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REVIEW

Surface electromyography applications in the sport

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Abstract

The electrophysiological techniques (neurography and needle electromyography) allow us an approach to the knowledge of the neuromuscular function. Electromyography obtains the electrical activity from the muscle in rest or in contraction (maximum and static voluntary contraction). In its clinical application, electromyography helps to the diagnosis and follow-up of a process of neuromuscular type.

On the other hand, kinesiological or surface electromyography (SEMG) allows the study of the muscular activity in dynamics, which we can apply to the biomechanical movement analysis, gait analysis, studies of muscular fatigue, sport performance and applications in work medicine and ergonomics.

SEMG brings advantages like the fact that is a bloodless test, of being able to analyze varying muscles at the same time, in motion and in actions of non limited duration. The processed one brings us parameters of amplitude and frequencies, which we will use for descriptive and comparative studies. As a balancing entry, it does not allow us to study deep musculature, and some aspects of definition are lost in the obtained outlines.

PALABRAS CLAVE
Electromiografía de superficie;
Aplicaciones;
Fatiga;
Biomecánica;
Electrofisiología

Aplicaciones de la electromiografía de superficie en el deporte

Resumen

Las técnicas electrofisiológicas (neurografía y electromiografía de aguja) permiten una aproximación al conocimiento de la función neuromuscular. La electromiografía obtiene la actividad eléctrica del músculo en reposo o activo (contracción voluntaria máxima y estática). En su aplicación clínica, asiste al diagnóstico y al seguimiento de un proceso de tipo neuromuscular.

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Por otro lado, la electromiografía de superficie (EMGS) o cinesiológica permite estudiar la actividad muscular en acciones dinámicas, siendo aplicable al análisis biomecánico de un gesto, al análisis de la marcha, en estudios de fatiga muscular y de rendimiento deportivo y en áreas como la medicina laboral y la ergonomía.
La EMGS ofrece algunas ventajas: es incruenta y permite analizar simultáneamente distintos músculos en movimiento y en acciones de duración ilimitada. El procesado de la señal electromiográfica proporciona parámetros de amplitud y frecuencia para estudios descriptivos y comparativos. No obstante, no permite valorar la musculatura profunda y aporta menos definición que los electromiogramas de aguja.

Introduction

Electrophysiological techniques enable us to relatively easily obtain very valuable information about neuromuscular activity[1]. Two techniques are usually used in clinical situations: neurography and needle electromyography. The former allows the study of the response potential of a sensory, motor or mixed nerve branch subjected to an electrical stimulus applied to the surface. The latter allows the direct and precise recording of the electrical activity of the muscle being studied, both in repose and in attempts at maximum contraction.

Another technique for recording the electrical activity of muscles is surface electromyography (SEMG), which has other advantages and applications, both in research and in clinical practice. In this review details are given of this technique, as well as of its current principal applications.

Definition of electromyography

Electromyography is the recording of the electrical activity of muscles, and therefore constitutes an extension of the physical exploration and testing of the integrity of the motor system[2,3].

It can be said that SEMG, sometimes called kinesiological electromyography, is the electromyographical analysis that makes it possible to obtain an electrical signal from a muscle in a moving body[4-6]. It has to be added, by way of clarification, that according to this definition its use is limited to those actions that involve a dynamic movement. Nevertheless, it is also applicable to the study of static actions that require a muscular effort of a postural type.

It is based on the fact that muscular activation involves:

- A prior ionic diffusion within the muscle, which generates an electric field around it proportional to the ionic concentration. This electrical field is detected by the EMG electrodes.
- A consequent mechanical response occurs due to the articular moment generated by the force that the muscle makes upon contracting.

The principal purpose of this type of measurement is to establish the activity of one or more muscles involved in a particular action. This includes:

- Determining, at each moment, whether the muscle is active or inactive.
- Determining the degree of activity exhibited during periods in which there is activity.
- Determining what type of relationship or interaction the muscle maintains with the rest of the muscles involved in the action under study (the concept of *intermuscular coordination*).

In order to be able to identify the moments and periods in which the activation of the different muscles involved in a specific dynamic action occurs, it is essential to synchronise the electromyographic recording with the recording of other measurement systems that provide cinematic data. These systems usually involve the use of cameras, electrogoniometers and other recording equipment together with their programs, and provide us with position, speed and acceleration measurements. In addition, the study can be complemented with systems that analyse forces, also called kinetic systems, such as podometry and a force platform. SEMG forms part of this approach and has been introduced as an important part of biomechanical analysis[4,7].

SEMG: uses and applications

Analysis of a movement

The analysis of movement usually includes a cinematic study and a kinetic study. The cinematic study is responsible for determining the position, speed and acceleration parameters, both linear and angular. Different camera and marker systems are used for this purpose. The kinetic study determines the internal or external forces involved, related to the movement being analysed. To carry out this study, instruments such as force platforms and other devices for measuring forces are used. Electromyography enables us to record muscular activity, and it is often advisable to carry out a synchronised cinematic measurement at the same time. In this way, the two types of data can be contrasted and it is possible to establish:

- How long the muscle is activated for, the start and end of the activation in relation to the articular position.
- The degree of muscular activity which itself reflects the

level of muscular effort. However, this must not be confused with the level of muscular force, as the electrical signal detected is a function of the ionic concentration in the muscle.

SEMG facilitates tasks such as defining muscular participation in a particular movement[8] or observing the activation of the musculature in a segment in response to the mobilisation of other segments[9]. These aspects are relevant in areas such as sports medicine, occupational medicine and, increasingly, in ergonomic studies[10-21].

Gait analysis

Gait analyses constitute a specific type of movement analysis, gait having the particular characteristic of being a cyclical and complex action. Currently there are closed programs for analysing gait, which make it possible to compare the data obtained from an individual with what is considered to be within the normal range, as well as to compare one limb with another for the same individual.

SEMG focuses on the activation times and intermuscular coordination which are important parameters in the evaluation of pathologies with disturbances of movement and disturbances of neurological origin that affect the gait. They are similarly important in post-surgery evaluation in cases of articular prosthetic implants[22-25] and where there is articular instability and/or damage to ligaments[26].

Evaluating fatigue

In prolonged movements a series of electrophysiological changes take place linked to the development of a fatigue process that produces observable changes in the electromyographic traces. This is of special interest in sports medicine, occupational medicine and ergonomics. Using this technique we can determine the existence or absence of this fatigue process, analyse its development over time and compare its behaviour in different situations[11,20,27-35].

Evaluation of muscle activity during a diagnostic and/or therapeutic process

SEMG can be very useful for the initial evaluation of muscle activity and during a therapeutic treatment or process. The degree of muscular activation, comparison with a healthy limb, the observation of muscular coordination or the agonist/antagonist relationship are phenomena that can be altered in pathological situations and in therapeutic situations where attempts are being made to restore normality. SEMG is a suitable technique to use in such cases[36,37].

Studies have been carried out on using SEMG for the evaluation and monitoring of femoropatellar syndrome. The results of such studies are not as yet very clear[38]. Some studies have observed the existence of alterations in the activation pattern of the vastus medialis and the vastus lateralis of the quadriceps muscle[39-41], although other studies have not produced these results[42-43].

Significant alterations have been observed in the electromyographic recordings in cases of lumbago. These make a greater understanding of the condition possible, helping in its diagnosis, treatment and prevention [44-46]. In some studies a large degree of activation of the lumbar musculature has been observed in people affected by lumbago in comparison with a control group[47]. Others show a delay in the activation of the transverse muscle of the abdomen during movements of the limbs[48-50]. In some cases, a neuromuscular imbalance of the extensor muscles of the vertebral column has also been observed[51]. In others, an alteration in the median frequency of the electromyographic signal has been observed during the physical evaluation of these patients while carrying out an established isometric test of the resistance of the extensor muscles of the trunk[44,52,53].

Facilitating miofeedback techniques

SEMG is an essential tool in this technique, applicable when postural re-education is required. The electromyographical signal provides the patient and the therapist with information about the activation moments of the muscles being treated. In the rehabilitation field, SEMG can be a useful tool in the work of propioception[36].

Evaluating sports performance

The fact that SEMG can analyse dynamic situations makes it of special interest in the field of sports[54,55]. The improvement in the efficiency of a movement involves the correct use of the muscles, in terms of both economy of effort and effectiveness, as well as in the prevention of injury. In a training process, improvements in these parameters can be sought, follow-up carried out and corrective measures or steps for improvement determined[7,14,19,56]. In particular, the performance of a task can be improved in terms of muscular activation and/or in terms of muscular fatigue, based on the analysis of the frequency of the electromyographic traces observed[10]. It has to be remembered that the EMG does not provide us with muscular force parameters[54,57], although it is an indicator of the muscular effort made in a particular action[6,14,58]. In relation to this, it is important to stress that the relationship between EMG activity and effort is only qualitative[7].

Recently, experiments have also been carried out in the sports area on applications for purposes such as the evaluation of the type of muscle fibre[59] and the characterisation of muscles[60].

Evaluation of neuromuscular disorder

When there is a neuromuscular basis to a disorder, changes are seen in the results of the analysis of the electromyographic signal. An anomalous electrical signal which is indicative of pathology can be seen in the trace obtained using needle electrodes. A quantitative analysis can also be carried out[61,62]. With SEMG there is less signal resolution and therefore information is lost compared to that provided by a recording made with a needle electrode. Methods to reduce this have been developed over a number of years. In this regard, dynamic electromyographic studies have been carried out using specially designed, flexible intramuscular electrodes. Work is also being carried out on *high spatial resolution electromyography* (HSR EMG). This aims to approximate the information from traces obtained intramuscularly by means of a system of multiple surface electrodes[63,64]. The objective is to be able to analyse the *motor unit potentials* (MUPs) in a way similar to that of clinical electromyographic techniques, to be able to contribute to the diagnosis and follow-up of disorders of neuromuscular origin[65-68]. The aim is to detect the presence of pathological potentials such as fasciculation potentials[69,70] by exploiting the ability of SEMG in relation to the detection of time and space factors. Work is also being carried out on obtaining the number and type of MUPs and the *motor unit* (MU) recruitment strategies, although this is still controversial and results vary[71-79]. There is evidence that SEMG could contribute to the detection of problems that are neuromuscular in character, as well as to the study of fatigue associated with certain disorders such as post-polio syndrome or myotonic distrophy[80]. However, it is not clear whether it is really of use in distinguishing between a neuropathic process and/or a myopathic process[80]. Some data has been gathered, including data from the use of SEMG to evaluate cases of entrapment neuropathy[81]. This field of application is very interesting though more results need to be obtained and contrasted.

Coactivation

Another phenomenon that can be analysed using SEMG is that of coactivation, understood as the simultaneous existence of activity in agonistic and antagonistic muscles[37,82], which is important in evaluating the quality of movement. Significant alterations in coactivation are related to situations of immaturity of the neuromuscular system, also observed specifically in individuals with Down Syndrome[83].

SEMG methodology

It is important to prepare the patient well and to apply the technique correctly[84-86]. It is also necessary to guard against possible errors in the interpretation of the recordings[5]. The SEMG involves three phases (the preparation phase, the recording phase and the processing phase) which are described below.

Preparation phase

1. *Preparation of the individual and the provision of information in advance.* It is essential to adequately inform the individual about the procedure to be followed during the recording session and about particular aspects of the study, such as its objectives, usefulness and possible applications. It is necessary to obtain the individual's informed consent in writing. The individual signs this, stating that he or she has been given information about the process and is both interested in and approves of the recording taking place. It is advisable to collect information on substance use and abuse, medication being taken and whether the patient is suffering from any illnesses, particularly those that could affect muscular function. The existence of any neuromuscular conditions and musculoskeletal disorders must be noted. Depending on the study, it will also be necessary to establish anthropometric parameters such as weight and height.

2. *Preparing the skin.* The skin's impedance must be reduced so as to obtain a good quality electrical signal. To do this, it is advisable to shared and rub the skin with an abrasive gel to reduce the dry layer of the skin or dead cells, and to eliminate sweat by cleaning the skin with alcohol.

3. *Positioning the electrodes.* It is essential to position the electrodes correctly to obtain a good signal[87-90]. The best position, provided it is possible, is on the mid line of the muscle belly, between the myotendinous junction and the motor point[84,91,92]. To achieve this, published guides can be used to ensure the methodology is followed correctly[84]. It is very important to always use the same position on different individuals and for different recordings taken from the same individual, given that the signal recorded varies according to the area of the muscle on which the electrodes are positioned. It is also advisable to maintain an optimum distance between the electrodes[84,89,93]. Furthermore the *cross-talk* phenomenon must be avoided. This consists of the contamination of the signal from the muscle under study by signals from other nearby muscles[84,94-97]. To prevent this, the areas adjacent to other muscles must be avoided and the muscle activity being recorded must be tested thoroughly. Cardiac activity is another possible contamination of the electrical signal. This appears in recordings at an upper thoracic and scapular level but there are programs that aim to eliminate this.

Each muscle is examined by positioning two electrodes on it, separated by a distance of one or two centimetres (Figure 1). The use of surface electrodes creates what is called a *detection volume,* that is to say, the volume of tissue from which the electrode is capable of detecting an electrical signal. The energy detected coming from the motor units will depend on the depth at which these are situated within the detection volume, such that the deeper they are the lesser the amount of energy that will reach the electrode. The *conduction volume* is the volume of tissue through which the electrical signal travels to the electrodes.

In addition, a reference electrode has to be positioned far from the recording area and on electrically neutral tissue. For this, areas close to a bone plane are usually chosen, such as for example the tibial diaphysis or the cubital styloids in the wrist.

Advantages and disadvantages of surface electrodes (figure 1)

- They allow a global recording of the muscle.
- They are non-invasive.
- There are no limitations in relation to the surface studied or the recording time.
- Only the study of superficial musculature is possible.

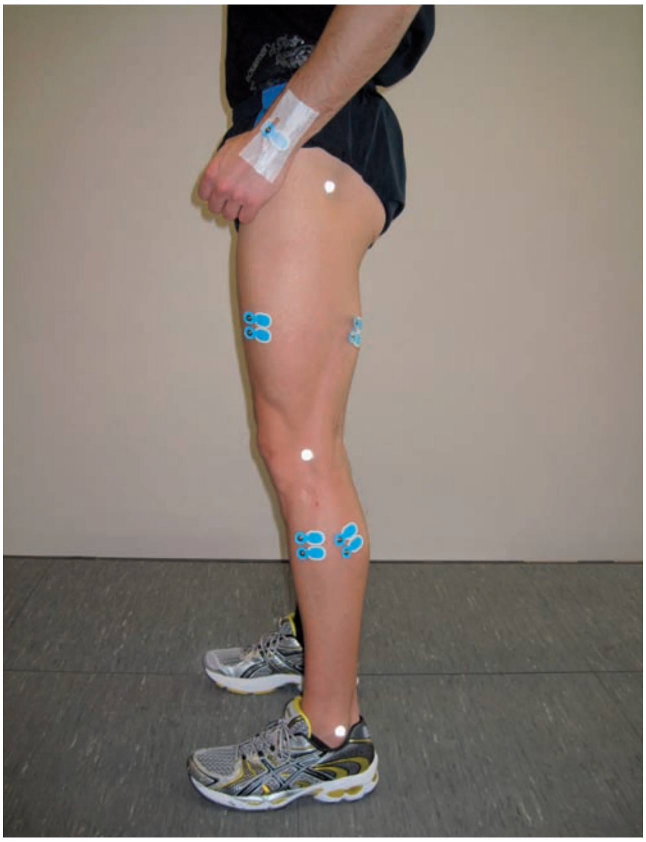

Figure 1 Example of positioning the surface electrodes on the musculature to be analysed (the vastus externus, ischiotibial muscles, peroneus longis and gastrocnemius externus). In this case, the analysis is accompanied by a cinematic study, in which reflective markers are also placed on the different anatomical points of reference.

- They require the skin to be correctly prepared.
- Traces are obtained with a lower frequency spectrum.

Advantages and disadvantages of intramuscular electrodes (figure 2)

- They allow a more local recording of the muscle.
- They are invasive.
- They make the study of superficial and profound musculature possible.
- Less preparation of the skin is required.
- They capture a higher spectrum of frequencies.

Recording phase

4. *Obtaining maximum voluntary contraction (MVC).* Maximum voluntary contraction is required to standardise the traces obtained of the maximum activity of a particular muscle in a specific individual. By standardising the traces, it is possible to compare different recordings from different subjects. To make this comparison three maximum isometric contractions 6 seconds long are obtained, with a brief rest between each one. These serve to calculate an average for the intermediate periods of the three. In this way it is possible to compare values that are not absolute values (Figure 3).

5. *Recording.* Recording is the phase in which the electromyographic signal corresponding to the action or movement being studied is obtained (Figure 4).

Processing phase

6. *Processing the signal.* The raw signal has to be prepared so that it can be easily observed and analysed. The type of processing will depend on the type of analysis we wish to make from the trace. Essentially two types of analysis are carried out: the analysis of amplitudes and the analysis of frequencies.

Analysis of amplitudes

This analysis aims to convert a highly variable electromyographic signal of alternating positive and negative values into a graph that approximates to the level of muscle activation. To carry out this analysis, the process outlined below is followed:

- Filtration of the signal, eliminating potentials of amplitudes and/or frequencies outside the normal spectrum, that often are the consequence of interference from equipment or some other type of contamination of the recording.
- Rectification of all the signal's negative and positive potentials. This is the equivalent of taking the absolute value of the signal, without taking the positive or negative sign into account.
- The application of a smoothing algorithm in order to obtain an image that is closer to the muscle activation and is easier to observe. One of the most frequently used algorithms is the *Root Mean Square,* a formula that represents the strength of the signal.
- Standardisation according to the MVC, in which the numeric amplitude values resulting from the smoothing algorithm are divided by the maximum voluntary contraction value, thereby obtaining percentage maximum voluntary contraction values.

Analysis of the frequencies

- Filtering. This procedure is described in the section on the analysis of amplitudes. It is only necessary if it has not been used beforehand.
- Use of the Fast Fourier Transform (FFT) or the system for signal decomposition across the different frequencies of which it is comprised (Figure 5). The objective is to determine the electromyographic frequency spectrum. Signal theory states that any variable signal can be obtained by adding different signals from one single frequency with different amplitudes. The frequency spectrum of a signal is represented on a graph showing the frequencies that make up this signal and the intensity with which they do so.

FFT is the ideal process for static actions, since it assumes that the frequency spectrum does not vary over time. This does not occur in dynamic actions, and as a consequence other methods of frequency analysis are used that show the variation of the spectrum over time, such as for example a *wavelet*. Pope et al[98] carried out a study of the extensor musculature of the vertebral column at level L3, finding that the wavelet detects the variations in

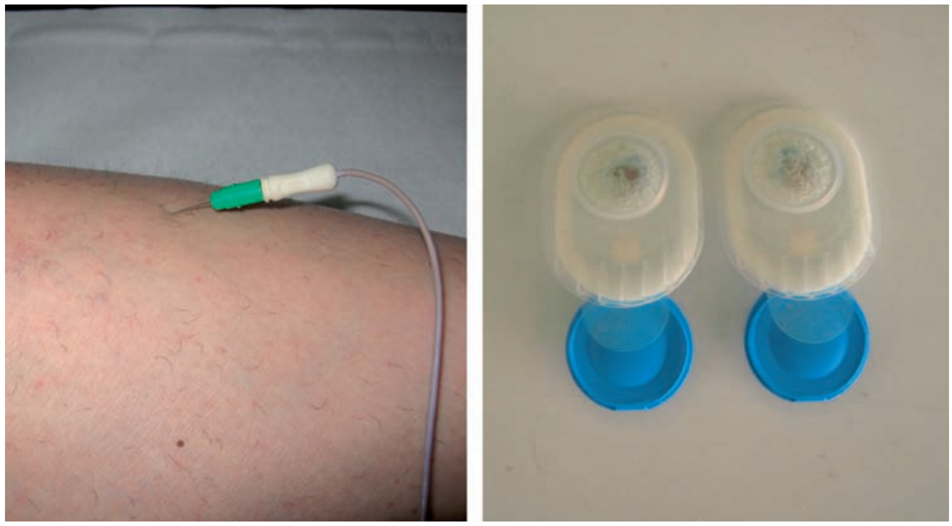

Figure 2 Intramuscular needle electrode during a recording of a muscle at rest (left). Surface electrodes (right).

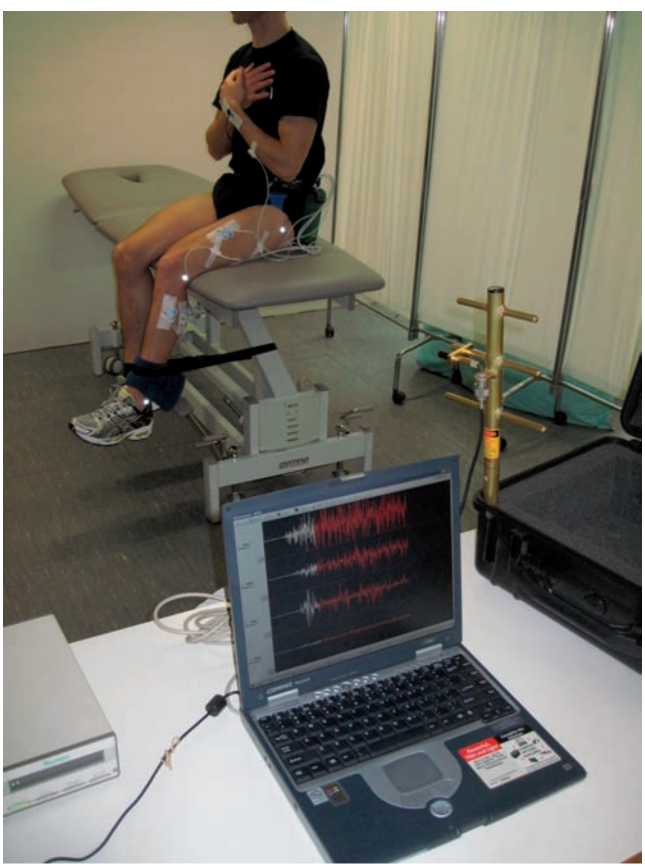

Figure 3 Recording the maximum voluntary contraction. In this case, the quadriceps muscle is recorded.

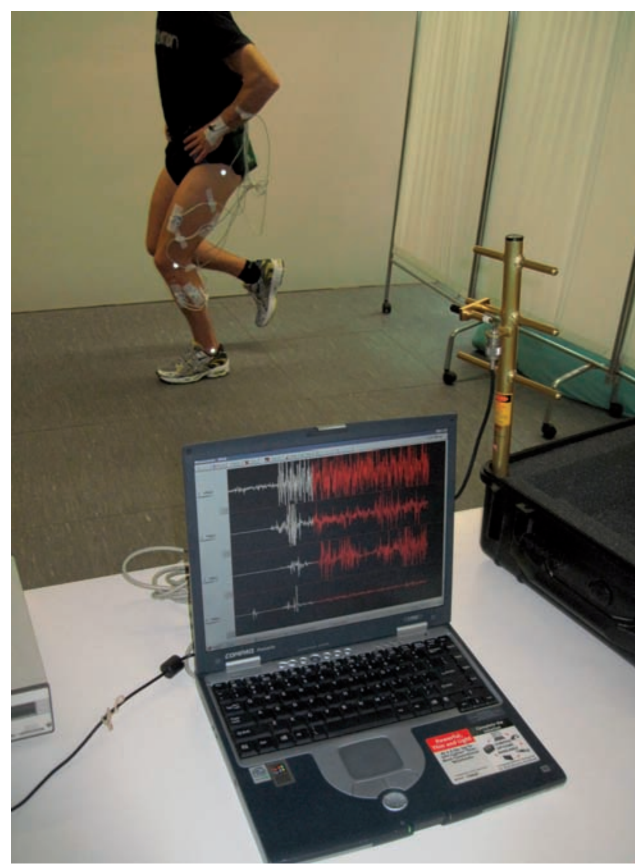

Figure 4 Obtaining the electromyographical signal during the recording phase.

muscular activity over time better than FFT. Karlsson and Gerdle[99] also used the wavelet in increasing isometric actions of knee extensors. Xiao and Leung[100] support the use of the same method in isokinetic actions of maximum intensity.

The analysis of frequencies over time, in addition to being useful in dynamic actions, is also useful in situations of fatigue through prolonged effort, where the spectrum tends to be displaced towards the left on the graph, to lower frequency values.

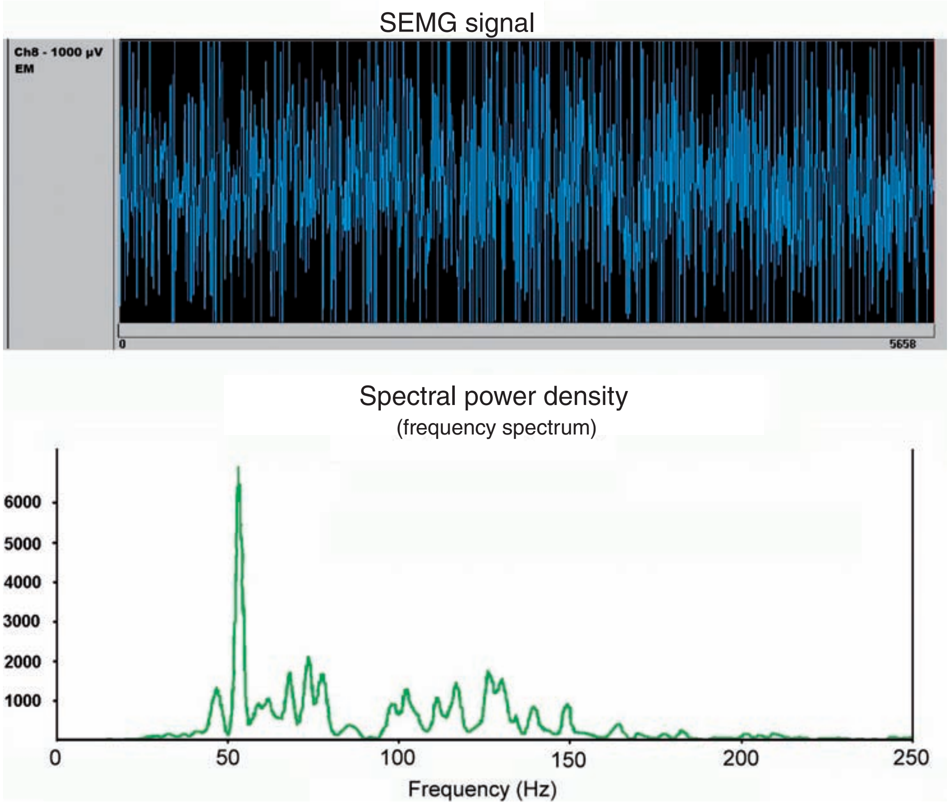

Figure 5 Graphic representation of the frequency spectrum obtained from an electromyographical recording.

The limitations of SEMG

Due to the characteristics of the electrodes used, SEMG enables us to study different muscles at the same time, without any inconvenience to the individual, with the advantage that the majority of SEMG equipment can accommodate different inputs (corresponding to different muscles) simultaneously. It also allows greater reproducibility of the traces obtained in different recordings. In addition, the recording obtained is more representative of the muscle as a whole rather than of a particular area.

Nevertheless, as already discussed, obtaining traces that provide less information regarding the characteristics of the MUPs is a limitation in those cases where this particular type of examination is of specific interest.

Another limitation is the fact that in some dynamic actions there can be displacement and modification of the volume of the muscle being analysed. A change in the relative position of the muscle in relation to the electrode means that the same spatial relationship is not maintained between them, which affects the intensity of the signal that is recorded. Because of this, the best conditions for carrying out an SEMG, depending on the use and application required, are those that are similar to those needed for an isometric type of study[7,54,57,101].

Finally, when the aim is to describe and/or compare a motor pattern, the study of all actions that are cyclical is strongly recommended. This makes it possible to compare identical periods of different cycles.

Conclusions

Currently we have the means to carry out surface electromyographic studies that complete biomechanical analyses. This has varied applications in the field of and also in occupational medicine and ergonomics. We can use SEMG to monitor locomotor apparatus diseases and movement disorders. In the therapeutic area, it is useful for post-treatment evaluation and re-education. It provides us with data when the objective is improvement in the performance or efficiency of a movement. In conditions such as disorders that are of neuromuscular origin, advances are being made with the aim of using electromyographic traces to obtain reliable information about motor units.

However, the methodological limitations and/or the interpretation limitations that there can be in each application of SEMG have to be borne in mind.

Conflict of interest

The authors have no conflicts of interest.

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