thickness with respect to the other layers, because they are areas where the information is received.

One detail that should be taken into account is that when the information reaches the primary projection area, it does not do so haphazardly, but rather follows a very specific path of conduction in the granular layers.

Another interesting detail of primary projection areas: there is a topography that reflects the distribution of receptors on the periphery. For example: for each sector of the retina there is a corresponding sector in the visual primary projection area or Brodmann area 17, a specific set of neurons (the rods of the retina correspond to a more external sector of the PPA (Primary Projection Area) and the cones correspond to a deeper or more central sector). In these primary projection areas, access to information is organized and stimulation of the neurons that constitute it also follows a specific order. The combination of this information between the granular layers also follows a precise order. There is a structural and functional order to capture information with greater quality.