1.2 Sensory modalities

Sensory modality:

Sensory modality is the specificity of sensory systems to receive a certain type of information and not another, though this is not exclusive.

For example, the visual system is specialized for capturing light. The rods and cones are activated by a chemical process in the retina triggered by the access of light information. However, if we close our eyes and aurally stimulate the eyelids, we can also activate the rods and cones and generate visual information, i.e. the same receptors specialized in capturing information of a particular modality may also capture information of another. However, sensory modality refers to the type of information for which these systems have become specialized.

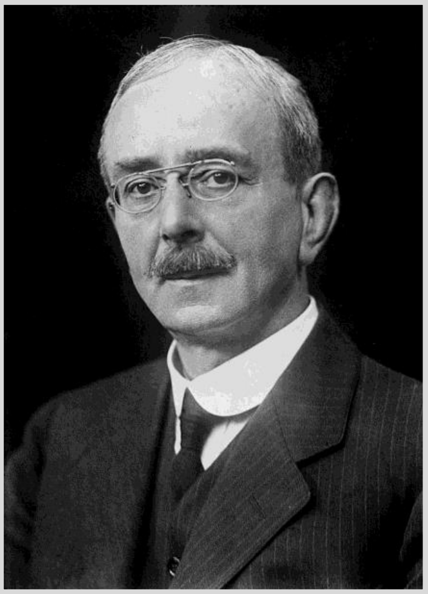
1.2.1 Proprioception

The term **proprioception** was coined in the late nineteenth century and early twentieth century by Charles Scott Sherrington (Nobel Prize for Medicine in 1932). "Proprio" comes from "oneself," "ception" comes from "reception," therefore, proprioception means "to receive information from oneself."

Proprioception is a sensory system that provides information that contributes to the overall perception we have of our body at rest or in motion. This component of perception arises from the excitation of receptors located in the skin, joint capsules, muscles, tendons and inner ear.

But the key aspect is how this information is analyzed by the higher nerve centers. The mission of the proprioceptive system is to verify the situation of the peripheral systems responsible for movement and non-movement or position. Proprioceptors estimate, consult, and weigh the state of the effectors responsible for position and movement. The muscular system is subjugated to the passive motor apparatus, but the latter is not so only regarding the mechanical forces acting on our body, but also with respect to other functional systems, especially the neuroendocrine (e.g. neuropeptides and their key influence on connective tissue).

Figure 4: Charles Scott Sherrington



Source: https://goo.gl/pR6KMD

We shall start out with the observation that proprioception is very important for the integration of posture and movement. Walter Hess had a brilliant idea of an analogy to explain this: the example of acrobats.

There are 3 acrobats where two are on the ground holding the third one above them. Imagine that the task of the one that is above is to jump. What happens if at the time that he intends to jump, the ones below are not concentrated or distracted? We could hypothesize that at the moment of jumping, the acrobat would push back his teammates and the gesture would fail. However, if the two lower acrobats first strengthen the link between them and only then, once firmly connected, the acrobat above jumps, the jump will have more quality, support and obviously a lower risk of causing injury to those that are below. If the bottom two are languid at the time of the jump, there could even be a fracture.

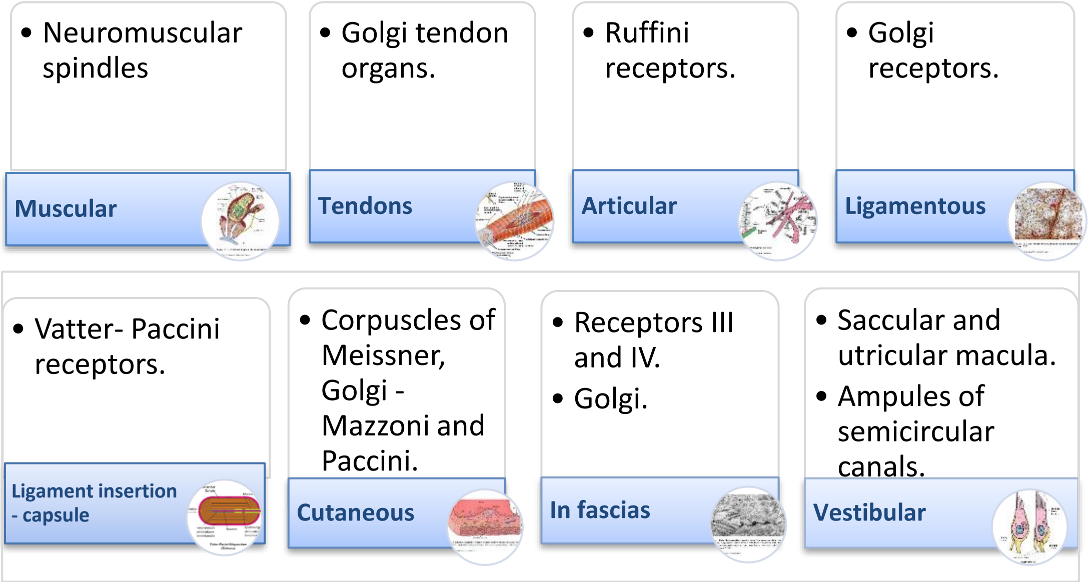
When the brain, the commander of this action, detects that the bottom two are distracted, this initial project to recruit many muscle fibers will suffer an inhibitory process. If we persist in the intention of generating high levels of force, in support of the base with the disconnected and distracted lower acrobats, we can potentially inflict serious injury on them.

This is the analogy that Walter Hess used to explain the relationship between posture and movement: imagine a line between the shoulders of the acrobats below and above. Below the line "position," above the line "movement"; below the line "tonic activity," above "dynamic"; below "stability," above "propulsion." In short, what we mean by this is that the anticipation of postural stabilizers provides quality to the motor gesture. In proper programming of human movement, the gamma activity and the alpha gamma loop should anticipate the alpha activity. The quality of the propulsive motion system can never be superior to the quality of the actions inherent to stability and posture, even for the purpose of generating high levels of strength.

The relationship of this and proprioception is precisely that the actions of the stabilizer system depend on the quality of information that the proprioceptive systems can potentially generate and inform the central nervous system. That is why improving proprioception optimizes the quality of movement, improves the transfer and generation of force by reducing the magnitude of the inhibitory phenomena. This is extremely important in injury prevention mechanisms.

When we talk about proprioceptors, we recognize various types, with differential functions and with afferent neurons that communicate with the CNS and transmit data with different codes to be interpreted and, from there, to generate more relevant regulations of the motor act.

Figure 5: Proprioceptive Receptors



Source: prepared by the author.

Proprioceptive receptors provide the information for the definition of these concepts:

- *Statesthesia:* this is the sense of position or non-movement.
- *Kinesthesia:* refers to the sense of change of position or movement.
- *Coenesthesia:* the aggregate of impressions arising from organic sensations, which forms the basis of one's awareness of the body or bodily state. It involves an awareness of the overall state of the

body to perform its own functions and from the neuromuscular standpoint, perhaps it can be described as the desire and willingness to move.

Among the different proprioceptors, we find: **muscular** (spindles and intrafusal fibers) **tendon** receptors, **joint** receptors (Ruffini), **ligamentous** (described by Camilo Golgi), receptors of the **insertion of the capsule ligament** (Vater-Pacini), **cutaneous** (Meiser, Golgi and Paccini), and receptors **in fascias.** Particularly, these receptors in fascias influence the regulation of the motor act, just as vestibular receptors influencing their regulation through so-called **macules** (both saccular and utricular, that detect accelerations forward, up and down, and turns and braking in the transverse axis), and the **ampules** (in the semicircular canals, which allow us to detect starts and/or accelerations of turns around medial and longitudinal axes).

The arrangement of these proprioceptors will be well detailed as we process them analytically. Basically, the intramuscular fibers, the neuromuscular spindles and the intrafusal fibers are in the middle third of the muscle, while Golgi bodies are located in the muscle - tendon transition, because they monitor the degree of tension in the connective tissue.

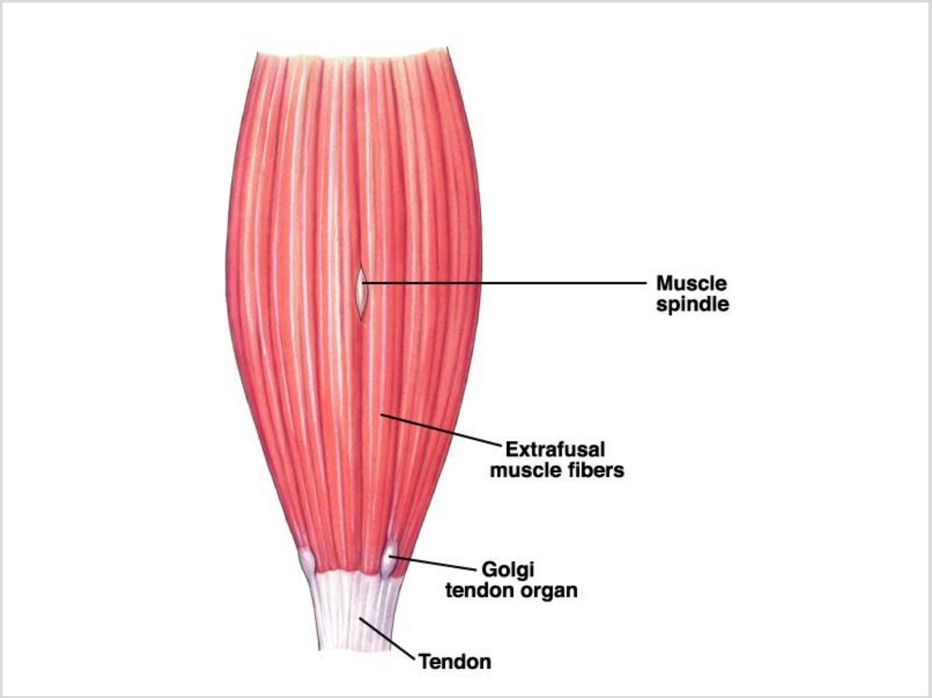
Proprioceptors allow us to understand the difference between kinesthesia, statesthesia, and coenesthesia. These receptors have the particularity of constantly transmitting information to the central nervous system. All proprioceptors (intrafusal receptors, tendon, ligamentous, etc.), except for cutaneous receptors, emit a discharge of action potentials at a certain frequency. As soon as a change in position is produced by a traction, compression, or torsion, by which the muscle, tendon, or joint receptors are stimulated, there is a modification in the discharge per unit of time which makes us aware that we have moved, i.e., the change of position.

Proprioception leads us to recognize position by a sense called **statesthesia.** When we change position and the same receptors modify the pattern of discharge per unit time, we note that change of position and we realize that we have moved. This sense is called: **Kinesthesia.** Statesthesia and kinesthesia are not the same; however, the information from which we become aware of position and movement is provided by the same sensors.

On the other hand, **coenesthesia** is the sense that allows us to detect the general arrangement of organs and systems to perform the functions associated with them. Most likely you have woken up in the morning and had a strong desire to move, you feel prone to movement, wanting to train or move, and yet other days you feel almost like "the atmosphere crushes you," you feel heavy, and you do not feel like moving. How is it that we feel these sensations for movement? The coenesthetic sense is precisely that which gives us information about the state in which the protagonists of our future actions are to be able to implement them appropriately or not. Coenesthesia also depends on proprioception, on interoception in general, while kinesthesia and statesthesia are particularly dependent on proprioception.

There are a lot of proprioceptors; however, we are going to describe two of them (the best known) in order to explain how they operate in the regulation of human movement. These two are: neuromuscular spindles (and the intrafusal fibers they accommodate) and the Golgi tendon organs. Both have a common denominator: the intrafusal fiber monitors muscle length and the Golgi organs sense the degree of tension in connective tissue. Neither are force sensors, this is very important to point out as it is often believed that the Golgi tendon organs rate force and what is really rated is the degree of tension in connective tissue. From this they will trigger reflex actions conducive to the protection of this passive motor apparatus.

Figure 6: Neuromuscular Spindles and Golgi Organs



Source: University of Costa Rica, SF, http://bit.ly/29pwkeC

Neuromuscular spindles and Golgi tendon organs are, at least, those for which the most descriptive and explanatory literature is available. Both have one thing in common: they record the tension levels in connective tissue. Neither are force sensors, though they contribute strongly to its modulation, and both play a key role in motor control and injury prevention.

First, let's concentrate on the intrafusals fibers found inside sacs that are called **neuromuscular spindles.** Neuromuscular spindles, which are located in the middle third or muscle belly of the skeletal striated muscle, are connective tissue sheaths that are attached to the other endomysium and connect to both ends of the skeletal striated muscle. These sheaths or bags accommodate a limited number (between 2 and 4 and up to 10 and 12) of specialized muscle fibers that are different morphologically, functionally, and structurally from the rest of the fibers therein. It is precisely because they are inside these bags known as neuromuscular spindles that these fibers are called **intrafusals,** to distinguish them from fibers that are outside or on the external side of the sacks, called **extrafusal fibers**.

Inside the neuromuscular spindle, the intrafusal fibers are not all the same. There is a percentage of intrafusals known as **dynamic nuclear bag fibers,** others as **static nuclear bag** and others called **nuclear chain.** Generally speaking, in the same way we find skeletal striated muscle fibers that are slow and fast, in the neuromuscular spindle we also find slow and fast intrafusals. What is the distinguishing feature of these intrafusal fibers when compared to extrafusal fibers? Intrafusal fibers have contractile ends like extrafusal fibers; however, the middle third of the intrafusal fiber has no contractile filaments, only an extension of the sarcoplasm that contains a large number of nuclei within it. This middle third of the intrafusal fiber is in contact (by continuity, i.e., by an anatomical link) with a sensory neuron; in the case of rapid intrafusals, they are connected to a **sensory neuron type IA,** while slow intrafusals are connected to a **sensory neuron type IIA** with a slower conduction speed.

This central portion of the intrafusal fiber that has no contractile filaments is specialized to respond to longitudinal deformation. When this central portion is stretched, it modifies the resting state of the sensory neuron and notifies the central nervous system of this change.

As mentioned earlier, there are three types of intrafusals. Those called dynamic nuclear bag (they are smaller, limited to 2 or 3 per spindle) are specialized mainly in registering the length increase rate, that is, the change in length as far as speed is concerned. These emit particular CNS data and generate a **dynamic tension reflex or traction stretch reflex** resulting in the contraction of the extrafusal fibers. From this contraction, the stretch will be limited, thus protecting the connective tissue from injury.

If we enter the playing field having uncalibrated the proprioceptive systems so that the quality of information they collect is not "good," we are increasing the risk of injury because we will not have proper mechanisms for the protection of the connective tissue. For the same reason, we will not be able to recruit motor units effectively and will therefore be less limited in the act of stretching. If this occurs sharply and suddenly, we run the risk of dragging the connective tissue and injuring it.

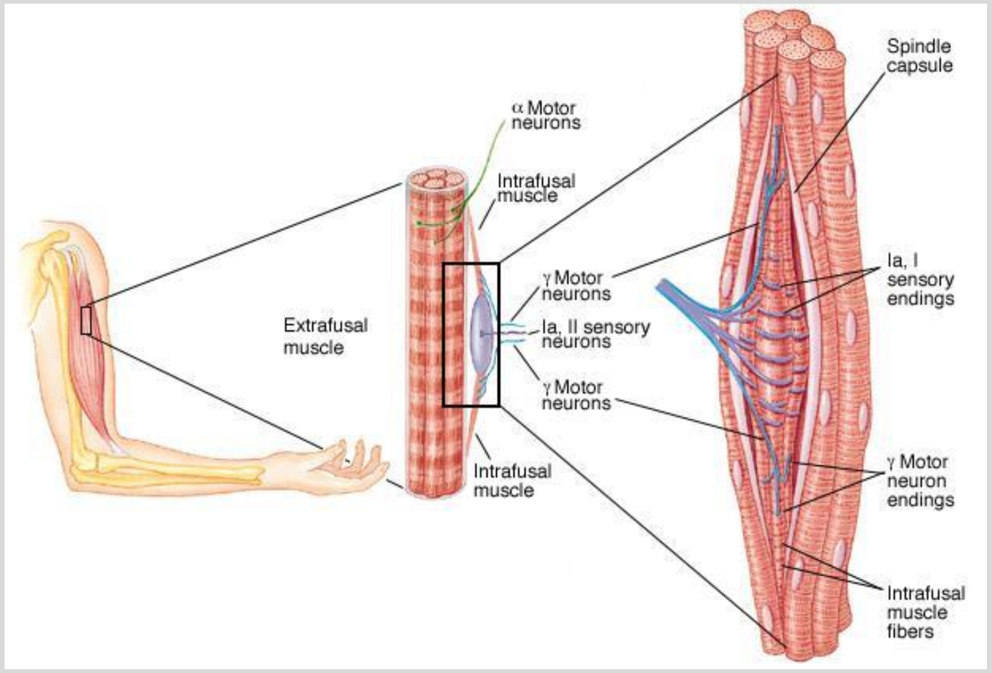
We also have intrafusals known as slow materialized, which is why they are called static nuclear bag fibers (larger and bulkier than the dynamic nuclear bag), and those known as intrafusal nuclear chain fibers, where the nuclei are in the middle (in the noncontractile sector) and not bundled (but rather, lined up in rows). The big difference between the static nuclear bag and the nuclear chain is that, in the first, the type IIA receptor spirally surrounds this central third of the intrafusal fiber (just as the intrafusal fiber of the dynamic nuclear bag does, where the sensory type IA neuron also spirally surrounds the intrafusal fiber). These receptors are called **anulo-spiral receptors.** Intrafusal nuclear chain fibers, instead of having the type IIA sensory neuron wrapping it in its central sector, its unmyelinated terminals are directly deposited in this sector. When the sensory neuron exits the neuromuscular spindle, it recovers its myelin contents (it is demyelinated inside the intrafusal fiber).

What do the static nuclear bag and nuclear chain intrafusal fibers do? They no longer monitor the speed of length change, rather they notify the CNS of magnitude and duration of change in length; as a result, another reflex called **static traction stretch reflex** is generated at the level of the spinal cord. By recruiting slow fibers, this reflex increases muscle tone for the purposes of protecting the connective tissue from injury by stretching, no longer of an explosive and sudden kind, but those whose magnitude and duration could damage the tissue.

Intrafusal fibers, both static and dynamic nuclear bag and nuclear chain, generate a traction stretch reflex, but two different versions of it. A dynamic one which recruits fast twitch fibers and a static one which recruits slow fibers. The former adapts much faster and lasts much less, thus immediately protecting connective tissue from sudden stretching. The latter adapts much more slowly, i.e., it lasts longer and protects connective tissue from injury for the duration of the stretching and the adaptive process.

Remember that there are different types of intrafusal fibers: one innervated by a type IA sensory neuron and another by a type IIA sensory neuron. There are two types of information, one that emits stretching speed and another reporting on the extent of the stretching; the question now is: if we have two types of information that are sent to the central nervous system, why are there three morpho-functional differentiations of intrafusal fiber? What are there three different types of intrafusal fibers for if there are two types of data that are transmitted to the CNS for the regulation of the motor act? These are some of the questions that science still cannot answer. The distribution of intrafusal fibers in different muscle groups varies and that influences the adjustment of motor movements which require a finer or more accurate coordination than those which are much coarser.

Figure 7: Neuromuscular Spindle II



Source: University of Murcia, SF, http://goo.gl/mP5BLo

The link between the sensory neuron and the sarcolemma of the intrafusal fiber is anatomically direct and has no synaptic cleft. Thus, the relationship is continuous, not contiguous. This link exists between ion channels sensitive to stretching, which regulate the entry of calcium and communicate with the cytoskeleton. This process is by mechanical transduction, which changes the digital pattern. We see how the sensory neuron, with no space between it and the sarcolemma of the intrafusal fiber, has an anatomical structural connection through what are called ion channels that allow direct contact. This allows us to understand that when the central portion of the intrafusal fiber is deformed, the structure of the sensory neuron changes more easily. Resulting from this, the generation of impulses to the CNS is modified.

Therefore, there is much to say regarding how this **muscular proprioceptive system** (which is the best known and most abundant or the most significant for proprioceptive analysis) influences the regulation of the motor act as such.

Proprioceptive systems, particularly neuromuscular spindles, are subjected to influences generated by other functional systems. By way of example: the intrafusal fiber has receptors that are stimulated by hormonal activity, so that the concentration of testosterone, the growth hormone, and estrogen calibrate the proprioceptors. This affects how they function during motor actions in the everyday life or sports. It could also explain how, increasing the tension of intrafusal fibers under the influence of these hormones, we can easily understand the lower stretching potential in men as compared to women. Another of the influences of intrafusal fibers relates to the more or less gelatinous state of the intra-sarcoplasmic structures that configure it, called thixotropic properties.

There are, then, various influences on the neuromuscular spindle: the state of the intrafusal fiber is variable and depends on many factors. Some of them are: hormonal factors, thixotropic factors and neuro-tonics factors. This will be decisive in their educational implications.

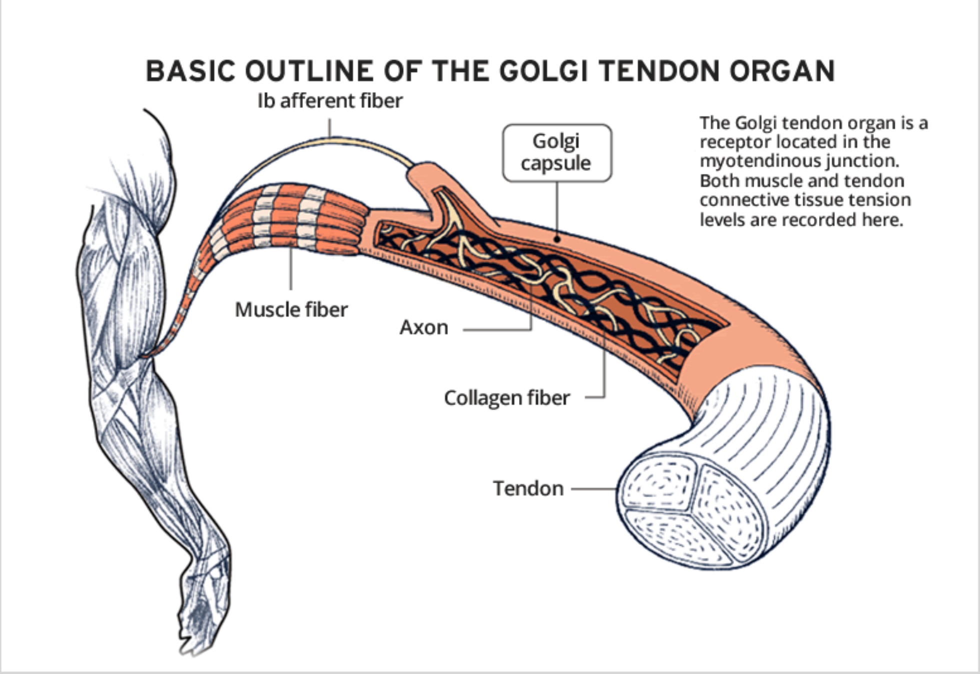
Hormones (such as testosterone, growth hormone, and estrogens) are a great influence because they have receptors in these fibers. The thixotropic properties can be understood as the degree of esterification of the gels, both intrafiber and those relating the fascias and their friction. Finally, muscle tone and the greater or lesser discharge of the gamma motor system, on which depends the tone of the intrafusal fiber and its impact on its own responses.

The intrafusal fibers promote regulatory reflex responses, but rather than talking about reflexes, such manifestations should be understood as **regulative behavior.** They have precise objectives and trigger integrated synergistic movements with well-defined objectives inherent to the conservation of homeostasis. We will briefly explain two traction stretch reflexes: first, one known as **dynamic or phasic,** which arises from the activation of the dynamic nuclear bag intrafusals (with innervation IA) and communicate information regarding the stretching speed. This reflex has a low threshold and rapid adaptation, it reflexively activates the fast extrafusal fibers (FT) and its main role is to protect the structure against fast stretches; on the other hand, we have the **slow or tonic reflex.** This one depends on the activation of nuclear static bag and nuclear chain intrafusals (with innervation IIA), which communicate information concerning the magnitude and intensity of stretching. With a higher threshold than the rapid ones, and slower adaptation, they reflexively activate slow extrafusals (ST).

Golgi Tendon Organ

It is a **sensor of the degree of tension of connective tissue,** both muscular and tendon. Perhaps its greatest contribution has to do with preventing injury by activating the autogenic inhibition reflex. When load levels supported by the connective tissue are excessive, the Golgi organ promotes an inhibitory regulative response. In its maximum expression, it is known as a clasp-knife reaction. It performs other important functions in motor control in general and, apparently, is also found in the fascias, although little is known about these locations and their specific functions.

Figure 8: Golgi Tendon Organ, Autogenic Inhibition Reflex



Source: Di Santo. 2011.

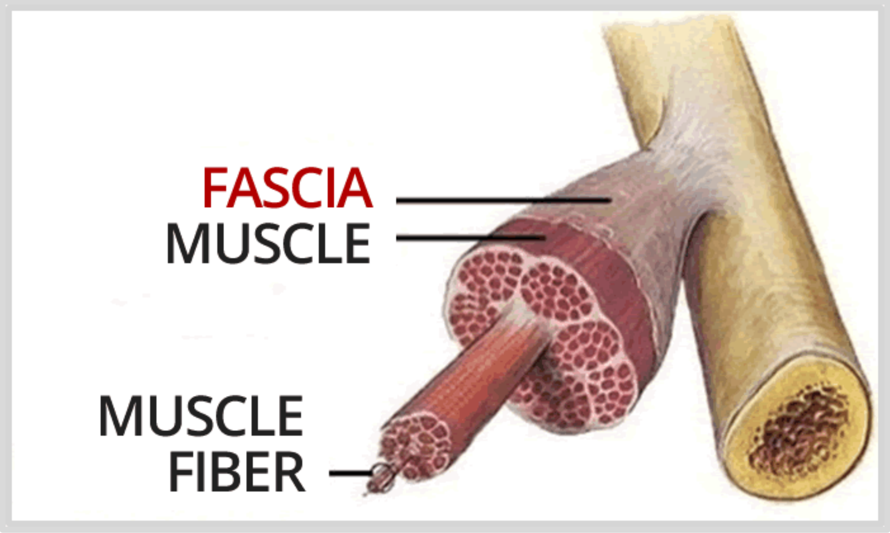
The **autogenic inhibition reflex** is trineuronal and bisynaptic. Before stretching, it takes longer to promote its specific effects than the traction stretch reflex and most records show that it is not before 6 seconds that its inhibitory effect predominates over the excitement of the traction stretch reflex. Its inhibitory effects can be quickly reversed. During dynamic gestures, its contribution does not seem to be inhibitory, but rather excitatory; therefore, in postural and motor regulations, its responsibilities appear to be different, though little is known of the latter function. This reflex (autogenic inhibition) is promoted by all those stimuli that generate an increase in tension of connective tissue, such as stretching, myotendinous union massage, eccentric contractions, concentric and vibration.

The Fascias

The **fascias** are much more than mere muscle sheath. They constitute a high value **proprioceptive network** for motor control and the promotion of reflex responses necessary for the quality of muscle function.

The fascia represents the dense connective tissue (regular and irregular) that forms, in different ways (fascia, tendons, ligaments, joint capsules, neural coating, etc.), a continuous network of connection between the elements of the locomotor system, as well as the loose connective tissue. It fills the interstices of the body and, thus, creates links among all its anatomical components (vascular, nervous, visceral). These links act not only as a means of anatomical union, but also fulfill functional tasks.

Figure 9: Fascias and Complex Architecture



Source: salud y pilates [Health and Pilates]. Undated. Taken on 7/20/16 from http://goo.gl/rWC3JA

It plays an important role in maintaining body posture, movement control, and integration. The fascia not only surrounds the muscle fiber (epimysium) but also infiltrates the muscle and adipose tissue and this makes it very specific for each person.

It forms a three-dimensional network of interconnection between the macro- and the micro-structural body that penetrates the deepest spaces of its construction. These connections can reach cellular and intracellular levels. Epimuscular connectivity is not just mechanical, but neuro proprioceptive. This is key in the transmission of force and range of motion.

The **proprioceptive refinement of fascias** was proposed by Schleip (2013), who formulated principles for training the fascias. Very briefly, he suggests regular maintenance in the condition of fascias as a possible strategy for a better motor control. This is one of the most important pillars of fitness. He suggests:

- Slow static and dynamic stretching.
- Micro-stretching and pandiculations.
- Regular tension.
- Tumbling and lymphatic drains.

These are fine myelinated fibers that start at the fascias. Remember that the Receptors III are mechanical distortion receptors (ergoreceptors) and some of the Receptors IV are nociceptors and others are metaboreceptors. Receptors III initiate and maintain the exercise's ventilatory reflex responses. They are activated when oxygen consumption and blood flow increases and while the intermittent sustained contraction stimulates them.

In recent years, there has been much research on the role of fascias as proprioceptor organs. However, there are many doubts about the role of fascias:

How are proprioceptors distributed in the fascias? Does this distribution depend on the architecture of these fascias? How do they contribute to motor control? What happens when they are injured?

Capsular and Ligamentous Receptors

They respond primarily to compressive and torsional forces.

Ruffini in capsules, Golgi in ligaments, and Vater-Pacini in the insertion of the ligament in the capsule, provide crucial information regarding regulation of muscle activity, on which joint stability depends. Indeed, a ligament "links" because it informs.

To conclude:

- Proprioceptors work together.
- Their dissociation, for training, is virtually impossible.
- We cannot train one type of proprioceptors without the other or without each other.
- The evaluation and training proposal involves an integrated and comprehensive approach.
- Touch and proprioception also do not readily dissociate, which allows us to address another type of sensitivity: haptics.
- Only the vestibular sense could be addressed with a little more independence, but not much.

1.2.2 Tactile and haptic modalities

The **tactile sense** is key to motor control in most human movements, but in sports its role is crucial. Primarily in combat sports with fastening components, tactile data are very important for the fine and final regulation.
In the elderly, the provision of information from touch receptors is very important for most adaptive behaviors. The same applies to all activities in which the manipulation of elements is a distinguishing feature.

The lack of attention to this sensory system in the literature of most training methodologies never ceases to surprise us. However, its contribution is equally or more important than other sensory analyzers and can be trained like any other. It takes on vital importance when access to the visual analyzer is impossible. We have not found specific methodological proposals for training it, hence the need to propose some elementary coordinates. Usually, they work in synergy with the proprioceptive analyzers that allow differential processing, very important for motor behavior: haptic sensitivity.

We employ haptic sensitivity in all daily activities. When we lift weights, in detecting the weight of an object, and even that of our own body, we cannot separate the information provided by the tactile and proprioceptive receptors, that is, when we tie our laces, when we button our clothes, when we cook, etc.

Both tactile and proprioceptive sensitivity as well as haptic sensitivity operate syncretically in most human actions. They can be trained separately, no doubt, although they operate in an integrated and comprehensive manner in motor control.

1.2.3 Vision

This is perhaps the most influential sensory system in the resolution of motor actions in team sports and many others. The speed for processing and constructing images is key to motor functions involved in survival.

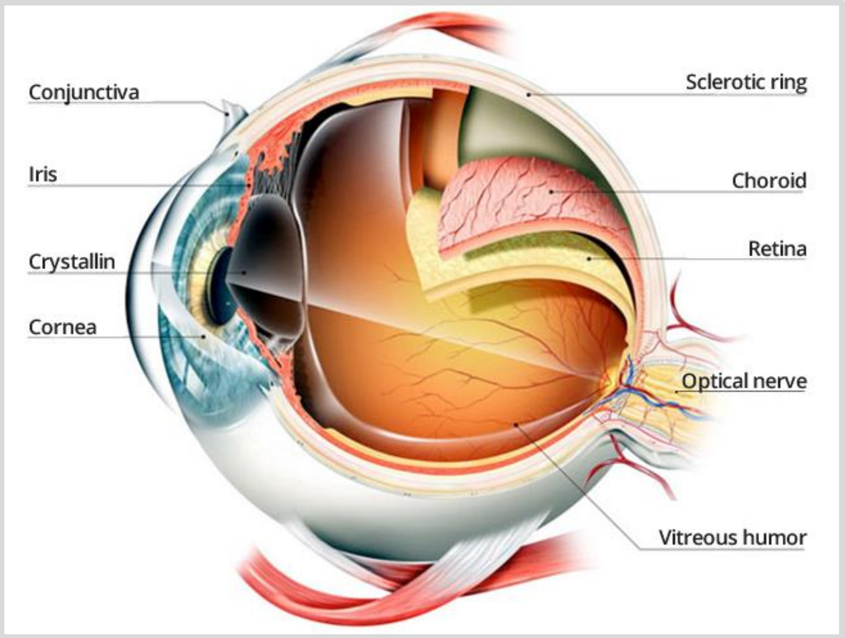
- The process of seeing consists roughly of the following steps:
- Light from the sun or other sources shines on the objects and is reflected by these.
- Visible light enters the eye, penetrates numerous transparent bodies and is refracted, so an inverted image of the object is formed on the surface of the retina.
- The retina converts the signals (action potentials generated at different frequencies) which, via the optic nerve, head for integrative CNS centers.
- The information from the retina is processed in complex neuronal groups located primarily in the thalamus, the brain stem and the cortex. The sense and perception of vision result from integrating them.
- As a final step, there is a motor adjustment of the eye as an instrument for collecting external information.

Remember that the human eye captures waves between **400 to 700 nanometers;** below this are infrared rays and above ultraviolet ones. The visual range capable of being grasped by the human eye is within these 300 nanometers. The human eye or eyeball is the organ whose job it is to receive visual impressions formed by concentric tunics enclosing transparent media, muscles that move it, and parareceptors that protect it.

The concentric tunics are arranged in the external portion (fibrous sclera and cornea), medium (vascular or choroidal) and internal (or neural retina). The function of these structures is to surround and contain the so-called transparent media (the cornea plays the dual role of enveloping tunic and transparent medium). The transparent chambers are formed by an anterior chamber (aqueous humor) and a rear chamber (vitreous humor).

One of the most important structures in visual processing is the **retina.** This is the layer where the transformation of light energy into action potentials occurs, which can be transmitted by neural pathway to relay centers and primary cortex in the occipital lobe. It extends from the opening in the optic nerve to the posterior surface of the iris and is composed of two parts: anterior and posterior. The latter retains sensory properties, since it is molded to the vitreous humor and is linked to it. In sum, it is pulled by it and contains two very important sectors, namely: the papilla or optic disc and macula lutea.

Figure 10: Anatomy of the Human Eye



Source: https://goo.gl/yRqWLp

Retinal layers

The retina contains **ten parallel layers.** Beginning from the surface to the innermost, they are:

1) Retinal pigment epithelium cell layer: the outermost layer of the retina. It consists of cubic cells that are not neurons and possesses melanin granules that give it a characteristic pigmentation.
2) Photoreceptor cell layer: is formed by the outer segments of the rods and cones.
3) External limiting layer: it is not a membrane, rather an inter cellular junction of the adherent zonula type (or desmosomes band) between the photoreceptor cells and the Müller cells.
4) Nuclear or external granular layer: consists of the cell nuclei of photoreceptor cells.

5) Outer plexiform layer: the region of synaptic connection between photoreceptor cells and bipolar cells.
6) Nuclear or inner granular layer: consists of the cell nuclei of bipolar cells, horizontal cells, and amacrine cells.
7) Inner plexiform layer: the region of synaptic connection between bipolar, amacrine, and ganglion cells.
8) Ganglion cell layer: consists of nuclei of ganglion cells.
9) Optic nerve fiber layer: is formed by ganglion cell axons forming the optic nerve.
10) Internal limiting layer: separating the retina from the vitreous humor.

Six types of neurons process visual information:

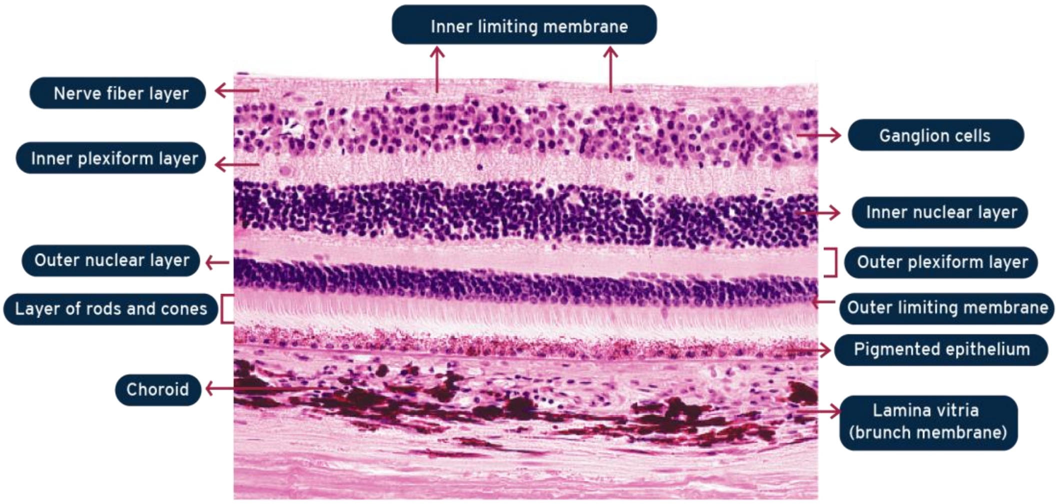
- Photoreceptors.
- Bipolar cells.
- Ganglion cells.
- Horizontal cells.
- Amacrine cells.
- Interplexiform cells.

The range of useful vision of the human eye varies between 1 minute and 10 seconds, i.e., about 11 log units approximately (double the 5 log units of most sensory receptors). The reason for this doubled range of sensitivity is the presence in the retina of two receptor systems:

- Receptors for night vision, called rods.
- Receptors for daylight vision, called cones.

The views differ on two essential qualities of visual perception: a) detecting **brightness** and b) the perception of **color.** In the moonlight, objects have no color, but vary in brightness. In sunlight, objects differ in brightness and color. The sensory surface of the eye, the retina, originates from the diencephalon and is, therefore, a part of the CNS. As mentioned earlier, it contains several layers.

Figure 11: Image of the Retinal Layers



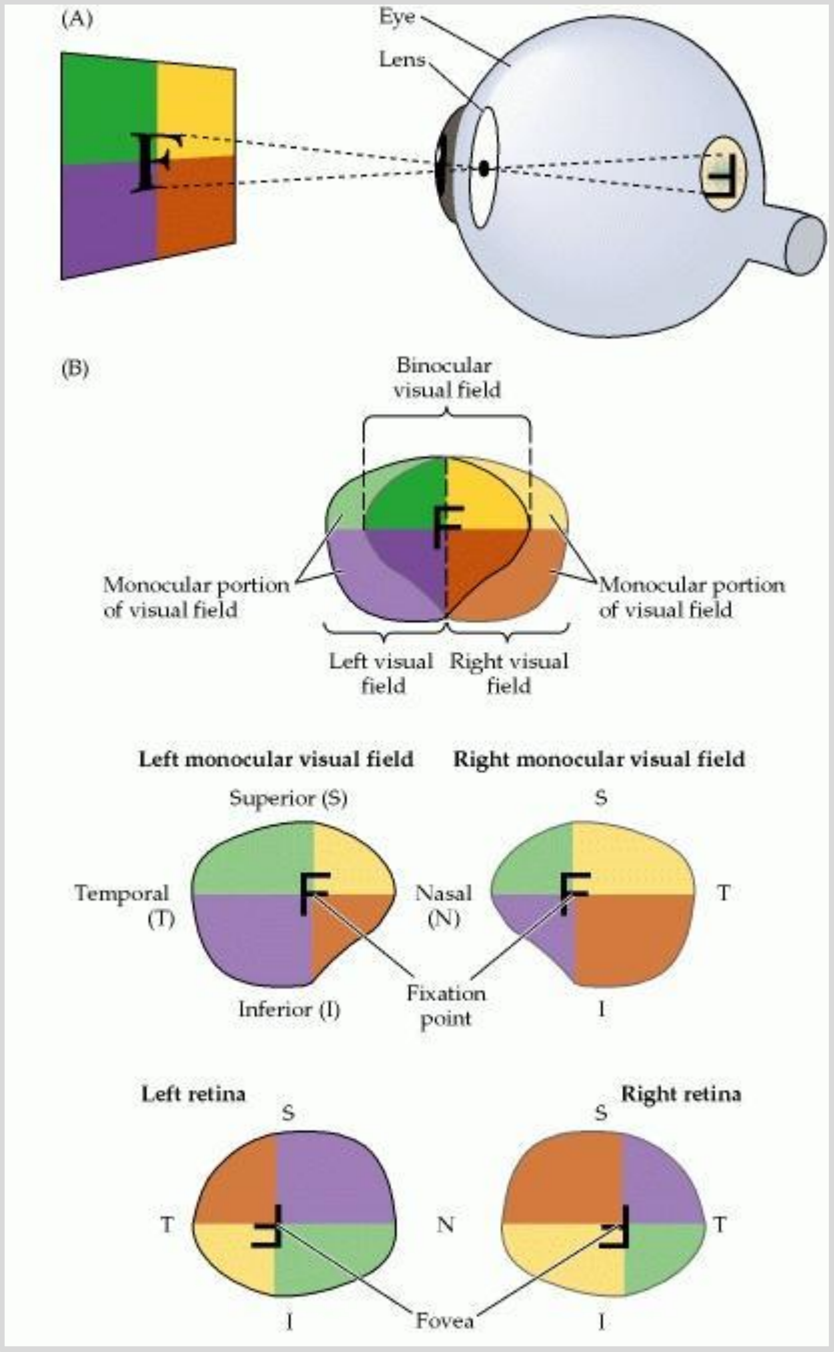
Source: Adapted from "El globo ocular desglosado" [The Break-Down of the Eyeball]. Undated. Taken on 7/20/2016 from http://goo.gl/eulNQ0

Some features:

- We see that the different layers are separated by membranes.
- There are also retinal membranes ("fascias").
- There is intra-retinal connectivity.
- The retina is a center for processing visual information and not only the reception of stimuli.
- The light passes through several layers in the retina before modifying the rhodopsin (transmembrane protein found in retinal rod disks).

The spatial relationships between the ganglion cells of the retina are maintained as organized representations or visual spatial maps. In addition, most of these structures receive information from both eyes, which requires these afferents to be integrated to form a coherent map of individual points in space. As a general rule, the information from the left half of the visual world is represented in the right half of the brain and vice versa.

Figure 12: Entry of Information Into the Eye



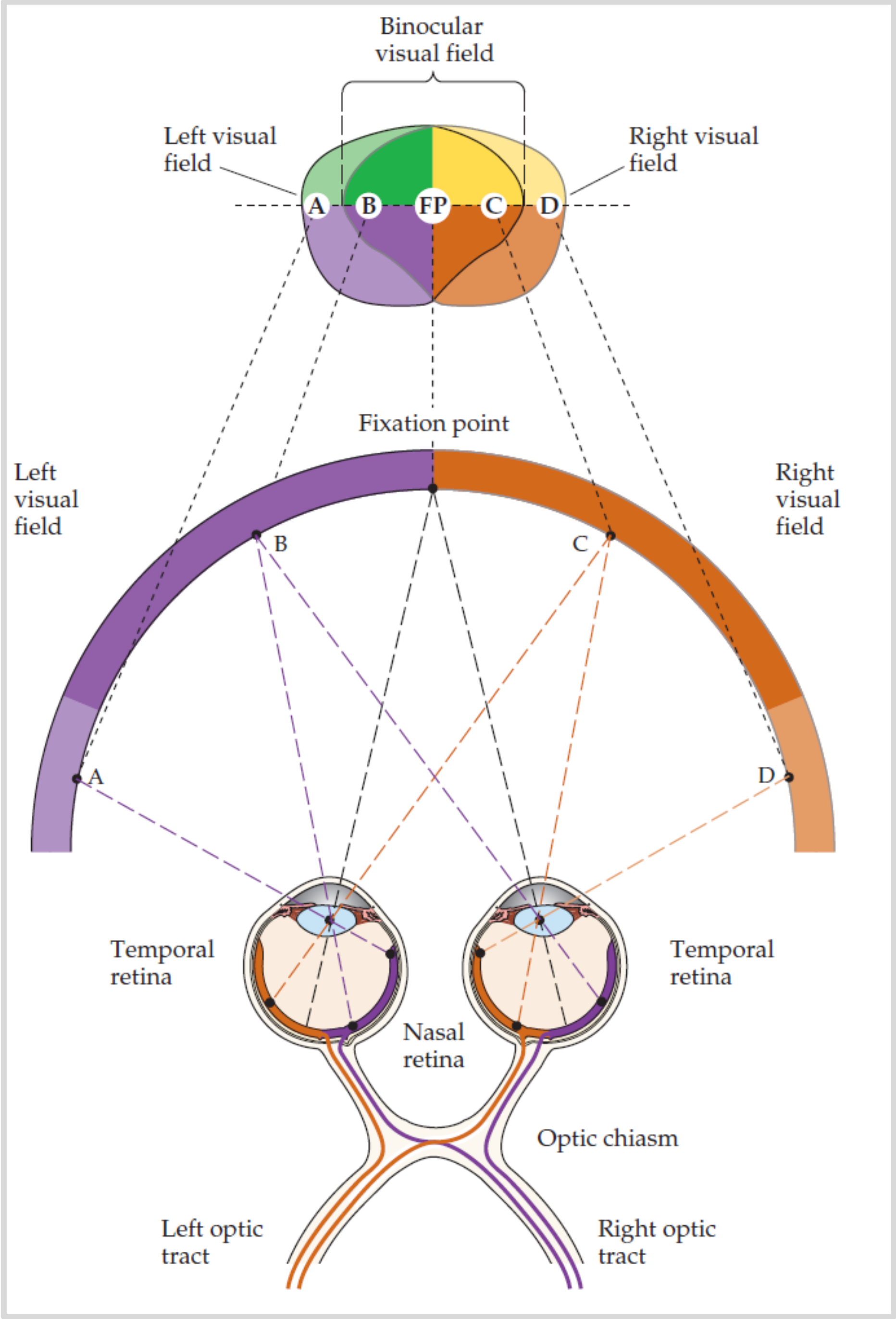
Source: Purves, Dale. 2015, p. 288

Knowledge of the neural basis, for the proper layout of the efferents from both eyes, requires one to consider how images on the two retinas are projected and the central destination of ganglion cells located in different parts of the retina. Each eye observes a sector of the visual space. For descriptive purposes, each retina and its corresponding visual space are divided into quadrants. The surface of the retina is subdivided by vertical and horizontal lines that intersect at the center of the fovea. The vertical line divides the retina in the **nasal and temporal** divisions, while the horizontal line marks the **upper and lower** divisions. The vertical and horizontal lines corresponding to the visual space (also called meridians) intersect at an attachment point (one in which the visual space falls on the fovea) and define the quadrants of the visual space. The interweaving of the rays of light diverging from different points on an object in the pupil inverts images of objects in the visual field and swaps them from left to right on the retinal surface. Accordingly, the objects found in the temporal portion of the visual field are observed by the nasal portion of the retina, while the objects on the upper portion are observed by the lower portion of the retina.

With both eyes open, both foveae usually align with a single target point in the visual space, making the visual fields of both eyes widely overlap. The binocular field of vision presents two symmetrical visual hemifields (left and right). The left binocular hemifield involves the right visual nasal field and the temporal visual field of the left eye. The right hemifield involves the temporal visual field of the right eye and the nasal visual field of the left eye. Temporal visual fields are more extensive than the nasal ones, reflecting their sizes. Accordingly, vision on the periphery of the visual field is strictly monocular, mediated by the most medial portion of the retina. Most of the rest of the visual field can be observed by both eyes; that is, the individual points in visual space, which are located between the nasal visual field of one eye and the temporal visual field of the other.

Ganglion cells located in the nasal divide of each retina give rise to axons that cross at the optic chiasm, while those located in the temporal retina give rise to axons that remain on the same side. The limit or decussation line between the ganglion cells that are projected in a contralateral and ipsilateral sense is a line passing through the center of the fovea that defines the border between the nasal and temporal hemiretinas. The images of objects in the left nasal hemifield fall on the nasal retina of the left eye and the temporal retina of the right eye, while the axons of ganglion cells (in these regions of the two retinas) are projected through the right optic tract. Objects in the right visual hemifield fall on the nasal retina of the right eye and the temporal retina of the left eye, while the axons of ganglion cells (in this region) are projected through the left optic tract. As already mentioned, the objects in the monocular portions of the visual hemifields are only seen by the extreme nasal retina of each eye: the axons of ganglion cells in these regions (like the rest of the nasal retina) are in the contralateral optic tract. Therefore, unlike the optic nerve, the optic tract contains the axons of ganglion cells originating in both eyes and represents the contralateral field of vision. The following graphic explains this description.

Figure 13: Left and Right Visual Field



Source: Purves, Dale., 2007, p. 288

Areas of Visual Cerebral Projection

Information processed by the retina is transmitted to the brain by the ganglion axons of the optic nerves, one for each eye, in two different routes. The primary route through the **geniculate striate pathway** and the secondary route**,** meanwhile, through the **tectopulvinar system.** These two systems are two specific formations located at precise locations in the brain. The two optic nerves cross at the optical chiasma. At this crossroads in the form of an X, fibers of the left eye go to the right brain and others to the left. Similarly, fibers of the right eye go to the left brain and others to the right.

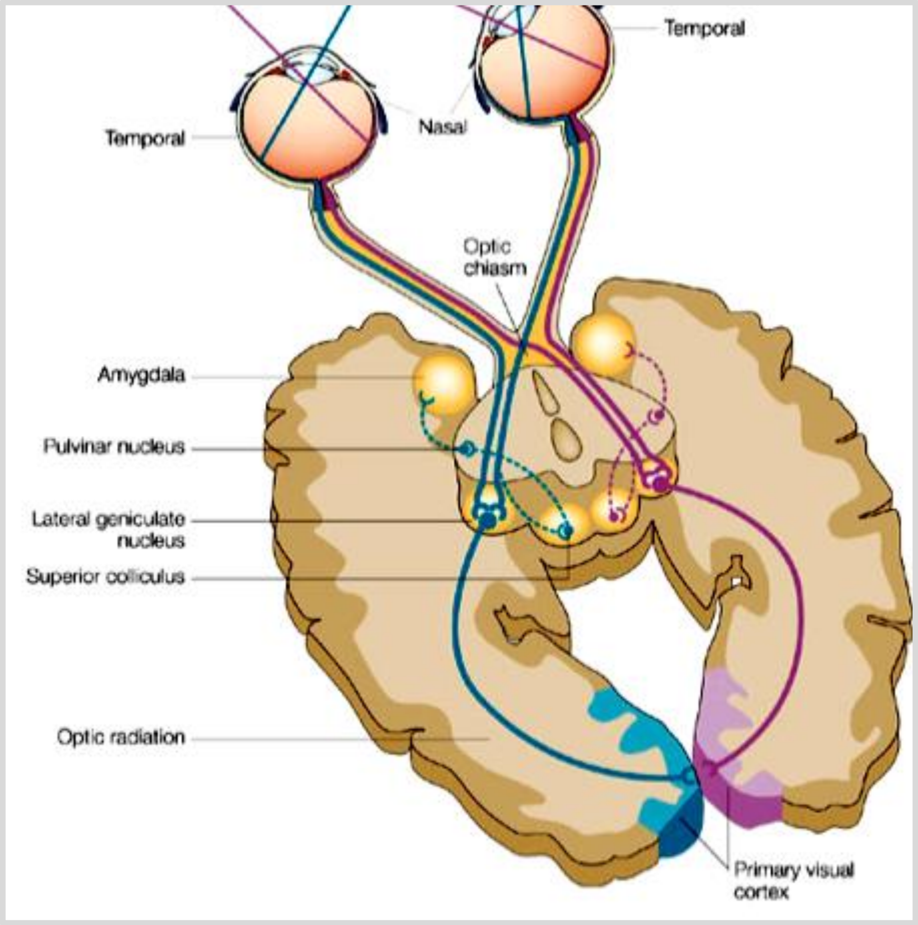
The fibers of the temporal retina (the side closest to the ear) remain in the same hemisphere, while the fibers of the nasal retina (closest to the nose) cross to the other hemisphere.

We will detail below the primary and secondary pathways of the optic tracts:

Geniculate striate system: formed of fiber bundles leaving the optic chiasm, are not now called optic nerve, but optic tract. A major part of these fibers reach a brain formation called lateral geniculate nucleus (LGN) located in the thalamus (midbrain), where they synapse with corresponding neurons. The fibers exiting the LGN open fan-like and reach the occipital lobe (posterior area of the brain), that is, area 17 (striate cortex or primary visual cortex) and areas 18 and 19 (extrastriate cortex or secondary visual cortex). Visual functions of the geniculate striate system specialize in identifying and recognizing images.

- *Tectopulvinar system:* the other part of the optic tract leads to a formation at the base of the brain (midbrain), evolutionarily much older, known as the tectum. The visual part of the tectum connects to the superior colliculus, where the projection goes further up to the thalamus, the pulvinar and the lateral posterior nuclei. Finally, the fibers are directed to the visual areas of the cortex.
  The visual functions of the tectopulvinar system have to do with the location of objects in space.

Figure 14: Geniculate Striatum and Tectopulvinar Systems

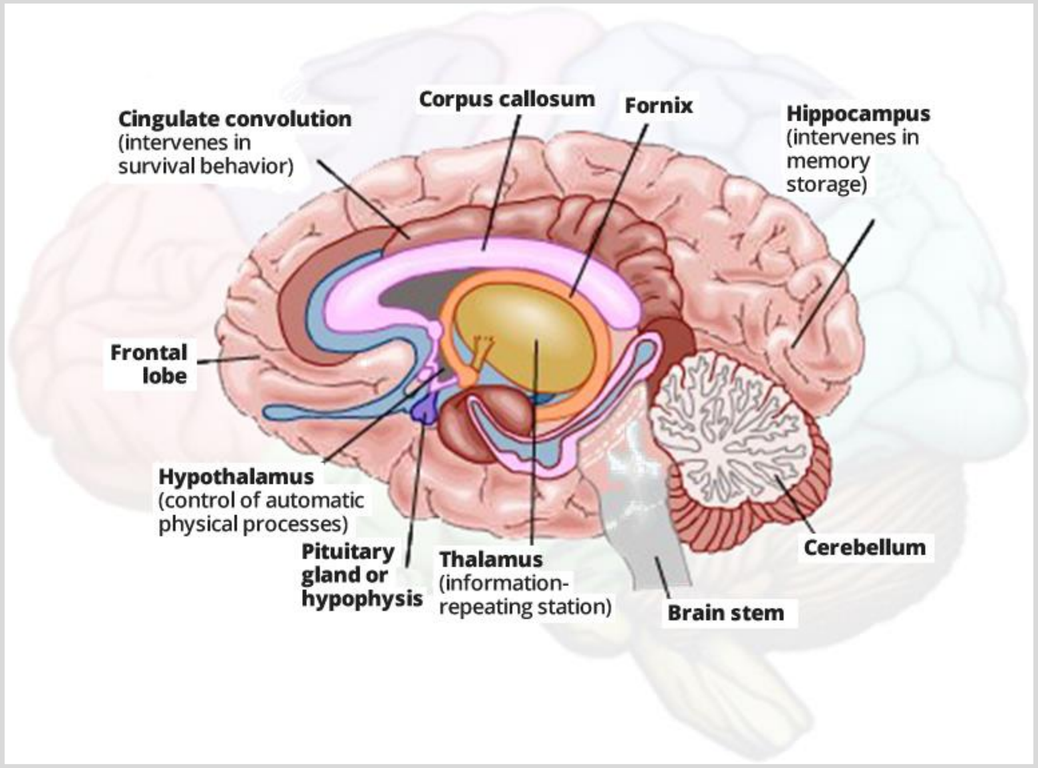


Source: http://goo.gl/o0516A

Optical Thalamus

It is a small sensory brain, where all afferent information is processed before continuing its journey to the primary cortex, except olfactory data. The thalamus also maps retinal information, with spatial distributions, as if it were a sensory homunculus. The switching is ordered. It is an ovoid nuclear complex, large, located in the wall of the diencephalon. On the outside there is a layer of myelinated fibers called external medullary lamina that separates the main organ from the reticular nucleus. The main mass is called posterior thalamus. The anterior thalamus is the reticular nucleus and adjacent structures.

Figure 15: Thalamus



Source: http://goo.gl/bjT5sz

In Summary

We could compare the physiology of the eye with a camera: the images that are recorded on film, are processed in the brain. This allows these images to be integrated into the rest of the senses.

As we saw earlier, highly complex phenomena of the visual system occur in the retina. Light must pass through the layers of the eye to the brain.

The first transparent layer is the cornea that closes the anterior chamber. The iris acts like the diaphragm of a camera and regulates the amount of light passing through the pupil. The iris has different colors.

The lens is a converging lens constituted by plates, joined by ligaments to the second layer of the eye or choroid. By action of the muscles, the lens accommodates its shape to allow the projection of an inverted image on the retina. Variations in the size of the lens and pupil diameter are what allow us to focus on objects at different distances from the visual field.
In the retina and its layers, as mentioned above, cells called cones coexist, which are preferably stimulated during the day, allowing them

to perceive color images. At night the rods are stimulated and therefore we see objects in black and white.

1.2.4 Vestibular hearing

The Auditory System

The auditory system is a set of structures specialized in recruiting, receiving, analyzing, and coding sound reaching us from the environment. It sends information to the brain as nerve impulses for them to be perceived and interpreted. It works in synergy with other sensory systems, especially with the visual.

Anatomically it comprises:

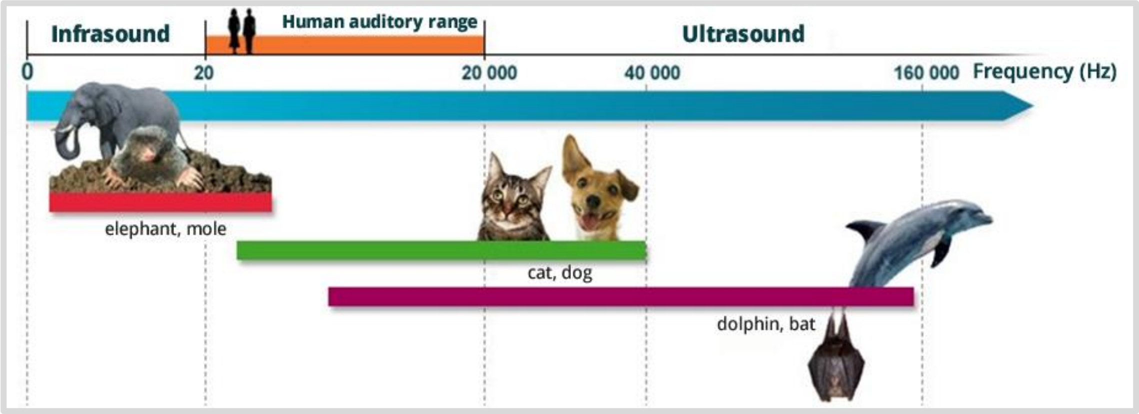
1) ***External ear***: ear and ear canal.
2) ***Middle ear:*** eardrum, ossicles, tympanic and mastoid cavities, hammer and stirrup muscles, and the Eustachian tube.
3) ***Inner ear:*** cochlear portion, nerve pathways, nuclei and auditory nerve centers of the stem, thalamus and cortex.

The auditory system is vital in physical activities as it is key to motor control. This impacts fundamentally on sports with dribbling or bounce passes and in most sports in which we encounter auditory perturbations. As an introduction, we will begin by defining sound.

Sound is adequate stimulation of the auditory receptor, it is a type of mechanical energy consisting of very small pressure variations of the environment, which propagate at high speed (340 m/s, 371,83 yd/s) in all directions from its source. This source is almost always a vibrating object, like our vocal cords. These pressure variations are repeated many times per second. The number of variations per second is called **frequency** and expressed in Hertz (Hz). Humans can capture frequencies between **20 and 20,000 Hz.** Below these figures, we speak of infrasound; above, ultrasound. Neither is perceptible by the human ear.

Sounds are pure when they are made of a single frequency, or complex when composed by several (which are what we hear daily). A few HZ frequency is low and one of many Hz is high pitched. **Amplitude** is a physical dimension of sound that refers to large or small variations of pressure and is measured in decibels (dB). Frequency is a physical dimension of sound that causes auditory sensations which we define as pitch or tone.

Figure 16: Sound Frequencies



Source: http://goo.gl/ZZC19Z

Functions of the Outer Ear

Made up of the ear and the ear canal, it allows sound to access the deep structures of the inner ear, protecting the latter from damage from the outside and helps locate the source of the sound, which is key to identifying potential sources of danger or food. Finally, another feature that the outer ear possesses is **resonance**. Upon reaching the ear canal, the sound undergoes a change in the composition of frequencies, resulting in increased intensity.

Functions of the Middle Ear

It comprises the tympanic membrane, the ossicles, the hammer and stirrup muscles, the Eustachian tube, the mastoid air cavities and membranes. The most important function is to operate as an **acoustic transformer,** that is, to make the passage of the acoustic energy from the outside air medium into the liquid medium efficient. Without the middle ear, the sound would not enter the inner ear fluid, but rather be reflected to the outside, without stimulating the receptor cells. The middle ear produces an increase in sound pressure that reaches the oval window, by differences in areas between the eardrum, the hammer anvil, and the stirrup. By differences in surface and leverage, it amplifies the sound that the oval window finally receives 22 times.

The hammer transmits the vibrations of the tympanic membrane to the anvil, the stirrup, and finally this latter to the oval window. Surface differences account for the amplification.

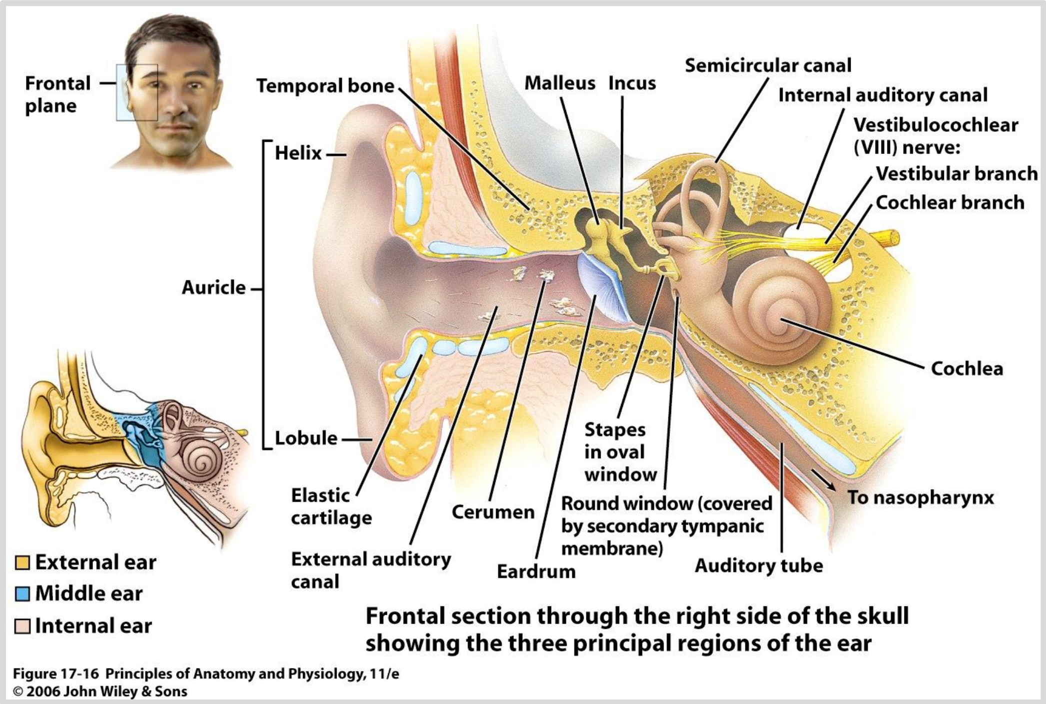
Middle Ear and Other Considerations

The middle ear protects the round window and channels sound energy such that it only reaches the oval window, preventing it from reaching the round window. If the sound reached the two windows simultaneously, it would cancel itself by acting on both sides of the cochlear basilar membrane (two waves in the opposite direction). It also communicates air cavities of the middle ear with the nasopharynx: replenishing and maintaining air pressure balance. It regulates energy and reduces the mobility of the ossicles to amplify the sound in the right measure. Thus it makes viable the transmission to the inner ear and at the same time protects it.

The Inner Ear

The inner ear consists of two parts: on the one hand the **anterior maze or cochlea** (auditory portion), and on the other the **posterior or vestibular labyrinth** (perceptive portion for accelerations and rotations). The cochlea is tube-shaped, coiled on itself, which makes more than two turns on the central axis, with walls formed of solid bone. This structure contains liquids: inside there are two different liquids, separated by membranes, namely, the **perilymph** and **endolymph.** Finally, it contains ducts and membranes: the **basilar and Reissner membranes** and the **tympanic, middle and vestibular ducts** (in the middle, over the basilar, is the organ of Corti).

Figure 17: Ear Structures



Source: Universidad de Cantabria, undated, http://goo.gl/Q22o4I

Cochlear Mechanics

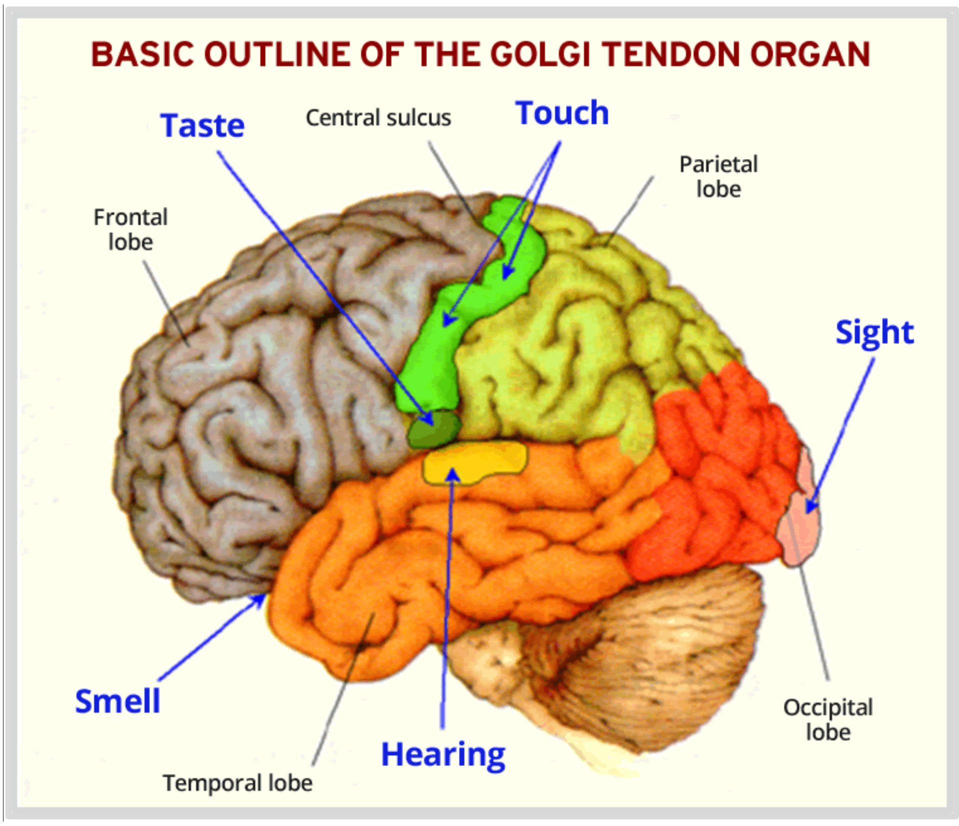
When sound reaches the oval window thanks to vibrations of the stirrup, it is transmitted through the perilymph of the vestibular duct and makes Reissner's membrane vibrate. Through it, it also makes the endolymph and the basilar membrane vibrate, on which rest the organ of Corti. The vibrations reach the perilymph of the tympanic duct, and finally, the round window. The closure of the round window allows the transmission of vibrations around the cochlea. By moving the basilar membrane, this forms "traveling waves" that are deployed to the apex. The deformation of the basilar membrane by traveling waves produces changes in the organ of Corti. This cilia deformation in the organ of Corti, is the last mechanical event in hearing.

Non Mechanical Auditory Processing

- ***Organ of Corti:*** its cells make up the 8th cranial nerve or auditory nerve, which leaves the ear.
- ***Thalamus***: this includes the lateral geniculate nuclei, according to the tones.

- ***Cortex***: the sense of hearing focuses on areas 41 and 42 in the temporal lobe.

Figure 18: Brain Areas and the Senses



Source: Percepnet. 9/20/07. Taken on 7/20/2016 from http://goo.gl/iSdGBb

Vestibular System

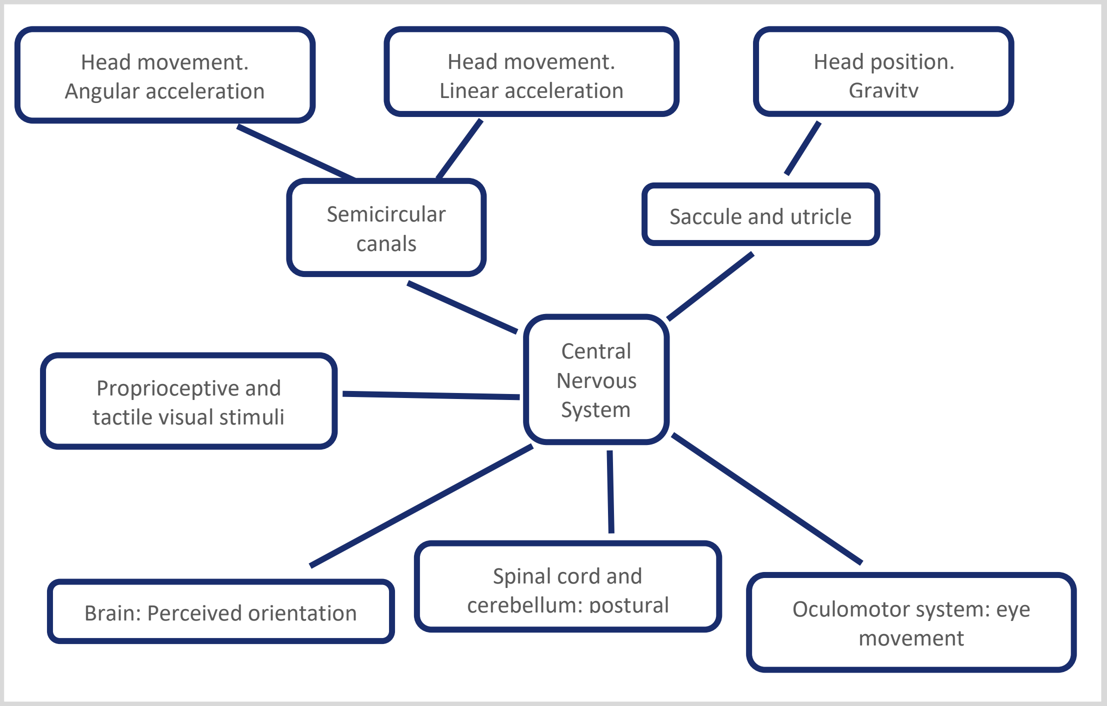
The equilibrium system is more complex than the auditory system, mainly due to the motor component. There is no one structure which alone performs this operation. The system consists of multiple sensory impulses from vestibular terminals, sensory organs, the visual system, the somatosensory and proprioceptive systems. Then, the information is integrated at the level of the brainstem and cerebellum, with significant influence of the cerebral cortex (such as frontal, parietal, and occipital lobes). The integrated information causes various stereotypical motor reactions, eye movement, postural control, and perceptual output pulses.

The Functions of the Vestibular System are:

- To inform the central nervous system of any acceleration or deceleration, angular or linear.
- To assist in visual orientation, by controlling the eye muscles.
- To control the tone of skeletal muscles for maintaining proper posture.

Below is a diagram illustrating the role of the vestibular system in controlling posture, eye movements, and perception of orientation.

Figure 19: Table of the Vestibular System



Source: prepared by the author.

Information provided by the labyrinth:

- Information on the position of the head in space.
(Static Function: Macular receptors)
- Information on head movements.
(Kinetic Function: ampullary receptors)

The stages of the transformation of vestibular stimulation in a sensory encoded message at the vestibular nerve level are:

1) Modification of the stimulus by the labyrinthine structures depending on the mechanical and hydrodynamic characteristics.
2) Mechanosensory transduction and appearance of a receptor potential.
3) Formation of a postsynaptic generator potential and action potential.

The **semicircular canals** are organized in pairs:

1) The two horizontal canals.
2) The upper canal and rear contralateral canal.
3) The rear and the upper contralateral canal.

The **otolith organs** also function in pairs, where the two utricular macula are approximately located on the horizontal plane and the two saccular macula are on the vertical plane with an angulation of approximately 30° inward with respect to the sagittal plane.

Operation of the Semicircular Canals

When the head rotates, the endolymph stands still by inertia, pushes the gelatin of the ampule and tilts the stereociliato to one side. Since the semicircular canals of one side are arranged symmetrically with the other side, on one side the stereocilia lean towards kinocilia and the discharge of the vestibular nerve increases on that side, while on the other side they are tilted towards the opposite direction of the kinocilia and the discharge of the vestibular nerve decreases.

At rest, the vestibular nerve has an activity of about 50 action potentials per second and is the same on both sides. Since the vestibular nuclei have inhibitory connections with the contralateral nuclei, when the activity is the same on both sides, this activity cancels out.

When the head rotates, the activity increases on one side and decreases on the other, and this imbalance is subjectively perceived as the head turning and produces compensatory eye movements.

The semicircular canals are involved in the vestibular-ocular reflex. This reflex serves to maintain a stable gaze on the same point. When the semicircular canals detect a turn of the head, the vestibular nuclei send signals to the nuclei that control eye movement, so that the eyes rotate in the opposite directions from the head, to compensate for the movement and keep looking at the same point.

Operation of the Utricle and Saccule

The structures of the vestibular apparatus involved in tonic reflexes are the **utricle** and **saccule.** These are the ones that detect the static head position relative to the vertical (the semicircular canals detect rotational movements only, but not the static position).

The utricle and saccule are membrane bags full of endolymph, with a wall area covered in an epithelium of ciliated cells. These cilia cells are covered with a gel, on which are deposited the calcium carbonate crystals. When the head bends with respect to the vertical, the calcium carbonate crystals tend to slip sideways by weight and, in so doing, tilt the **stereocilia** to one side.

When the stereocilia are tilted in the direction of the kinocilia, the ciliated cell depolarizes. This is because the stereocilia are connected to neighboring stereocilia filaments and these filaments are bound to potassium channels in the membrane. When the stereocilia bend toward the kinocilia, the filaments are placed in tension and the tension opens potassium channels. As the concentration of potassium in the endolymph is very high, potassium enters the cell and depolarizes it. If the stereocilia bend in the opposite direction, the cell is hyperpolarized. Thus the utricle and saccule detect whether the head is tilted.

Tonic Postural Reflexes

Tonic postural reflexes are a set of reflexes whose function is to maintain the head and the body's upright position with respect to the vertical. They are controlled by the brainstem nuclei, making them easier to study in a brainless preparation, where the brainstem is disconnected from the upper levels. On one hand, tonic postural reflexes use information from the vestibular apparatus, which indicates the position of the head in space (vestibular reflexes) and, on the other, information from receptors in the neck muscles, which indicate whether the neck is flexed or rotated (cervical reflexes). Tonic reflexes act on the neck position **(vestibulocollic and cervicocollic reflex)** and extremities **(vestibulospinal and cervicospinal reflex).**

The physiological function of the cervicocollic and vestibulocollic reflexes is to maintain head position.

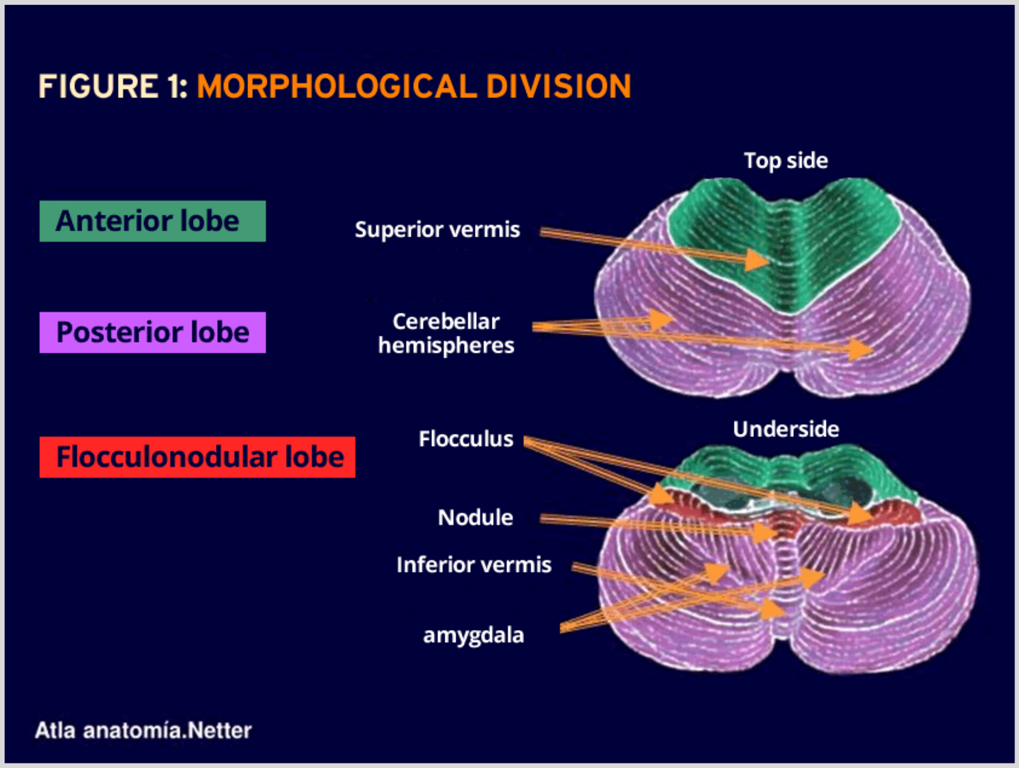
The vestibulospinal reflex tends to prevent falling when the subject is on a slope and the cervicospinal reflex cancels the vestibulospinal when the head position moves by bending the neck.

Vestibular-Cerebellum

The vestibular-cerebellum corresponds anatomically to the **flocculus.** It collaborates with the vestibular nuclei in the functions of maintaining equilibrium and adjustment of the vestibulo-ocular reflex.

The vestibular-cerebellar injuries, on the one hand, produce similar symptoms to injuries to the vestibular nuclei in the cotralateral side. The reason for this is that, since the cortex of the vestibulocerebellum inhibits ipsilateral vestibular nuclei, vestibulocerebellum injury produces ipsilateral vestibular hyperactivity, which is equivalent to an injury to the contralateral vestibular nuclei.

Figure 20: Morphological Division of the Cerebellum



Source: http://goo.gl/odAtnz

References

Asociación Educar (Education Association) (2015). http://www.asociacioneducar.com/.

Baddeley, A. (1983). *Working Memory.* Oxford.

Bañuelo, F. S. (1990). *Didáctica de la Educación Física y el Deporte. [Teaching Physical Education and Sports]*. Madrid: Gymnos.

Bermeosolo, J. (2012). *Working Memory and Procedural Memory in Specific Learning Difficulties and Language: Some Findings.* Revista Chilena de
Fonoudiología, 18.

Boulch, J. L. (1989). *El deporte educativo; psicokinética y aprendizaje motor [Educational Sports; The Mind in Movement and Motor Learning].* Buenos Aires: Paidos.

Boulche, J. L. (2002). *Hacia una ciencia del movimiento humano [Towards a Science of Human Movement]*. Barcelona: Paidotribo.

Corraze, J. (1988). *Las bases neuro-psicologicas del movimiento [Neuropsychological Bases of Movement]*. Barcelona: Paidotribo.

Corraze, J. (1988). *Las bases neuropsicológicas del movimiento [Neuropsychological Bases of Movement]*. Barcelona: Paidotribo.

Cratty, B. (1974). *Motricidad y psiquismo [Motor Function and the Psyche].* Madrid: Miñon.

Damasio, A. (2006). *El error de Descartes* [*Descartes's Error]*. Buenos Aires: Critica.

Damasio, A. (2007). *En busca de Spinoza* [*Looking for Spinoza]*. Barcelona: Critica.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of Skill Acquisition.* Canada: Human Kinetics.

Desarrollo y aprendizaje motor [Development and Motor Learning]. (2009). Cordoba, Argentina: IPEF.

Di Santo, A. (2016). *Sistema Sensorial* [*Sensory System]* [Recorded by N. Acosta]. Cordoba, Argentina.

Di Santo, M. (2015). *Influencia de Antonio Damasio* [*The Influence of Antonio Damasio]* [Recorded by N. Acosta]. Cordoba, Argentina.

Di Santo, M. (2015). *Eferencia central* [*Central Eference]* [Recorded by N. Acosta]. Cordoba, Argentina.

Di Santo, M. (2015). *Imagen del movimiento [Motor imagery*] [Recorded by N. Acosta]. Cordoba, Argentina.

Di Santo, M. (2015). *Pensando en movimiento [Thinking in Movement*] [Recorded by N. Acosta]. Cordoba, Argentina.

Di Santo, M. (2015). *Programación neuromotora* [*Neuromotor Programming]* [Recorded by N. Acosta]. Cordoba, Argentina.

Di Santo, M. (2015). *Programación neuromotora* [*Neuromotor Programming]* [Recorded by N. Acosta]. Cordoba, Argentina.

Di Santo, M. (2015). *Toma de decisión y lógica motriz* [*Decision Making and Motor Logic]*. Cordoba, Argentina.

Digby, E., & Khan, M. (2010). *Vision and Goal-Directed Movement*. Canada: Human Kinetics.

Domjan, M. (2009). *Principios de aprendizaje y conducta* [*Principles of Learning and Behavior]*. Madrid: Rogar.

Ernst, M. (2002). Neural Systems and Cue-Induced Cocaine Craving. http://www.nature.com/npp/journal/v26/n3/full/1395814a.html, 7.

Etchepareboda, M., & Abad-Mas, L. (2010). http://www.lafun.com.ar/.

Fairbrother, J. (2010). *Fundamentals of Motor Behavior*. Canada: Human Kinetics.

Gardiner, P. (2011). *Advanced Neuromuscular Exercise Physiology*. Canada: Human Kinetics.

Grosser, M. (1988). *Principios del entrenamiento deportivo* [*Principles of Sports Training]*. Spain: Martinez Roca.

Guyton, C., & Hall, J. (2006). *Textbook of Medical Physiology*. Barcelona: Elsevier.

Jacques, C. (1987). *Las bases neuropsicológicas del movimiento [Neuropsychological Bases of Movement].* Barcelona: Paidotribo.

Jeanne, L., & Seidler, R. (2011). Age differences in callosal contributions to cognitive processes
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3137668/

Kandel, E. (1997). *Neurociencia y Conducta* [*Neuroscience and Behavior].* Madrid: Prentice Hall.

Kurt, M., & Günter, S. (1987). *Teoría del movimiento; motricidad deportiva [The Theory of Movement; Sports Motor Skills].* Buenos Aires: 1987.

Lacey, S., & Lawson, R. (2013). *Multisensory Imagery.* New York: Springer.

Latash, M. (2008). *Neurophysiological Basis of Movement* (2nd ed.). United States: Human Kinetics.

Latash, M. (2012). *Fundamentals of Motor Control.* United States: AP.

Loyber, I. (1988). *Funciones motoras del sistema nervioso [Motor Functions of the Nervous System].* Cordoba: El galeno.

Loyber, I. (2012). *Funciones motoras del sistema nervioso [Motor Functions of the Nervous System].* Cordoba: El Galeno.

Loyber, I. (2012). *Introducción a la fisiología del sistema nervioso [Introduction to the Physiology of the Nervous System].* Cordoba: El Ganelo.

Mark, L. (2008). *Synergy.* England: Oxford University.

Neumaier, A. (2002). *Entrenamiento de la técnica* [*Technique Training].* Barcelona: Paidotribo.

Cardinali, D. (2007). *Neurociencia aplicada: sus fundamentos [Applied Neuroscience : Its Foundations].* Buenos Aires: Panamericana.

Purves, D. (2007). *Neurosciences.* Buenos Aires: Panamericana.

Rachel, S., Jin, B., & Anguera, J. (2013). Neurocognitive Contributions to Motor Skill Learning: The Role of Working Memory
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534841/.

Richard, S., & Timothy , L. (2014). *Motor Learning and Performance.* Canada: Humanic Kinetics.

Richardson, J. (1996). *Working Memory and Human Cognition.* Oxford. Oxford University.

Rigal, R. (1979). *Motricidad humana [Human Motor Skill].* Madrid: Pila Teleña.

Ripoll, R. D. (2014). *Neurociencia cognitiva* [*Cognitive Neuroscience].* Madrid: Panamericana.

Roger M, E. (2008). *Neuromechanics of Human Movement.* Canada: Human Kinetics.

Ruiz Perez, L. (1994). *Deporte y aprendizaje [Sports and Learning].* Visor: Madrid.

Snell, R. (1999). *Neuroanatomy.* Fourth edition. Buenos Aires: Panamericana.

Stefano, T. (2009). *Neurosciences and Sports.* Barcelona: Paidotribo.

Tamorri, S. (2004). *Neuroscience and Sport.* Barcelona: Paidotribo.

Tamorri, S. (2004). *Neuroscience and Sport. Psicología deportiva procesos mentales del atleta.*
[Sports Psychology Processes of the Athlete] Barcelona: Paidotribo.

Universidad de Cantabria, (S.F.), Taken from http://2.bp.blogspot.com/-EdC6hSDAQWw/VAvxXE0438I/AAAAAAAABGU/_7rz97u55Z4/s1600/anatomia%2Boido.png

University of Murcia, (Undated), Taken from http://ocw.um.es/gat/contenidos/palopez/contenidos/motoneuronas.jpg

Universidad de Costa Rica, (Undated), Taken from http://163.178.103.176/Fisiologia/neurofisiologia/pract_bas_1/FG13_03a.jpg

Universidad Nacional de Tucumán, (Undated), Taken from http://www.herrera.unt.edu.ar/bioingenieria/temas_inves/sist_nervioso/Image52.gif

Weineck, J. (2006). *Entrenamiento total* [*Total Training].* Barcelona: Paidotribo.

Zhou. (2000). El entrenamiento cruzado: una posibilidad del mantenimiento de la forma ante lesiones unilaterales (Cross Training: A Possibility of Maintaining Shape with Unilateral Vestibular Lesion). *Medicina Esport*, 15.