Module 4: Evaluation of muscle properties in relation to sports

In this module, we will address two types of evaluation that are directly related to muscles. On the one hand, surface electromyography (SEMG) provides information on muscle behavior, both in static and dynamic actions. Its most functional and essential characteristic is that it allows us to study how muscles organize themselves and interact when executing any type of action, even at maximum intensity or when maintaining a posture. For this reason, it is a key instrument in biomechanical analyses related to neuromuscular control and coordination, although we will analyze its limitations.

On the other hand, tensiomyography provides us with information on the mechanical characteristics of the muscle and its contractile capacity. This is a passive type of evaluation, since it is carried out while the subject is resting and in a stable position, which is a necessary condition for this study.

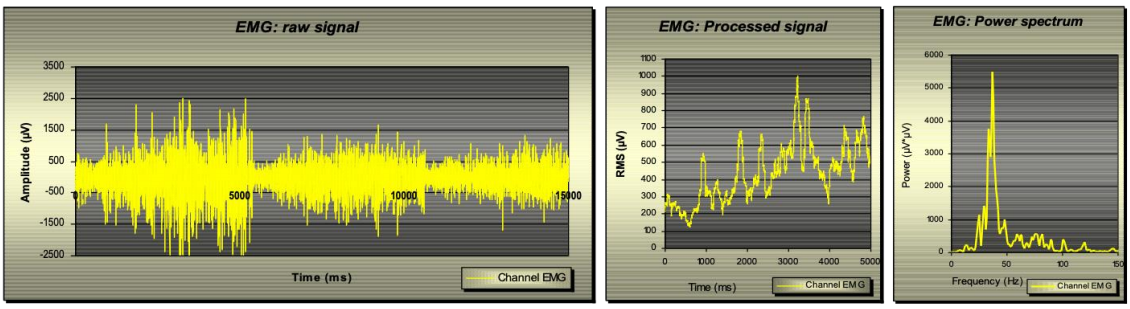
These assessments are non-invasive, aim to study the muscle, have an indirect connection with the development of strength, and can complement one other through the type of information they provide.

4.1 Surface electromyography

SEMG, also known as kinesiological electromyography (Soderberg and Knutson, 2000), allows the electrical signal of the muscle to be obtained by performing a movement. The need to study how different muscles interact in a movement was previously addressed by Professor John V. Basmajian (1976), who linked this methodological possibility to the study of neuromuscular coordination.

SEMG operates by capturing the electrical activity that takes place during a muscle contraction. This occurs when the motor neuron chemically activates the muscle fiber in its neuromuscular junction and an electrical charge is produced, which is sent by the different myofibrils and enables the contraction of the sarcomeres. The electromagnetic field created as a result is used to detect muscle activity (Basmajian and De Luca, 1985). The signal extends through the tissues, allowing it to reach the cutaneous level. It is a low-magnitude signal that is measured in mv or μV (Cram and Kasman, 1998), and is formed by joining the upper and lower body activity in relation to the set of action potentials of the different UMs (MUAPTs), which are activated and recorded through the system (Kippers, 1999; Cram and Kasman, 1998; de Luca, 1984). Processing this raw data will make it possible to process the signal in a simpler way, in order to study both power and frequency parameters (Figure 1).

Figure 1: Raw signal, signal processing and display of the frequency spectrum of the signal generated



Source: Prepared by the authors.

Through this operational mechanism, SEMG provides us with a representation of the set of muscle activities, while the intramuscular electromyography (commonly used in clinical evaluation) will provide data on a very specific part of the muscle (Christensen, Sogaard, Jensen, Finsen and Sjogaard, 1995) and can be used in biomechanical studies. Professor de Luca (1997) explains the three key features of SEMG:

- Determine the activation timing of the different muscles involved in an action.
- Make a qualitative estimate of muscle strength.
- Obtain quantitative data on the intensity of muscle fatigue by studying the frequencies of the signals collected.

If we reflect on the possibilities of electromyography, we would realize that there is great potential in this type of analysis in terms of data, because it provides us with knowledge on the individual muscles, which will allow us to compare the resulting data in key coordination movements. Despite these possibilities, SEMG has several methodological limitations, such as the characteristics of the instruments used, the potential crosstalk in a recording (muscle activity adjacent to the muscle being studied) (Cram and Kasman, 1998), and the problems that arise when assessing dynamic actions.

An important aspect is the standardization of the electromyographic signal. Burden (2010) identifies isometric MVC (MVIC) as a valid method of standardization of this signal; that is, the reference value in which all measurements may be represented in percentages (Figure 2). This method currently has a high degree of reproducibility, along with the lesser-used submaximal isometric action. Signal standardization is necessary in order to make comparisons between different measurements, subjects and studies. There is another signal standardization methodology, as the author points out in this review, but the most widely-used parameter is the MVIC.

Figure 2: Position to acquire a maximum voluntary isometric contraction (MVIC) of the hamstring muscles, through manual resistance provided by the assessor.

Source: Romero Rodríguez, 2003, p. 101.

4.1.1 The study of electromyographic amplitude and its connection to muscle strength

Electromyographic amplitude is studied through the integrated electromyography parameter (iEMG), which is defined by the area under the curve of the rectified electromyographic signal. This parameter provides us with data on the absolute value of the raw signal obtained. In order to give a greater physical meaning to the electromyographic amplitude assessment, the root mean square (RMS) is typically used to represent signal strength (De Luca, 1997). In Cram and Kasman (1998), we can see how this value is calculated.

The parameters of amplitude provide an idea of the muscular effort carried out in an action, although there is no total proportionality between the electromyographic signal and muscle strength (Clarys, 2000; Vilarroya, Marco and Moros, 1997). This is because the electrical signal detected depends on the ionic concentration in the muscle being studied (Massó et al, 2010). The production of strength will also depend on the length of the muscle when activated, and this occurs in both static and dynamic actions, although in different proportions (De Luca, 1997).

This relationship has been studied for years, since Viitasalo and Komi (1977) argued that this was true for actions with a constant velocity and in isometric recordings. However, for the latter, this relationship was only identified until the load reached 70% of the MVIC, after which the relationship was lost. To this end, De Luca (1997) increased the correlation to 80% of the MVIC, so that it has a greater impact on the qualitative interpretation of the SEMG activation - strength ratio than a quantitative parameter.

Extreme caution should be exercised when conducting an analysis on dynamic actions. Carius, Kugler, Kuhwald and Wollny (2015) analyzed actions in motion and recorded a good level of reliability in the electromyographic amplitude signal, with a higher intraclass correlation coefficient (ICC) compared to the frequency signal recorded. This was seen in flexion and extension of the elbow in the biceps brachii, brachioradialis and vastus lateralis of the triceps brachii.

This data was recorded in the comparative analysis of individuals. On the contrary, when the analysis compared different series, the results were poor in terms of reliability. As the aforementioned authors explain, the difference in the coefficient of variation (CV) between the three muscles can be caused by anatomical differences among them, as well as by the amount of subcutaneous tissue, the amount of movement between electrodes and active muscle fibers, the difference in the proportion of the existing fiber type, and the difference in the amount of cross-talk (disturbance from signals in adjacent muscles). Topic 3 of this unit will address the limitation of SEMG in the study of dynamic actions.

4.1.2 Analysis of electromyographic signal frequency parameters and their relationship with muscle strength and power

The signal frequency parameters have been described as follows: MF (median frequency), MPF (mean power frequency) and the mode (frequency of peaks in the spectrum) (De Luca, 1984). These parameters have been linearly connected to the conduction velocity of muscle fibers (Stulen and De Luca, 1981). In order to assess the maturity with which SEMG has been utilized from a methodological perspective, it is worth highlighting several studies, such as those by Petrofsly, Glaser, Philips, Lind and Williams (1982), in addition to Viitasalo and Komi (1977). These studies opted to use MPF in the study of muscle fatigue, since they argue that this parameter is less sensitive to changes in strength. In this respect, Daanen, Mazure, Holewijn and Van der Velde (1990) obtained a good level of reproducibility (0.97) in the biceps brachii, in submaximal isometric actions in different measurements of the same subject (there was significant variability between subjects, making it difficult to determine a general frequency behavior in relation to a muscle).

Viitasalo and Komi (1975) calculated a range of test-retest reproducibility of MPF between 0.77 and 0.88. On the contrary, De Luca (1997) stated why the use of MF is more optimal, arguing that it is less sensitive to noise and more sensitive to the biochemical and physiological factors produced within the muscles in isometric actions (see Figure 3). Despite the different arguments, we must keep in mind that these are two valid parameters in terms of methodology, even in patients with some type of disorder, such as lower back pain (Roy, De Luca and Casavant, 1989).

Calculating the frequency of the signal makes it possible to develop the frequency spectrum that is produced in a certain action. The study of this

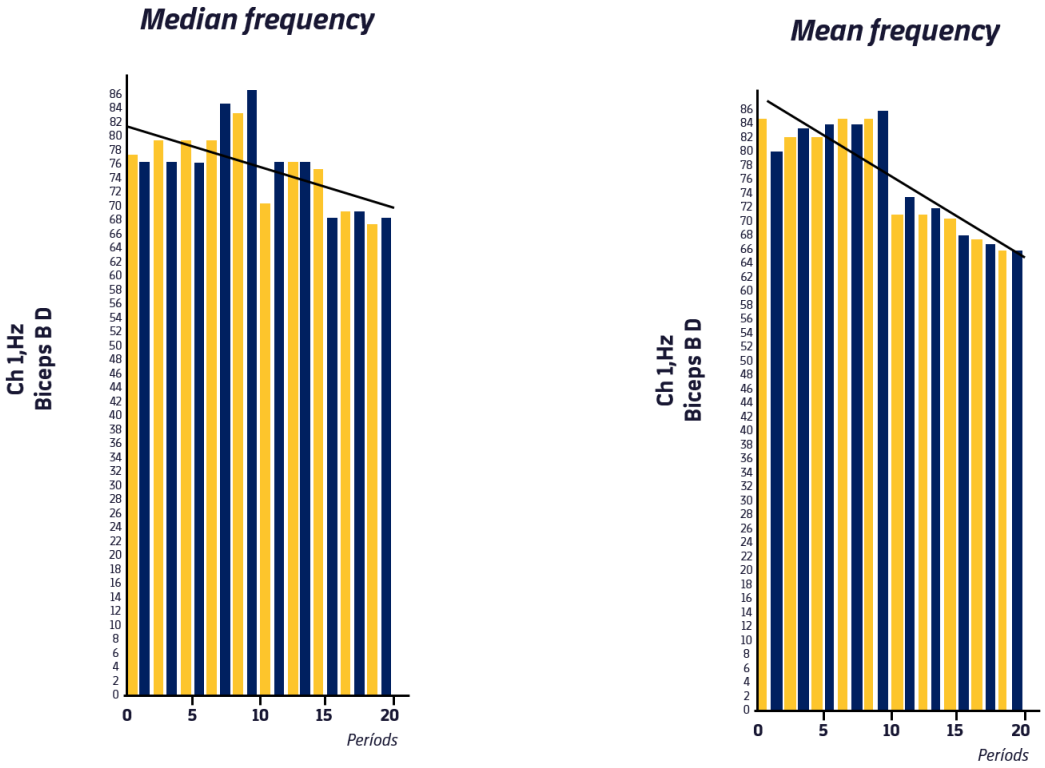
spectrum is important because it provides us with information on all of the frequencies in which the motor units recorded in a movement have participated, and allows us to study the electrical output of each of the frequencies (De Luca, 1997; Vilarroya et al., 1997).

Different algorithms have been used in the calculation of frequencies. Fast Fourier Transform (FFT) has normally been applied, although Potvin and Bent (1997) explained that because the dynamic nature of an action affects the electromyographic steady-state signal, this type of algorithm has numerous limitations in dynamic studies. For this reason, Roy, Bonato and Knaflitz (1998) support the use of such a method only when the non-steady state behavior of the signal is very slow.

Previous studies have supported the use of FFT in dynamic actions (Shankar, Gander and Brandell, 1989; Sakamaoto, Usui, Hayami and Ohkoshi, 1982). However, the wavelet transform has been subsequently applied to more accurately express a frequency spectrum in a dynamic signal, as was studied for many years in maximum intensity isokinetic actions (Xiao and Leung, 1997), in isometric actions of the spine extensors (Pope, et al., 2000), and how it was also used in brief actions with non-steady state signals (Karlsson and Gerdle, 2001).

In this module, we will discuss studies related to the wavelet transform in dynamic actions. In relation to the study of frequencies, other authors have applied the Cohen wavelet transform (Bonato et al., 2001; Roy et al., 1998).

Figure 3: Constructing the progression of the frequency parameters (MF and MPF) in successive isometric tension recordings of the biceps brachii (series of 10 seconds)

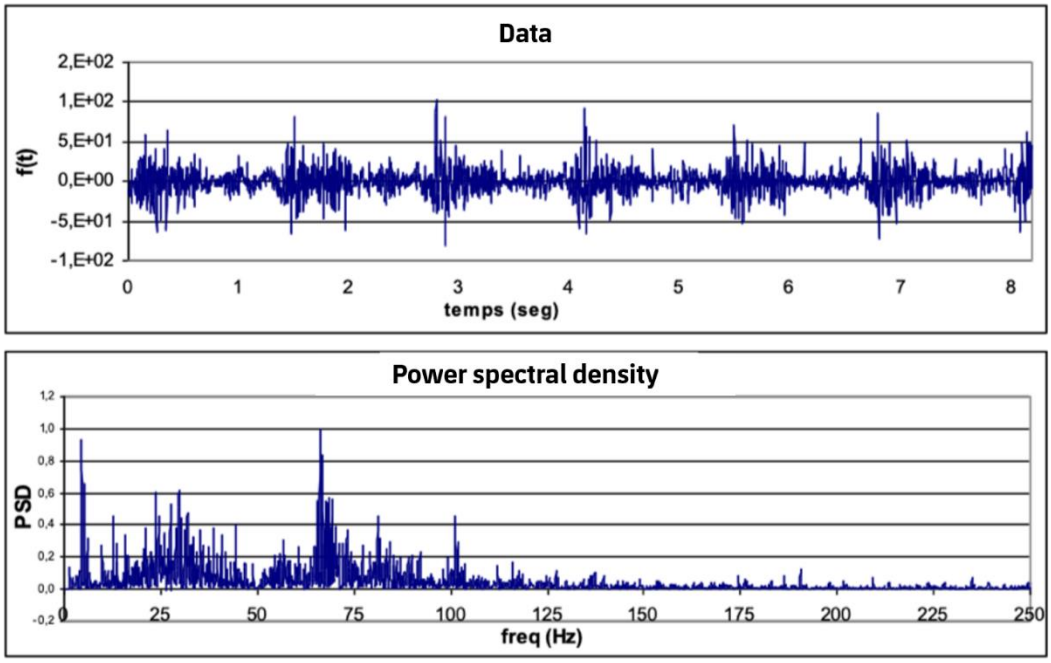


Source: Prepared by the authors.

In the figure, we can see how both parameters show a decrease in frequency as the series progressed. The SEMG recording corresponds to the biceps brachii.

Despite the difficulties in the analysis, it is necessary to consider the study of the frequency spectrum (Figure 4) in relation to the decrease in strength and the appearance of muscle fatigue, since the scientific evidence proves its usefulness, as was mentioned by De Luca (1997). Considering the interpretation of the frequency spectrum, it is important to highlight the premise of this analysis, which indicates that, at the onset of fatigue following prolonged exercise, a variation of the spectrum is obtained; consisting of the displacement of the signal to the left (lower frequencies), as compared to a state of non-fatigue (Massó et al., 2010).

Figure 4: Electromyographic signal (top image), and generating its frequency spectrum using the FFT (bottom image)



Source: Romero Rodríguez, 2003, p. 98.

Vestergaard-Poulsen, Thomsen and Sinkjaer (1995) described changes in the frequency spectrum of SEMG, and its relationship to the accumulation of protons and lactate in the tibialis anterior. This was done with the aim of linking metabolism to MU recruitment, as changes in amplitude and frequency are identified as changes in MU recruitment. Despite this hypothesis, which was supported in previous literature, the authors did not record such a relationship (as was the case in the work of Ament, Bonga, Hof, and Verkerke, 1993). They argue that the change of frequencies obtained was the result of an alteration in the excitation-contraction (EC) mechanism, potentially due to a decrease in the impulse propagation speed in muscle fibers (a reduction in the release of calcium from the sarcoplasmic reticulum and reduced myofibril sensitivity to calcium). This is supported by the evidence that the electromyographic frequency cannot be altered by pH or lactate accumulation, since these two factors remain altered at the same time that the frequency has an almost instant recovery.

It is clear that in the study of fatiguing dynamic actions, electromyographic frequency variables reveal more stable data, compared to parameters of amplitude. Larson, et al. (1999) made repeated acquisitions on different days of the MPF and RMS EMG in maximum isokinetic knee extension actions, detecting an optimal reproducibility in the three parameters. In a very similar design, Gerdle, Larsson and Karlsson (2000) analyzed the reproducibility of these variables in the VL, VM and RF of the quadriceps, finding a greater correlation in the MF than the RMS, in terms of the maximum isokinetic peak.

These results support the preferential use of frequency parameters in the electromyographic measurement of dynamic actions. In terms of movement -

in this case, the act of pedaling - Gamet, Duchêne and Goubel (1996) studied the reproducibility of the MPF of the RF through SEMG, observing an optimal level of reproducibility in the same subject, which suggests that the MPF kinetics can characterize an individual at any given time (which is also supported by Larson, et al, 1999). This last study also shows the use of frequency parameters and is performed in a cyclical action, which enables the use of electromyography in a more stable context, as compared to a more complex movement.

There are different studies on dynamic actions that explain how the frequency parameters of the electromyographic signal are more dependent on applied force and muscle length, but less so on velocity of execution (Shankar et al., 1989). This was also recorded by Christensen et al. (1995), who observed that the MPF of the frequency spectrum depends on muscle length (and therefore on the joint angle). In order to validate the studies using frequency parameters, Öber, Sandsjö and Kadefors (1992) argued that it can be confidently said that there is localized muscle fatigue, only when the decrease in MPF exceeds 8% of its initial value.

4.1.3 Electromyographic study of intermuscular coordination in relation to sports

Given its properties, SEMG has typically experienced difficulties in interpreting the data collected in dynamic actions, since the electrodes that capture muscle activity are located on the skin and, below it, the muscle slides constantly when in movement, which means that the signal cannot guarantee a continuous study of the electrical activity of certain motor units. For this reason, the relationship between the different SEMG variables in dynamic fatiguing actions, such as RMS, MPF and MF, have been questioned by different researchers, based on the variation in muscle length and strength produced during the recordings (Öberg, Sandsjö and Kadefors, 1990; De Luca, 1984).

This has led to data collection from the study of isometric actions, with regard to both signal amplitude and frequency (Potvin and Bent, 1997; Bigland-Ritchie, Cafarelli and Vollestad, 1986; Moritani, Nagata and Mauro, 1982). In order to obtain a more stationary signal than the one produced through dynamic action, it is necessary to achieve a good level of stabilization of the electrodes. However, execution of the movement will be what triggers the aforementioned capture of the different UM (Clarys, 2000; Roy et al., 1998).

This limitation can be controlled to a certain extent by situating the activation of the muscle closer to isometrics, but doing so reduces functionality to measurement, if the aim is to perform studies related to the biomechanical analysis of an action. To alleviate this situation, De Luca (1997) puts forth the idea of analyzing limited windows of movement, in order to extrapolate the results obtained. In addition, the author proposes repeating the action to be assessed in a cyclical way, making it possible to evaluate the same range of movement in different repetitions of an action, which will provide greater stability in the measurement.

Even today, we can confirm that there is little evidence to validate the unrestricted use of SEMG in dynamic actions, despite the numerous studies conducted with such actions. Ament et al. (1993) were able to compare the electromyographic changes in the gastrocnemius and soleus in static (plantar flexion) and dynamic fatiguing actions (elevated sprints on treadmill). These authors recorded how the MPF was significantly higher in isometric actions in the various muscles studied (between 30 and 40Hz higher than in dynamic exercise). Furthermore, although the fatigue-induced MPF changes were similar for the two types of actions in the gastrocnemius, they were greater in the soleus during dynamic actions. It is important to note that the decrease in the electromyographic frequency is much higher when measuring fatiguing actions than what is recorded in conduction velocity. During fatiguing isometric exercises, an increase in the electromyographic signal and a decrease in the MPF or FM were clearly observed, although this dynamic has been called into question when measurements are made while in motion.

In this regard, Hug (2011) presents the following idea, which is still relevant: a discussion on the limitations of SEMG when used to assess muscle coordination. That is, determining whether the neural control strategies related to movement can be studied using SEMG. As can be deduced from this article, the electromyographic data must be interpreted with caution, since the data reveals a high level of variability between subjects. Despite this, the author explains that the variability described might also be due to aspects such as the existence of crosstalk, the placement of electrodes in different areas and the type of signal processing, as was previously mentioned. We must also keep in mind that the variability between subjects should not be a problem when the signal is standardized. In addition, the patterns of sequencing and intensity of the activation in a single action will vary between subjects, as a result of their different characteristics and abilities. Despite studies such as those discussed, which reveal the difficulty of SEMG analysis in dynamic actions, this instrument has been widely used in the study of the biomechanics of various types of static and dynamic actions.

Valentin and Zsoldos (2016) explain that SEMG is currently used in different fields, such as clinical (existence of injuries), the study of functional tasks in a healthy population, and the analysis of tasks related to sports and exercise. In addition, these authors remind us of the work carried out in the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) project to methodologically standardize the use of this study technique (Hermens et al., 1999).

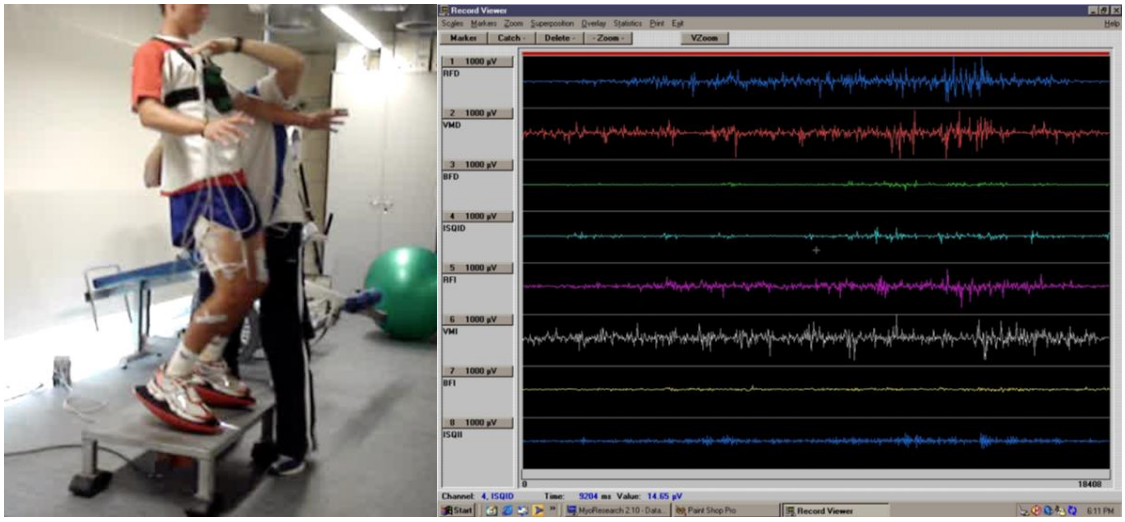
Relatively simple actions are studied in a clinical setting, even when carried out under dynamic conditions. Larsson et al. (1999) studied the reproducibility of the electromyographic signal in dynamic actions of a knee extension, by means of intraclass correlation (ICC); an exercise that is typically carried out in many post-injury recovery programs. The population studied performed three series (separated by one hour) of ten maximum isokinetic knee extension repetitions, collecting the quadriceps activity; from both the rectus femoris and the two vastus muscles. The maximum force and EMG signal amplitude (RMS)

revealed a good level of reproducibility, as did the frequency variable (MPF), especially in the vastus lateralis.

Massó et al. (2010) explain the usefulness of SEMG in the evaluation and monitoring of a recovery process. Among these aspects, we should highlight the study of signal intensity in the muscles involved; in comparison with the contralateral side in injuries of the extremities and the analysis of neuromuscular coordination, either to observe the activation sequencing or, more specifically, parameters such as the agonist-antagonist relationship in an action (see Figure 5). These authors discuss studies using SEMG for clinical purposes. Wong (2009) conducted a review on patellofemoral syndrome and presented the different results through SEMG, using studies that showed alterations in the activation patterns in the vastus lateralis and medialis of the quadriceps, while others did not record such an alteration. This leads us to consider the limited reliability of results among this population, which must be taken into account in such analyses.

In the case of lumbar spine conditions, different patterns of activation of the lumbar extensor muscles have been identified in people with such conditions, in comparison with healthy individuals, as described by Geisser et al. (2005) in a meta-analysis. Peroneal and anterior tibial muscles have also been studied in individuals who had experienced injuries in the external lateral ligament of the ankle, and there was a progression in the activation pattern that these subjects had experienced after an exercise program, based on balance and response capacity (Sheth, Yu, Laskowski and An, 1997; Osborne, Chou, Laskowski, Smith and Kaufman, 2001).

Figure 5: The electromyography signal makes it possible for the different muscles to sequence their activation with one another.



Source: Prepared by the authors.

In the image on the left, we can see a snapshot of a balancing exercise, in which the subject reacts to perturbations caused by the trainer. The SEMG image captured corresponds to the entire sequence of the series, which lasts approximately ten seconds. The musculature recorded between channels 1 and 4 corresponds to the rectus femoris, vastus medialis, biceps femoris, and the inner hamstrings (both semitendinosus and semimembranosus) on the right side; while channels 5 to 8 show the same muscles on the left side of the body.

In addition, Alizadehkhaiyat and Frostick (2015) conducted a review in a clinical context, focusing on electromyographic studies related to epicondylalgia in tennis players. These authors mention that there are indicators of increased activation of wrist extensor muscles in tennis players who play with one hand and have less experience, although there is not enough evidence linking it to the development of epicondylalgia. As the authors explain, this work is important because they found a broad variation in the study parameters in the studies reviewed, for example, within the analyzed population; in relation to gender, level of tennis, the type of electrodes used, the forearm muscles studied, the SEMG protocol implemented, the standardization carried out and the parameters used. In light of this fact, which illustrates the reality of the studies in the majority of areas where an electromyographic study is used, it is very difficult to draw conclusions regarding clinical issues. As far as we can see in the related literature, this also extends to the area of sporting performance.

Some of the studies mentioned support the use of SEMG in dynamic actions, but we should note that many of these analyze actions that are developed in a cyclical way, even in movement. This facilitates greater stabilization of the signal, but removes the method from the context of sports and other professions. In this latter area, Christensen et al (1995) suggest that the study of fatigue can be performed via electromyography in work tasks.

However, it is also true that in this study, the dynamic evaluation was closer to a static assessment; since slow, low-intensity actions were measured with a high level of control in the velocity of movement (concentric and eccentric actions revealed the same duration). In these conditions, the authors obtained similar RMS, MPF and MF results in both static and dynamic actions; a finding which was previously observed in actions performed at 20% of CVM (maximum voluntary contraction) (Muro, Nagata and Moritani, 1983; Christensen et al., 1995).

It is important to note that these studies can be criticized, if we want to draw conclusions on the actions carried out with a high degree of dynamism and intensity, since the movements analyzed were executed under a high level of control, which is not suitable in a sports context. However, at the 14th Congress of ISEK (International Society of Electromyography and Kinesiology), De Luca, Bonato, Roy, Moore and Vadnais (2002) explained how different dynamic actions in daily life can be analyzed through SEMG, underpinning this fact in an interesting way.

As was previously explained, SEMG provides us with information on how the different muscles intervene when executing an action; sequencing one another and dynamically varying their amplitudes and frequencies. Leisman, Zenhausern, Ferentz, Tefera and Zemcov (1995) studied a repetitive exercise of the EESS in two constant force tests: one short and one with a longer duration to the point of exhaustion, performed at 10, 25, 50 and 75% of the CVM. The results showed an increase in muscle efficiency, identified through learning the task by finding a decrease in signal amplitude (EMGI) in the different sessions recorded, with an increase in strength. Years ago, Professor Basmajian (1977) had already observed a significant decrease in antagonist muscle activity during progressive learning of a motor task, and this meant an improvement in motor control, among other aspects, if identified by the subject's ability to inhibit the activation of muscles that do not contribute to an action. In their study, Mulder and Hulstijn (1985) did not record a variation in the antagonist activity, instead identifying greater efficiency in the modification of the agonist muscle activity.

With regard to this motor learning, we must keep in mind that the methodological characteristics of SEMG make it an instrument that can be applied within sports, despite the limitations mentioned. The muscles that can be studied using this assessment technique must be superficial, keeping in mind that there are many muscles involved in sporting activities that can be analyzed using this instrument; allowing us to assess various aspects, such as the efficiency and effectiveness of a motor skill. This knowledge can be used in the areas of performance, prevention and readaptation to post-injury competition.

Despite this, we must keep in mind that this type of analysis has its limitations, as was previously mentioned, especially in the study of signal frequencies in a dynamic action. In addition, there are major obstacles when trying to obtain information on neuromuscular physiology and fibrillar composition. In this regard, Beck et al. (2009) conducted a study using GMM (mechanomyography) and EMG, in order to observe whether the frequency spectrum (MPF) in athletes with different characteristics (strength training and cardiorespiratory endurance training) resulted in different spectra in an isometric action of a knee extension. There were no differences between the two spectra. In this study, the researchers collected a biopsy of the vastus lateralis of the athletes studied. The analysis clearly differentiated a greater predominance of type II fibers in athletes who practice strength training, and type I fibers in those who practice endurance training, which showed that SEMG was not suitable for studying the fibrillar composition of the musculature. In contrast, SEMG has a strong ability to understand how different muscles perform in an action, how they sequence over time, and at what intensity and frequencies (even with limitations) they are (electrically) activated. All of this information is of great importance to the biomechanical studies of sports actions.

In the field of evaluation of sports actions, Kellis et al. (2003) studied the coactivation of the rectus femoris (RF) and the biceps femoris (BF) in drop jump (DJ) actions, by calculating the coactivation index (CI). They conducted this in subjects with explosive strength (long jumpers), and applied it from different

heights: 20, 40 and 60 cm. They recorded the electromyographic activity of these muscles, the ground reaction force using a force platform, and the kinematics of the actions through synchronization of video cameras. The latter made it possible to establish the pre-contact, deceleration and propulsion stages. They used various CI calculation methods, and this parameter was not affected by the height at which the DJ was performed. The results show a greater coactivation in the pre-contact stage, compared to deceleration and impulse. It is interesting to use this parameter in biomechanical studies on drop jumps, although it is necessary to establish the method used for its calculation, since each method in the study displayed variable values.

In terms of jump analysis, Jayalath, de Noronha, Weerakkody and Bini R. (2018) analyzed the studies on the effect of fatigue on ankle biomechanics within this action. When comparing conditions in fatiguing and non-fatiguing situations, these authors recorded an impairment of the jump biomechanics, due to the effect of fatigue; where the reduction of dorsiflexion is emphasized from the initial point of contact to the maximum flexion and power during the final stage of impulsion. All of these findings could be especially relevant in establishing preventive measures.

As for the functionality of the studies, the study by Rahnama, Lees and Reilly (2006) observed electromyographic activity in an intervention that simulated a soccer game through continuous activity of varying intensity on a treadmill. In this exercise, the electrical activity of the rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius (GC) was recorded before exercise, at the half-way point, and immediately at the end of the 90-minute procedure. The results showed a decrease in electrical activity in the different muscles analyzed, when comparing the pre- and post-intervention values, which indicates that the soccer game simulator triggered a decrease in myoelectric activity, although the exercise was sustained.

Within this section, we have addressed the limitations of SEMG in the analysis of dynamic actions. Despite this, studies have been conducted where this methodology is applied in actions with movement in different areas: clinical, in a healthy population, a work environment and sports environment. The results obtained reveal limitations in their interpretation, but they are also accepted in the scientific literature when this interpretation is coherent; given the amount of information that can be extracted through this type of analysis. In an attempt to gain more insight on SEMG methodology, various studies try to strengthen this evaluation tool. For example, the aforementioned study by Carius et al. (2015) incorporates an analysis of the signal through wavelet transform in bending actions and elbow flexion. In their conclusions, these authors support the use of the wavelet transform, even with low intensity signals due to the robustness of this measurement. The explanation is interesting: when close to 50% of the stretch-shortening cycle (SSC) of the studied action, the reproducibility of the wavelet transform variables briefly decreased. This is related to possible limitations of the method used in this study, but they also explain that the eccentric - concentric transition took place at this particular moment in the cycle, and these two muscle actions attain a different level of organization when working in coordination. They also note

that another benefit of using the wavelet transform is that it may be responsive to the study of the SSC transition.

González-Izal, Malanda, Gorostiaga and Izquierdo (2012) conducted a review of the different methodologies employed to study muscle fatigue using EMG. They analyze various proposals, including the wavelet transform. In their explanation, they discuss their previous experience with analysis parameters from the different ranges of the stationary wavelet transform, in which the original sample has not been altered (processed). They state that this type of analysis can reflect the characteristics of the surface electromyographic signal in amplitude, frequency and duration in a given formula. It seems that this type of analysis is less sensitive to noise in the signal.

Another study that supports the use of the wavelet transform is that of Vannozzi, Conforto and D'Alessio (2010), who emphasize its capacity in the electromyographic analysis of dynamic actions. When applied this way, it correctly detected muscle activation times in this type of moving signal.

Another methodology, in-line electrodes, aims to improve SEMG measurement in dynamic actions through the use of array electrodes, which involves the placement of multiple electrodes to better capture all muscle activity. In order to clearly display the difference, Gazzoni, Botter and Vieira (2017) explain the traditional placement of two electrodes used to record the electromyographic manifestation of superficial muscles, and thus study muscle fatigue.

The main objective of this methodology is to record the alterations in electrical properties of the muscle (the electrical expressions of fatigue), and therefore be able to capture the imminent fatiguing process that is later evidenced by a decrease in strength. In this context, the authors of this review present array as a methodological variant, which has been worked on for many years and progressively perfected. This method of capturing electrical energy in the muscle provides access to physiological variables, both on a global muscular level and in isolated UMs; allowing for the study of better precision when quantifying the signal transmission velocity, along with the evaluation of electrical output that indicates fatigue in specific areas of the muscle, and the analysis of isolated UMs. This provides the opportunity to increase our knowledge on motor control and the changes that occur in the membrane of the muscle fiber.

Farina, Merletti, Nazzaro and Caruso (2001) have been using the array technique for years, since there is no location in dynamic actions where an electrode could provide information on the entire joint range of movement, so in-line electrodes may be more useful. These authors reiterate that it is not possible to determine the fluctuations in the SEMG parameters in dynamic actions, as seen in the literature on cyclic actions (or stages of a cycle), or in repeated movements, if they are caused by changes in muscle activation or geometric variations in the muscle. For this reason, they urge caution in the interpretation of the results, at least until methods are developed to differentiate between these two possible causes. In any case, they explain that

averaging estimated electromyographic variables in a specific stage of a cycle (repeated angular variations) or during a cyclic action could be a good solution for analysis, as was previously mentioned.

Finally, within this unit, Professor Roger M. Enoka has conducted a review (Enoka, 2019), comparing studies on the signal decomposition acquired through SEMG. This author, together with other researchers, has created an important body of knowledge (we should highlight the work of Farina, Merletti and Enoka, 2014). This signal has been broken down into isolated UM stimulation times, which is known by its rate coding characteristics of these isolated UMs, as per recordings made with intramuscular electrodes. The different studies reviewed in this publication compare various methods of signal decomposition, and some of these are able to recreate a large number of the findings observed through intramuscular electromyography, although improvements are needed in this type of analysis. Despite this, Professor Enoka points out that this technology can potentially increase knowledge on the physiology of UMs, thus generating valuable information that can even be of use in a clinical setting.