1.1 Movement from the central nervous system

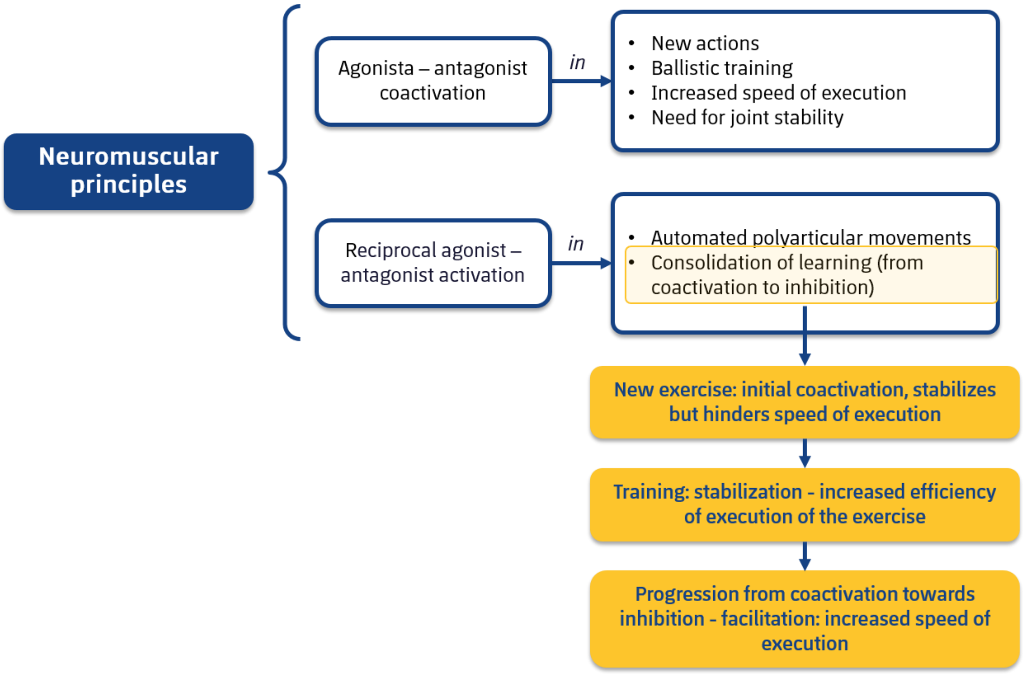
The central nervous system is aware of movements rather than muscles (Hughlings Jackson, 1889).

A person's strength is entirely determined by the way their muscles are controlled by the brain (Bosch 2015). This way of understanding movement responds to the cognitive theory approach to solving a problem in sports (Schmidt and Wrisberg, 2004). Although this is not the only way to explain sport-specific movements, especially if we approach the movements from an ecological perspective (Gibson, 1979), it remains one of the premises of the foundation of strength training.

Even the simplest of movements involves a contraction and a combination of coactivation, facilitation and inhibition (Lloyd, 2001) (Figure 1). In short, it is an organization of the movement that must be commanded from the central nervous system (CNS), when referring to the term known as "voluntary movement" (REF). We cannot forget this when it comes to training the different movements.

Sporting gestures are usually extremely complex actions. For this reason, executing these gestures by producing strength is not a simple task for the CNS, which not only involves a nerve impulse, but also different neuronal circuits of activation and inhibition that are organized with the aim of executing the requested movement. It is thus implausible to consider the possibility of strength training in isolation within sports, or from the perspective of movement that is separate from the action. The importance of strength training has been highlighted by numerous authors. Among these, Julio Tous Fajardo (2017) discusses **strength as the origin of motor skills, and, through its optimization, powers movement.** This hypothesis explains what was previously discussed more poetically. If we closely examine the idea of *optimization,* we will understand that it does not deal with increase or improvement, but rather the best way to adapt the application of strength to each sporting situation. This is why we can understand the need for strength training, with a focus on adapting this to the requirements of the sport, and not as a test that distorts the need for specificity.

Figure 1: Muscle principles and situations where one prevails over the other



Source: created by the author, based on Romero and Tous in Lloyd, 2001.

It also details the approach to a new exercise and its progression. This can be executed from the beginning with a high amount of coactivation, due to the lack of experience and progress towards greater efficiency and increased speed of execution. Inhibition of the musculature could slow down the explosive action.

The development and career of an athlete will be determined by his/her ability to produce specific sports movements that are adaptable to the changing context, which is typical of interactive sports in a shared space. This will undoubtedly influence the levels of technique, dexterity and strength that are necessary for each of these movements, in pursuit of overcoming opponents and advancing towards the goal. In order to achieve this, the athlete needs an adequate cognitive capacity to process stimuli (appropriate to the level and discipline practiced) and, at the same time, conditional development, according to the effort required while maintaining motor control (Massafret i Marimón, 2017).

Discussing motor control brings us closer to strength training, based on the concept of coordination. Bosch (2015) goes a step further and proposes the idea that, in sports, strength training consists of applying resistance to coordination training. It is understood in this manner because the essential neural component in the movement means that we cannot omit the concept of coordination when developing our strength training.

In this lesson, we will discuss the different levels of the neuromuscular system involved in generating strength, from the direction of the CNS to the adaptations that occur within skeletal muscle itself.

1.1.1 Cortical and subcortical control of movement I

When we refer to coordination, we cannot leave out the concept of **dexterity**. Bernstein (1996) explains this phenomenon as a function of control, and in order to build upon dexterity, focus must be placed on the central nervous system. According to this author, dexterity depends on the speed, agility, flexibility and skill of our body. This can be explained as **harmony in movement**, where a motor solution is found for every situation and in different conditions. The demands of different skill levels are determined by the degree of difficulty presented by the medium, rather than the movement itself. In this regard, dexterity as a harmonic and specific expression of the sport will be highly dependent on the motor control ability of the athlete. This process, which appears to be so simple and natural, is actually a complex system of organization that involves the coordinated participation of various systems and physiological mechanisms of the body.

Based on this, Bernstein (1996) proposes imagining how much an athlete would be distracted if all of the movements that occur simultaneously in the execution of a motor action required individualized control, with specific attention from our central nervous system. If this were true, it is clear that excessive multi-tasking would not allow for making the right movements in succession.

In order to better familiarize ourselves with motor control and understand its complexity, we must interpret movement within the concept of **degrees of freedom** (Bernstein, 1967). If we contemplate the amount and types of movements that each joint and limb of our body can perform, and we add the complex mobility of the spine, we would find an infinite number of possible combinations to express a motor action with high levels of dexterity, as required by sporting gestures. These combinations refer to the degrees of freedom, which cannot be ignored when designing and planning exercises in strength training.

We will explain some fundamental concepts that will make strength training a process that is entirely dependent on the neurobiological functions involved in the movement. If the objective of training is to improve the ability to produce strength with a certain sporting gesture, in order to optimize the performance as well as reduce injuries, we must ensure that the degrees of freedom controlled by the planned movement are not in opposition to those necessary for the correct execution of such gesture. In relation to Bernstein's degrees of freedom, Latash, Scholz, and Schöner (2007) propose a simple way of understanding this complex process. At all levels of analysis of the systems involved in the voluntary movement, in relation to performance, more elements participate than are actually necessary to successfully accomplish the exercise. To give a simple example, humans walk in order to transport their bodies from one point to another, without losing their upright posture. Based on this **problem of abundance**, Bernstein developed his theory of multiple hierarchy control of the voluntary movement. To this end, he used perfectly trained hammer throwers and analyzed their activity, which was repeated hundreds of times over a year. He noted that the variation in the distance between the hammer and the target at the time of impact was significantly less than the movement created by each of the joints during the gesture. Since the brain clearly could not send information directly to the hammer, he concluded that each joint did not act independently, but constantly corrected the errors of the others. Bernstein deduced that the brain, instead of controlling infinite degrees of freedom by eliminating kinematic redundancy, uses this redundancy to ensure greater precision (less variation) in the execution and final outcome of a motor action. In fact, during this experiment, Bernstein did not control the articular position of the limbs and joints of the hammer throwers, but only considered the location of impact of the hammer. This suggests that the brain formulates flexible and adaptable solutions for the same motor action, even when the starting position is not necessarily repeated, and compensates for all of the modifications that arise during the movement.

It is important to note that this experiment addressed the repetition of a stable exercise. Despite this, it is possible to agree with the author that the "motor learning" obtained from the repetition of an exercise helps the body adapt to the challenge of responding optimally to a specific sporting situation. From this point of view, we can understand training and thus the development of strength based on greater stability, but without losing sight of the fact that progress will be made towards applying strength in real situations or in game simulations (which will not be stable).

Following this, we can derive an approach to some similar problems experienced by the nervous system. For example: how many motor units and how many muscles are activated to achieve a certain torque of strength in each movement? How and why? These questions lead us to the appearance of different approaches to the **problem of motor control** (Latash et al., 2007):

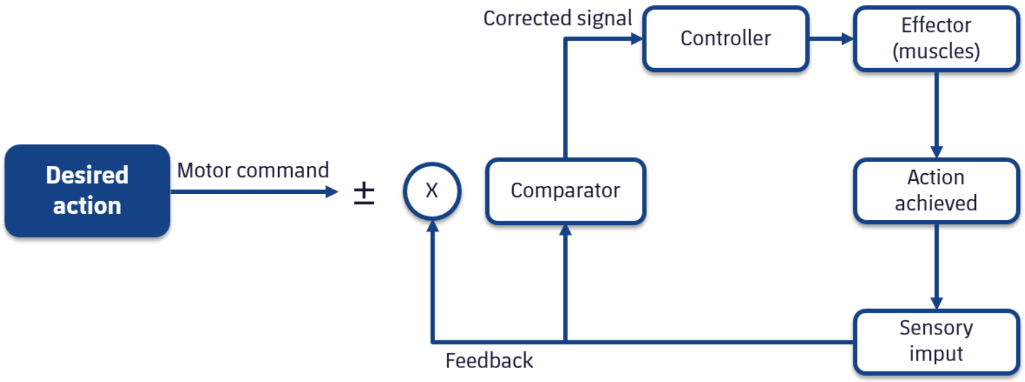
- **Elimination:** Suggests that the CNS solves the problem by reducing the number of degrees of freedom and using only those necessary to achieve the objective of the motor action. Apparently, limiting several degrees of freedom causes constraints, so that the movement within the space is done through the pre-selected route. This approach (elimination) has been mainly addressed at the kinematic level.
- **Optimization:** Some optimization principles are suggested in order to solve the problem of motor abundance, based on mechanical, psychological and engineering functions, including several more complex functions. In this regard, the system analyzes what it aims to produce and compares this to the cost of such production. Conclusions are thus drawn regarding the cost-benefit analysis of carrying out certain motor actions, when deciding how to carry these out. This hypothesis is considered an extremely simplistic manner of understanding motor control.
- **Synergies:** The most renowned concept for this "solution" is that of muscle synergies. Reference is made to muscle groups connected to one another in such a way that a single signal proportionately activates all of these together, creating synergy. When motor actions involve variants, this signal will be modified in order to provoke changes in the message or impulse sent to each of the muscles that form part of such synergy.

These three hypotheses view the abundance of degrees of freedom as a problem to be solved by the central nervous system, in the context of motor control. However, there are details to be taken into account, for example: blocking a joint in order to control the number of degrees of freedom does not lessen the need to control it, but rather the opposite. The forces of interaction and strength used to block the movement of said joint must constantly be adjusted with each movement to the remaining limbs of the body, as well as to the change in position that this entails. Latash (2007), in contrast with these hypotheses and in agreement with Bernstein's ideas, considers the abundance of degrees of freedom to be a benefit of the central nervous system, which can draw on infinite resources when designing a motor solution for each action; while ensuring stability, flexibility and variability to counteract the possible perturbations and modifications arising in the execution, as a result of the interaction with the surroundings.

This author thus suggests a different view of synergy and defines it as a neural organization of a system comprised of multiple elements that (1) organize the participation of different essential variables in the same action and (2) ensure covariation among essential variables, in order to stabilize those that have an impact on performance.

It is important to understand that when we design an exercise for an athlete, he/she will have a certain level of execution that will depend on motor control ability. The athlete's self-regulation, when carrying out a movement in a more optimal manner with each attempt, will be an aspect that the trainer and/or coach may modify in order to facilitate the movement. This is a key aspect of the teaching and learning process that is established with the athlete. In this regard, this course refers to the limitations of the cybernetic model of voluntary movement control (Figure 2), as expressed by Balagué, Torrents, Pol and Seirul·lo (2014). According to this model, the behavior becomes an exact reproduction of what was previously established, which limits the connections between the variables that interact in the execution of a motor action, and thus alters real sporting situations.

Figure 2: The cybernetic model of voluntary movement control



Source: Balagué, Torrents, Pol and Seirul·lo, 2014. p. 62.

In contrast to the model described above, these authors emphasize the principles of dynamic and nonlinear integration when analyzing movement from a training perspective. Synergies are created as a phenomenon of spontaneous appearance (unplanned). They even argue that synergy is not a neurobiological phenomenon, but rather a psychological phenomenon expressed through interpersonal relationships. "These phenomena emerge spontaneously through the interaction of their components and as a result of the tendency of living beings to organize and have order" (Balagué et al. 2014). The spontaneity of this phenomenon, based on its capacity for self-organization, is a *sine qua non* condition to be able to adapt the movement to a changing environment, as is the case with team sports. This demonstrates the tremendous contradiction of those training programs that focus their effort on achieving a desired response. In team sports, we should not refer to motor programs, but rather preferential synergies that will be configured through the relationship between individual characteristics and exposure to the environment. It is important to be able to observe how we evolve at this point, as well as through the introduction of these authors in a better ecological understanding of the sport.

We return to motor control and the **problem of abundance**. Bernstein proposes a system to build movement at different levels. This classification specifies the importance of the spinal cord, red nucleus, basal ganglia (Palidum and Striatum), thalamus, and various areas of the cortex to control movement. According to the author, almost all human movements are based on various levels, where one of these has a main role and the rest have secondary roles; providing the necessary support, which is usually **not** consciously perceived. These levels will depend on the actions performed and the paths used. We will examine these below:

A. **Paleokinetic or Rubrospinal Level:** according to Bernstein, this plays a particularly important role in the reflex regulation of muscle tone, and offers constant assistance in postural regulation when performing voluntary actions. This sensory aid primarily comes from the proprioceptors, which inform the CNS of the variations in tension and elongation of the different components of the musculoskeletal system, as well as the arrangement of the different body segments (REF), the configuration of the body and the forces interacting between these, and the location of the body. This level regulates rapid actions, situations in response to unexpected stimuli and specific body postures (those produced, for example, in gymnastic exercises).
B. **Level of synergies and patterns or thalamus-pallidum level:** large muscle groups are integrated at this level in order to produce coordinated movement patterns, which also primarily use proprioceptors as a source of sensory information. Bernstein argues that synergies are formed at this level. An example of this type of pattern is locomotion, which can be produced by the spinal cord without involving the brain. At this level, kinematic chains and their control are highly proprioceptive, where there is a tendency to repeat controlled patterns.
C. **Spatial or pyramid-striated level, divided into striated (extrapyramidal) (C1) and pyramidal (related to cortical control) (C2):** this level is used to perform specific actions in a given space, such as transporting an object from one location to another within a space, and is characterized by geometry. Proprioceptive, tactile, visual and vestibular senses interact. The striated level (C1) is responsible for the way in which the expected result is achieved, while the pyramidal level (C2) aims to achieve such result. Within this level, the movements involve objectives that are characterized by precision and adaptive variability. When we speak of variability, we refer to the errors or compensation of the extremities that present the necessary variations of movement to be able to solve similar tasks, which requires great plasticity of the CNS.
D. **Level of significant actions or parieto-premotor level:** Only human beings and some animals possess this level, which implies the existence of significant actions, i.e. with meaning and intent, and not

simply reduced to the mere execution of moving something from one side to the other. At this level, the automatisms and voluntary motor activities coexist, which are contrary to intuition and are related to knowledge. Each limb and segment of the body, both dominant and non-dominant, will have specific functions. When there are motor disorders at this level, they appear as an apraxia, which are neurological disorders characterized by the loss of ability to execute intentional, learned and familiar movements, despite having the physical ability (muscle tone and coordination) and the desire to carry them out. The difficulty with this is to achieve the result without altering the motor action.

E. **Level of highly coordinated symbolic actions, such as speaking or writing, on the basis of control (the highest level of cortical control):** this level is only found in humans. The actions carried out here are associated with the transmission of information (communication) through writing or speech that we use to transmit a message to another person. It is necessary to keep in mind that the previous levels coexist as well at this level. If we consider writing as an example at this level, we will observe the following:
    - Level E: presentation of the message to be transmitted, establishing a sequence of words correctly chosen and written.
    - Level D: ensures that letters are legible and that the spaces between words, pauses and punctuations are correct.
    - Level C: divided into two sub-levels, C2, which will ensure that all characters are written correctly, and C1, which will avoid clumsy arm and hand postures during writing.
    - Level B: in charge of controlling postural changes.
    - Level A: responsible for providing correct activation of the postural muscles of the arm, torso and legs, as well as correct functioning of spinal reflexes (Latash, 2012).

This scheme was published more than 50 years ago (Bernstein, 1967) and is far from obsolete, as there is no other approach at this time that addresses all of the steps, as this author has done (Latash, 2012).

Influences from the central nervous system

An individual's abilities do not reach their full potential when carrying out a motor action, which is fully recognized in the literature.

This means that, even when sum one is willing to execute a maximum effort, e.g. during a maximal strength assessment (regardless of the time needed to make one repetition), it would not be possible for this person to recruit every motor unit of the involved muscles. This is valid not only for concentric actions, but for eccentric and isometric actions to, even when this ones allow to produce higher strength values.

The reasons or arguments for which this phenomenon occurs may have both a peripheral and a central origin (ranging from coactivations that affect the performance or output of a task, to phenomena of supraspinal control). In reality, under normal conditions, human beings are unable to recruit more than 75% of the potentially available absolute force (REF).

This is because the percentage of force output is subject to the recruitment of motor units, which can be increased through training (without the need to depend on hypertrophy) or can decrease, as a result of processes of inactivity caused by injuries.

This theory is based in the fact that humans are able to reach values near to absolute strength only in presence of extreme emergency situations, like life risk (Porta and Cos, 1998). Therefore, from an unconscious perspective, it is the brain that underestimates the force-producing capacity from our musculoskeletal system, and as a result, the mental component cannot be ignored in strength stimuli during a training process (Bosch, 2015). This idea can be broadly applied to team sports that require maximum effort, in response to situations with low external resistance. Therefore, training becomes especially relevant when achieving the necessary adaptations and to be able to recruit the greatest amount of motor units.

Function of the cerebellum in motor control

The cerebellum is an organ that regulates movement, and in particular, processes motor activity that is dependent on other nerve centers. Within these are the different processes that sensory perceptions depend on. This center receives substantially superior afferent pathway information than it generates. This indicates that it is essentially a center that recruits and processes information. This activity generates data regarding the motor plan and how it will be executed. It participates in motor control, since it shapes the movement by means of inhibition and non-inhibition of different deep nuclei. Functionally, the cerebellum is divided into three parts:

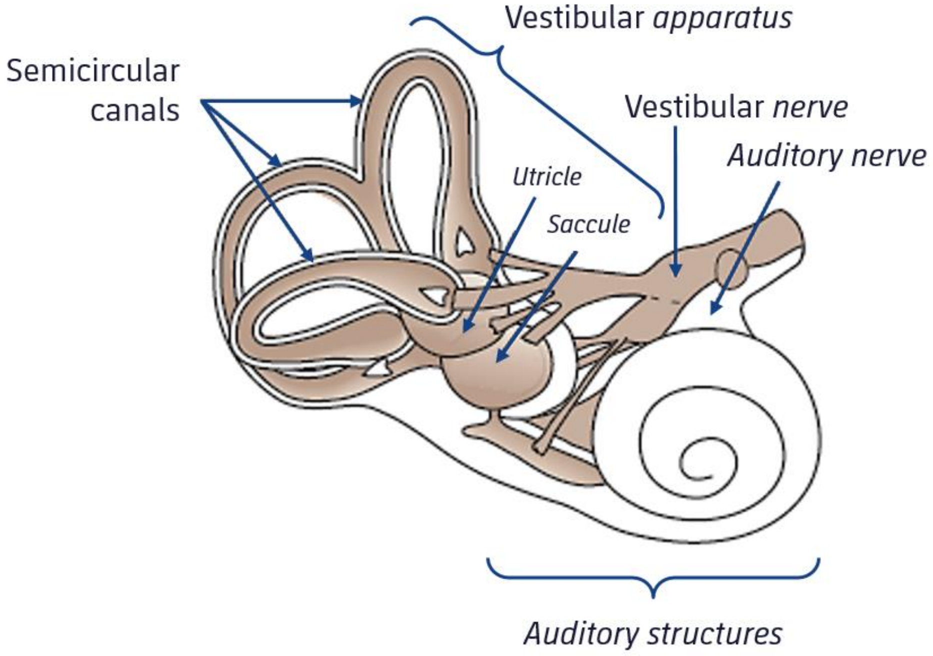
A. **Vestibulocerebellum**: integrates visual and vestibular information and facilitates posture and balance during walking. In order to do this, it is necessary to constantly receive information about the situation of the musculoskeletal system.
B. **Spinocerebellum**: a topographical representation of the torso and proximal section of the limbs in the vermis, and the distal section of the limbs in the paravermis. It is responsible for comparing the motor plan, designed with quality of movement in the execution, and receives information from the motor commands sent to the muscles, as well as a copy of how these commands are executed. This applies to its relationship with the cerebral cortex and spinal cord. If differences are found between the action plan and the execution carried out, this structure sends information through the motor pathways, generating feedback. This area is also credited with the ability to foresee the need for a correction prior to execution and, in this case, its intervention is known as feedforward, or anticipation. On the other hand, it regulates high-speed polyarticular movements, controlling the muscle actions and tone.
C. **Cerebrocerebellum**: intervenes in the planning, programming and learning of complex movements, but is not related to their quality. It plays a fundamental role in the execution of movements, sequencing, coordination, correction, and prediction of motor activities, especially in relation to learning and the acquisition of skills (Rodríguez Bonache and Rodríguez Bonache, 2016).

1.1.2 Cortical and subcortical control of movement II. Sensory areas and movement.

The vestibular apparatus

The ear has a dual function from a sensory point of view, as on the one hand, hearing can obtain valuable information for motor control. On the other hand, the inner ear houses the vestibular apparatus, which provides information on linear and angular movements of the head. This type of information allows for an overall assessment of the body movement, unlike muscle spindles, Golgi tendon apparatus and articular receptors; which only provide specific information about the musculoskeletal system. Figure 2 shows a diagram demonstrating how the vestibular apparatus is shaped.

Figure 3: The vestibular apparatus



Source: Edwards, 2010, p. 83.

The structures of the vestibular apparatus provide information in order to maintain a sense of balance. This sends kinesthetic information about the position of the head in relation to gravity, as well as accelerations and decelerations. This system is closely related to vision. When a person tries to follow an object with their sight, or when they move and try to keep their sight on an object, in both cases the head and eyes move in opposite directions. In order to coordinate the activity of the head with that of the eyes, compensatory movements are needed. This mechanism, provided by the vestibular apparatus, is known as the vestibulo-ocular reflex, which allows us to have control over the movement of the eyes; much faster than if we did this consciously (Edwards, 2010). It is important to take these aspects into account when designing training sessions, especially when introducing perceptual stimuli into strength training of sports skills.

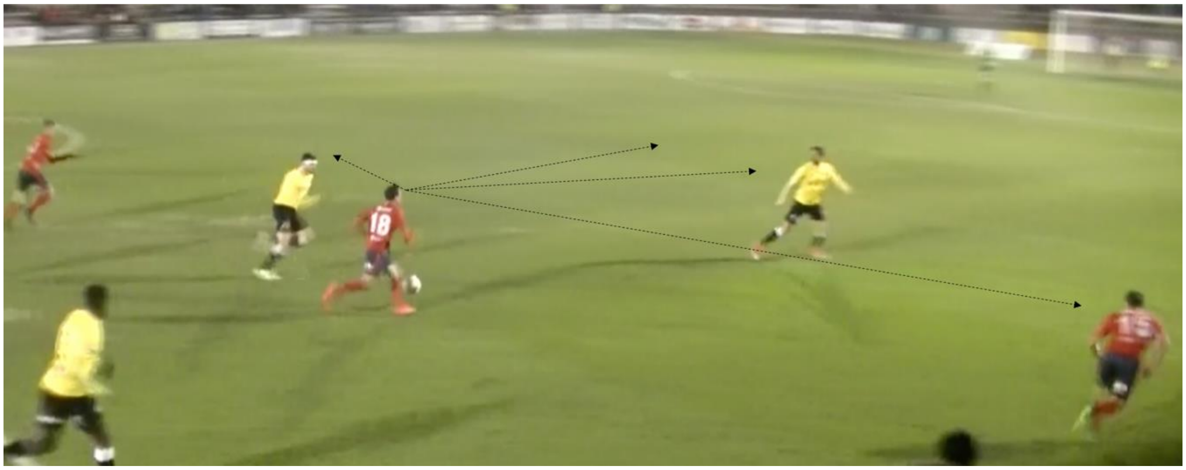
Figure 4: Destabilizing actions can lead to head positions that further increase the imbalance, and thus decrease the effectiveness of the action.

Source: Romero Rodriguez, 2018 (unpublished).

Visual system and movement

The visual system has two types of photoreceptors found in the retina: Rod cells, which provide visual information in greys and shadows, and cones, which provide visual information in colors. Although the cones provide the highest quality of vision, Rod cells are responsible for discerning movement in relation to the visual field of the surroundings. Thus, two visual systems appear, based on the information provided by the two types of photoreceptors, focal vision (cones) and peripheral vision (Rod Cells) (see Figure 5). Focal vision, apart from providing sharpness and quality in the image, has the disadvantage of demanding a large amount of attention, because it is a conscious intervention. In contrast, peripheral vision is processed quickly and automatically under unconscious control, which does not generate such demand for attention. This allows the focus to be placed on other aspects of motion control. Sensory input plays a crucial role in providing the necessary context within which specific skills can be developed. Part of this context depends on the visual system, since it is a source of information regarding how the body is situated and how it moves in relation to the surroundings (Edwards, 2010).

Figure 5: Using peripheral view in a game situation



Source: Romero Rodriguez, 2018 (unpublished).

The offensive player who has possession of the ball must first focus his/her attention on the closest defensive player (who is most likely to take the ball from him/her). Despite this, and according to the position of his/her head, he/she will control it through the periphery of his/her glance. The arrows mark the potential spatial references of the player, the two defenders, the offensive player he/she has in his/her field of vision, and the opponent's goal. It is also possible that, at this or any other time, the player will also be able to visualize his/her teammate who runs behind him/her on the left, and who is in a more advantageous position.

Affordances

The term affordances, introduced by Gibson (1977), evidently cannot be understood as a type of sensory receptor, but it has been introduced here for two reasons. First, it requires understanding the relationship between perception and action, which is not subject to the neural circuits as described, but is used by the aforementioned receptors, which are very close to the CNS. The second reason is because this course bases a significant amount of sports training on its understanding from an ecological physics perspective (Gibson, 1979). Edwards (2010) explains that affordances are

opportunities for action, which are collected through the sensory system. From this point of view, we should consider that it might be possible to alter the parameters of the exercises, so that these affordances emerge and facilitate the appearance of certain behaviors.

1.1.3 The excitation-contraction coupling. Recruitment of motor units and their relationship with the exercise

Excitability and action potential

Muscle and neural cells belong to the type of excitable cells, which can trigger an electrical signal under certain chemical conditions. This occurs through an ephemeral change in potential across the cell membrane, known as **action potentials**. The magnitude of this potential is not related to the size of the stimulus. As a result, if the stimulus is sufficient enough to trigger the aforementioned membrane change, it will mean that the stimulus has exceeded the threshold and the fiber will be activated. If, on the other hand, the magnitude of the stimulus is insufficient to exceed this threshold, it will not be activated. In this regard, two things can happen: either the threshold is exceeded and an action potential is generated, or this does not occur. This phenomenon is known as the all-or-none law, which will determine the occurrence of a muscular contraction (Latash, 2012).

Muscle contraction

Muscle contraction begins with a neural signal, as a result of the pathway of potential action through the axon of a spinal neuron, known as an **alpha motoneuron**. This signal activates muscle fiber through a neuromuscular synapse, also known as a motor endplate, which is the passage of a stimulus through the union between the neuron and muscle cell. The arrival of the stimulus generates changes in the aforementioned membrane potential of this cell and will enable a contraction of the innervated muscle cell (Latash, 2012). The action potential that runs through the membrane of a muscle fiber triggers other physical-chemical changes, which will culminate in force output through cross-bridge activation.

With regard to what has been explained so far, it is important to understand that the visible muscular contraction that we need to produce force will occur, thanks to the continuity of action potentials that are generated in large quantities of muscle fibers. In fact, muscle contraction will be determined by the frequency at which the action potentials are triggered, i.e. the number of stimuli per unit of time. If the muscle cell receives only one stimulus, the cross-bridge mechanism is quickly activated and the fiber will relax. During this simple contraction, the peak of force production will be reached in only 50 or 100 milliseconds, followed by a stage of a slower decrease in force, and a muscular contraction to generate force will not occur. If, on the other hand, two stimuli are produced in a sufficiently short time interval, the second one will reach its destination while the contraction of the first one is still in force. This will lead to a summation effect, where the second contraction will start from a higher force level and produce a greater peak in force. This sequence can be extrapolated to a continuation of large amounts of stimulus that will cause a mechanical summation, resulting in a sustained contraction known as **tetanus** or **tetanic contraction**.

Figure 6: Sports skills usually require great stabilization, as occurs in the eccentric braking actions that can be accompanied by struggles for the ball, as this image shows.

Source: Romero Rodriguez, 2018 (unpublished).

These two examples - single impulse contraction and tetanus - are cases not often seen in daily muscle functions. The frequency of stimuli that a muscle fiber receives allows it to produce contractions that form peaks and plateaus (from a visual point of view), in which the peaks of force do not reach the same intensities as the tetanus, nor do they drop to zero. Muscle contraction is a smooth contraction, as fiber contractions (and therefore, impulses) occur in a sequential manner over time (Latash 2012). On the other hand, sports actions achieve situations of tetanic contraction, but they quickly become accustomed to varying their anatomical location, so they are not sustained over time. In addition, muscle fibers maintain muscle activation at high intensities by sequencing the activation of certain fibers and relaxing others.

When training sports skills, it is important to keep in mind that the muscles are unidirectional creators of force, from a mechanical perspective; that is, they can pull, but not push. This does not mean that contractions only cause shortening in the muscle fiber, but that there are muscles that act concentrically (contraction) and others that act eccentrically when braking, controlling and facilitating joint stabilization (Figure 6). This is possible, due to the fact that the joints are surrounded by antagonistic muscles, which enable the regulation of joint stabilization in a continuous manner.

Influence of muscle length and speed of contraction on muscle strength

When the length of muscle fiber changes, the force it produces depends on the speed at which it varies. Thus, when a muscle is stretched, its strength will be greater than what is obtained in static conditions for that same length. On the other hand, when the muscle is shortened and reaches that same length, it will have less ability to produce force. This is related to the muscle's ability to accumulate elastic energy as it moves towards elongation. In fact, in sports activities, there are continuous stretch-shortening cycles (SSC), which alternate between one another. Stretching actions are commonly known as eccentric, while concentric refers to shortening actions.

Joints are composed of at least one pair of muscles that act in opposition, in order to enable effective joint stability (Lloyd, 2001). As a result, sports actions that require great stability (especially those that are produced in a closed kinetic chain) (Ellenbecker and Davies, 2001) will be subject to coactive actions. It is possible to understand how muscles do not present zero activation levels in these types of actions, even those that do not dominate the movement (Latash, 2012). On the other hand, as we have already mentioned in the figure referring to Lloyd (2001), explosive actions close to automation are produced, due to inhibition of the muscles that would make acceleration difficult for us.

Description of the motor units and the mechanism for recruiting them

Muscles are made up of large groups of muscle fibers. These fibers are innervated by alpha motor neurons that affect a certain number of muscle fibers. The combination of alpha motor neurons and the group of innervated muscle fibers are known as **motor units**. All muscle fibers in the same motor unit are activated simultaneously. The relationship between the type the motor neuron and the innervated muscle fibers will indicate whether the motor unit is of the "slow" or "fast" type. Smaller motor neurons make up smaller motor units and therefore operate on a lower amount of muscle fibers. These units can generate low levels of force, but for long periods of time (they are fatigue resistant). In contrast, large axon motor neurons form motor units with a high force-producing capacity, due to the amount of fibers that are innervated and their characteristics. These motor units usually fatigue quickly.

In natural and controlled conditions, in movements in which the need to produce force is increasing, the motor units are recruited in an orderly manner: the slowest and smallest units first, and the fastest and strongest are recruited gradually and in accordance an increased demand in force. This phenomenon is known as the **Henneman principle** (Henneman, 1957). The size of the motor neurons is highly variable, and it is understood that the tension needed to electrically excite the axons is highly dependent on their diameter (Henneman, 1957). It is important to note that this approach explains the eccentric contraction, but not the eccentric action, as Enoka (1996) explains further on in the text.

Regarding the **Henneman size principle,** it is important to note that the independent variable is the intensity of the stimulus, while the dependent variable is the recruitment of larger motor units (with a higher excitability threshold, and therefore more difficult to recruit). At no time is force proposed as a prerequisite for recruitment; on the contrary, it is the result of a more intense stimulus. This means that the level of effort in the voluntary movement will determine the degree of motor unit activity. Let us not forget that muscle action, i.e. movement, begins in the brain; unleashing action potentials that activate the recruitment of motor units, which will unfailingly respect the principle of size (Carpinelli, 2008).

We refer again to the amount of force produced. Bernstein suggested that the central nervous system, in principle, cannot predict the amount of force that will be produced as a result of its own order. This is because the emerging force of each order is the result of an interaction between the signals, in relation to the instantaneous state of the muscle in terms of its length and speed of contraction and elongation (Latash 2012). This instantaneous muscle situation also involves factors such as fatigue and the post-activation potentiation phenomenon (PAP), among others. Thus, a muscle's force output will depend on the size of the stimulus (recruitment), the frequency of that stimulus, and the synchronization of muscle fibers (Bosch, 2015). This force output would be even more unpredictable if there were no fixed and learned movement patterns that activated a certain number of motor units.