Chapter 9

Surface Electromyography in Sports and Exercise

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Additional information is available at the end of the chapter

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1. Introduction

Exercise is constantly gaining popularity. It has been widely used especially in the fields of sports performance and rehabilitation [1].

Performance and ability tests enable the success in education of sports and exercise. Various exercise equipments are used in test protocols that are developed for this goal. The reason to use various kinds of exercise equipments for performance measurement is that every equipment and protocol cause different responses in human body. The cause for evolution of different physiological responses is about the different shapes and densities of different muscles. In this very respect, the electromyographic measurements gain great importance.

Electromyographic studies help us understand the location of the problem in the system of movement. The problem may be localized to the peripheral nervous system or the muscle itself and sometimes may also be at the neuromuscular juntion. This diagnostic tool is therefore very valuable in the differential diagnosis of nerve and muscle diseases [2]. Electromyography is also used in morphological analysis of the motor unit [3. It is important to snychronize the systems that supply cinematic data with electromyography to determine the period when different muscles join the muscle movement. These systems use cameras, electrogoniometers and other registration tools with their programs in order to give us information about position, speed and acceleration measurements. Additionaly, the study can be completed with podometer and power platform as power analysis systems and this is called the kinetic system. Surface EMG (sEMG) is an important tool of biomechanical analysis and a very important part of this system. [4,5]. It helps to understand the role of a muscle in a spesific movement [6,7]

Surface EMG has increasing importance in sports and occupational medicine and in ergonomic studies [8,9]. It can also establish dynamic analysis and therefore is important in sports [10,11]. The utilization of muscles in a right and economical fashion helps improve activity and prevents the risk of injury. The most important points to achieve healthy training are the follow up of development and performing corrections where necessary [5,12,13]. The electromyographical analysis can determine muscle activation and fatigue and thus helps achieve development of performance [9].

Muscle activation is a result of the effort of muscle but the relationship between EMG activity and effort is only qualitative [5].

Surface EMG in current sports studies also deals with determination and descriptions of the muscle types [14,15].

2. Muscular system

Muscles are designed to exert force in order to move the body. Skeletal system and muscles are connected to each other by tendons. Combination of muscle and bone is brought about by the tendon intermeshing with the skeletal periosteum sheath. Tendons are the strong connective tissue composed of three layers. And this extends the length of all the muscle and collagen protein. Epimysium, perimysium and endomysium are the connnective tissues forming each tendon. There are three types of muscle tissue in the body, they are smooth, cardiac and skeletal muscles [16,17]. Specific anatomical features that affect the length of muscle fiber, muscle fiber type and muscle compartments may differ between muscles. EMG signals may be affected by them and therefore EMG recordings and interpretation of them must take anatomical differences into account [18,19].

2.1. Muscle types

2.1.1. Smooth muscle

Smooth muscle is found in the digestive tract, surrounds the blood vessels, airways and respiratory systems. Smooth muscle is innervated by the autonomic nervous system such as cardiac muscle and therefore we do not have voluntary control over its contractions [20,17].

2.1.2. Cardiac muscle

Cardiac muscular system is located in the heart tissue and has striped appearance under light microscopy. The same striations are also found in skeletal muscle and indicate the presence of different proteins required for muscle contraction [21,17].

2.1.3. Skeletal muscle

Skeletal muscular system has the only muscle type that can be voluntarily contracted and skeletal muscle has active elements forming the movement. The human body consists of more than 600 muscles [21,17]. The functions of the muscular system are movement of blood and food within the body, the ability to stop the body moving, to store oxygen and nutrients such as glycogen for energy production and, through the energy production reactions, to produce

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heat to help maintain body temperature [17]. Skeletal muscle converts chemical energy to mechanical and heat energy. Skeletal muscle uses adenosine triphosphate (ATP) as fuel during electrical, mechanical and chemical events. This process, called action potential begins with an electrical impulse from the brain [22,23]. This initiates a chain of biochemical reactions that ends in the burning of adenosine triphosphate, the fuel for muscle contraction. Its use results in the forces that move the limbs and generate heat. Electrodes attached to a muscle group record the electrical activity accompanying contraction; the name of this recording process is electromyography (EMG) [23].

2.2. The Motor Unit Action Potential (MUAP)

Motor units are the functional assets of the neuromuscular system. Each motor unit consists of a single motoneuron and the muscle fibers supplied by its axonal branches [24,25]. Once a motoneuron discharges, action potentials are generated at its neuromuscular junctions and then propagate along all the muscle fibers, toward the tendon regions. The summation of these potentials is termed motor unit action potentials and is responsible for the muscle contraction [25]. MUAP is the sum of the extracellular potentials of muscle fiber action potentials of a motor unit [3]. The waveform is determined by the natural properties of the relationship between muscle fibers. [24,3]. The extracellularly recorded MUAP, recorded along the length of the muscle fibers and away from the endplate region, has a triphasic waveform. The initial positive deflection represents the action potential propagating towards the electrode. As the potential passes in front of the electrode the main positive-negative deflection is recorded. When the action potential propagates away from the electrode the potential returns to the baseline. Slight repositioning of the electrode causes major changes in the electrical profile of the same motor unit. Therefore, one motor unit can give rise to MUAPs of different morphology at different recording sites. If the electrode is placed immediately over the endplate area, the initial positive deflection will not be recorded and the potential will have a biphasic waveform with an initial negative deflection [3]. All the muscle fibers of a motor unit work in unison; that is, all are discharged nearly synchronously upon the arrival of a nerve impulse along the axon and through its terminal branches to the motor end plates. A MUAP is recorded by a needle electrode. The recorded motor unit action potential can be derived from action potentials of a small number of muscle fibers, a moderate number of muscle fibers, or a great majority of muscle fibers belonging to the motor unit [26].

2.3. Types of muscle action

Among the variety of types of muscle action are the isometric, concentric and eccentric; all three forms occur during the actions seen in sport and exercise performance [27]. When there is no change in muscle length during muscle activation, the action is called isometric. Isometric action occurs when an athlete tries to leg-press a heavy load by flexing the quadriceps muscles, but cannot move the weight-stack in spite of a maximum effort. The muscle produces force, but it is insufficient to overcome the mass of the weight stack; hence, the overall muscle length does not shorten. Isometric muscle action occurs when the muscle contracts without moving, generating force while its length remains static. Isometric muscle actions are demonstrated in

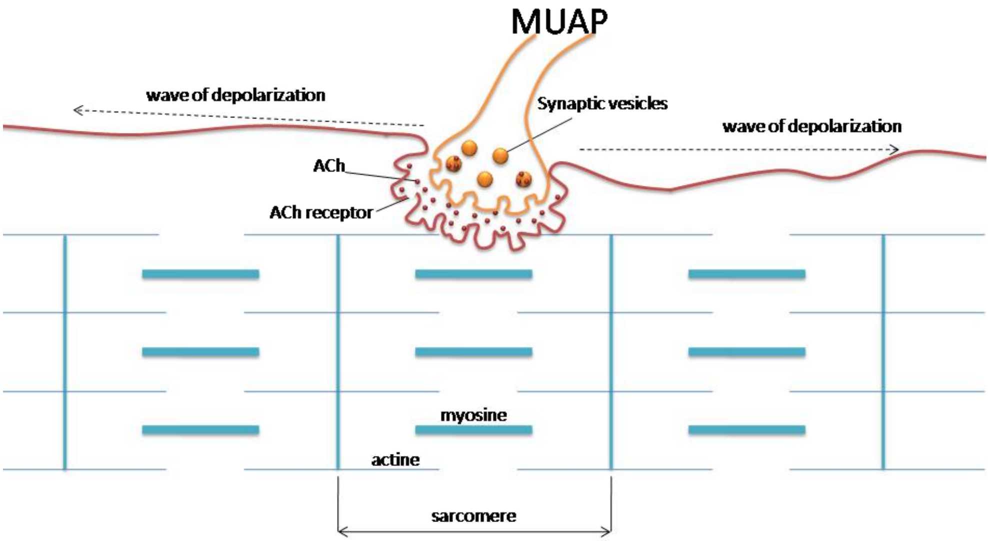

Figure 1. When a skeletal muscle fiber is activated by a MUAP, a wave of electrical depolarization travels along the surface of the fiber (drawn by Sözen H.).

an attempt to lift an immovable object or an object that is too heavy to move. The muscle fibers contract in an attempt to move the weight, but the muscle does not shorten in overall length because the object is too heavy to move [28,23,29]. Concentric muscle action occurs when the muscle force exceeds the external resistance, resulting in joint movement as the muscle shortens. Concentric action occurs when a muscle is active and shortening; for example, during the biceps curl the biceps shortens and exerts enough force to lift the barbell [23,29]. Eccentric muscle action occurs when the external resistance exceeds the force supplied by the muscle, resulting in joint movement as the muscle lengthens; for example, when lowering the barbell the biceps exerts force to ensure the movement is controlled. This is often referred to as the negative portion of the repetition. Even though the fibers are lengthening, they are also in a state of contraction, permitting the weight to return to the starting position in a controlled manner. During an eccentric action, an activated muscle is forced to elongate while producing tension [27,23,29].

3. Electromyography

Electromyography is the electrodiagnostic study of muscles and nerves. The test includes two components: Nerve conduction studies (NCS) and electromyogram (EMG). Nerve conduction studies measure how well and how fast the nerves can send electrical signals [30]. NCS can be defined as the recording of a peripheral neural impulse at some location distant from the site where a propagating action potential is induced in a peripheral nerve [2]. Nerve conduction studies provide unique quantitative information about neurological function in patients with a variety of neuromuscular disorders [31]. A nerve is stimulated at one or more sites along its course and the electrical response of the nerve is recorded. EMG testing involves evaluation of the electrical activity of a muscle and is one of the fundamental parts of the electrodiagnostic medical consultation. It is both an art and a science. It requires a thorough knowledge of the anatomy of the muscles being tested, machine settings and the neurophysiology behind the testing [2]. Obtaining the information produced by active muscle provides information about the activities of motor control centers [30,26]. This can be achieved invasively, by wires or needles inserted directly into the muscles, or noninvasively, by recording electrodes placed over the skin surface overlying the investigated muscles. The use of this latter modality is preferable in healthy voluntary sedentary subjects and in athletes, despite its limitations and drawbacks. To mention just a few of them, single-channel sEMG signals provide average information on the activity of many concurrently active motor units, the reproducibility of the results is often difficult, and standard recording procedures are still confined to few laboratories, therefore limiting comparisons among results obtained by clinical researchers [26]. EMG signal recordings used for years in bio-engineering, occupational- and sports medicine, physiotherapy, sports biomechanics, and also eventually for trainers and coaches [19,32]. Since the end of the 1960s there has been a development in miniaturized telemetric devices for monitoring complex human movements remotely. Especially for kinesiological purposes, the telemetric devices have recently been changed from two-channel registrations to eight or more-channel systems [32]. EMG is a seductive muse because it provides easy access to physiological processes that cause the muscle to generate force, produce movement, and accomplish the countless functions that allow us to interact with the world around us. The current state of surface EMG is enigmatic. It provides many important and useful applications, but it has many limitations that must be understood, considered, and eventually removed so that the discipline is more scientifically based and less reliant on the art of use. To its detriment, EMG is too easy to use and consequently too easy to abuse [5]. Electromyographic recordings are performed with intramuscular needle electrodes. However, surface electrodes are used in the study of sports science. Most of the issues affecting this modality have already been covered. Electrodes are almost always sited along the body of the muscle in question, with locations one-third and two-thirds along the length being the norm, As mentioned earlier, small pre-amplifiers are often used in order to improve signal-to-noise ratios, especially since telemetry of signals is increasingly used in order to maintain ecologically valid movement patterns [30,33,1,34]. Once the signal is filtered and amplified, some form of rectification of the signal is usually applied. As with other indices, examination of the raw signal waveform is interesting but offers little in the way of empirically analyzable data. Accordingly, and since the signal is made up of both positive and negative potentials, signals may be rectified by either ignoring all negative signals or reversing their polarity so that all signals are positive. Further signal conditioning may involve totaling activity across a regular time base, resetting counters to zero in order to provide an integrated signal. Analysis may look at amplitude or, more rarely, frequency. Increasingly, however, signal patterns are compared across two or more conditions. Thus, investigators may contrast “at rest” with active patterns, or use an increase from baseline measure, or contrast signals obtained under different execution conditions such as variations in speed. Subsequent treatments of data are increasingly complex, with the application of spectral analysis techniques to tease out underlying trends or collective patterns in the data. In this way, EMG data are making a full contribution to the comparatively new approaches within motor control, such as dynamical systems [33].

A key ingredient of strengthening protocols is *training intensity*, defined as the percentage of maximal voluntary force exerted [35]. EMG is commonly used to measure the level of muscle activation and provides a rough estimate of exercise intensity for specific muscles involved in the movement [36,35]. EMG signal has many contributions for finding the human body muscle functions [37]. EMG 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 [38].

Electromyographic analysis can provide information as to the relative amount of muscular activity an exercise requires, as well as the optimal positioning for the exercise [39]. Electrophysiological techniques enable us to relatively easily obtain very valuable information about neuromuscular activity [40]. Two techniques are usually used in clinical situations: neurography and needle EMG. 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 [41]. Another technique that determines the electrical activity of muscles is surface EMG. There are advantages and different application areas of sEMG in researches and in clinical practices [42,41]. In the study of muscle physiology, neural control of excitable muscle fibers is explained on the basis of the action potential mechanism. The electrical model for the motor action potential reveals how EMG signals provide us with a quantitative, reliable, and objective means of accessing muscular information [41,42,43]. When an alpha motoneuron cell is activated, the conduction of this excitation travels along the motor nerve's axon and neurotransmitters are released at the motor endplates. An endplate potential is formed at the muscle fibers and innervates the motor unit. Muscle fibres are composed of muscle cells that are in constant ionic equilibrium and also ionic flux. The semi-permeable membrane of each muscle cell forms a physical barrier between intracellular (typically negatively charged compared to external surface) and extracellular fluids, over which an ionic equilibrium is maintained [41,42,43]. These ionic equilibriums form a resting potential at the muscle fiber membrane (sarcolemma), typically -80 to -90mV (when not contracted). These potential differences are maintained by physiological processes found within the cell membrane and are called ion pumps. Ion pumps passively and actively regulate the flow of ions within the cell membrane [41,42,43]. When muscle fibers become innervated, the diffusion characteristics on the muscle fibre membrane are briefly modified, and Na^+ flows into muscle cell membranes resulting in depolarization. Active ion pumps in the muscle cells immediately restore the ionic equilibrium through the repolarization process which lasts typically 2-3ms [41,42,43]. When a certain threshold level is exceeded by the influx of Na^+ resulting in a depolarization of the cellular membrane, an action potential is developed and is characterized by a quick change from -80mV to +30mV. This monopolar electrical burst is restored in the repolarization phase and is followed by a hyperpolarization period. Beginning

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from the motor end plates, the action potential spreads across the muscle fibers in both directions at a propagation speed of 2-6m/s. The action potential leads to a release of calcium ions in the intracellular fluid and produces a chemical response resulting in a shortening of the contractile elements of muscle cells [41,42,43]. The depolarization-repolarization process described is a monopolar action potential that travels across the surface of the muscle fiber [41,42,43]. Electrodes in contact with this wave front present a bipolar signal to the EMG differential amplifiers because the electrodes are measuring the difference between two points along the direction of propagation of the wave front. EMG signals provide us with a viewing window into the electrical signals presented by multiple muscle fibres and are in fact a superposition of multiple action potentials [43].

3.1. Surface electromyography

Surface Electromyography is a non invasive technique for measuring muscle electrical activity that occurs during muscle contraction and relaxation cycles. EMG is unique in revealing what a muscle actually does at any moment during movement and postures. Moreover, it reveals objectively the fine interplay or coordination of muscles: this is patently impossible by any other means [40].

Surface EMG is widely used in many applications, such as:

Medical

- Orthopedic
- Surgery
- Functional Neurology
- Gait & Posture Analysis
- Urology (treatment of incontinence)
- Psychophysiology

Rehabilitation

- Post surgery/accident
- Neurological Rehabilitation
- Physical Therapy
- Physical Rehabilitation
- Active Training Therapy

Ergonomics

- Analysis of demand
- Risk Prevention

- Ergonomics Design
- Product Certification

Sports Science

- Biomechanics
- Movement Analysis
- Athletes Strength Training
- Sports Rehabilitation
- Motion analysis [41,42,43]

Although the noninvasive nature of surface EMG makes this technique ideal for clinical use and research, EMG data can be variable, which raises questions about the reliability of this technique [44]. Repeatability of EMG data is established for many isometric exercises but less is known about the reliability of this method of analysis during dynamic exercise, particularly ballistic movements [45,46,44]. Most studies assessing EMG reliability of data in dynamic movements have examined slow, controlled tasks, such as resistance training exercises or gait. Therefore, evaluation of the reliability of EMG during ballistic tasks is essential to determine the viability of this methodology for clinical and research applications [47,48-49-50,44]. Surface EMG, sometimes called kinesiological electromyography, is the electromyographic analysis that makes it possible to obtain an electrical signal from a muscle in a moving body [41]. 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 [41].

The visual systems employed for motion analysis of cycling, even though scientific and accurate, can only indicate the apparent movements. It is often necessary to know how the movements are actually performed against a resistive load. For this reason electromyographic techniques are employed in conjunction with biomechanical analyses [51]. EMG is generally used to indicate which muscle groups are active during a given segment of the pedal revolution.

Surface electrodes are usually attached to the muscle groups to be studied. The action potentials generated are recorded during the pedaling action, thereby allowing the researcher to gain a more complete insight into the muscles employed and the extent of their involvement while pedaling [22]. Within EMG, a particular specialty has been developed wherein the aim is to use EMG for the study of muscular function and co-ordination. This area of research is usually called kinesiological EMG [52,47]. The general aims of kinesiological EMG are to analyze the function and co-ordination of muscles in different movements and postures, in healthy subjects as well as in the disabled, in skilled actions as well as during training, in humans as well as in animals, under laboratory conditions as well as during daily or vacational activities [52]. This is usually used by a combination of EMG, kinesiological and biomechanical measurement techniques [52,47]. Because there are over 600 skeletal muscles in the human body and both irregular and complex involvement of the muscles may occur in neuromuscular diseases and in voluntary occupational or sports movements [52,21,17]. The measurement of kinesiological EMG in sport and specific field circumstances, such as the track and/or soccer field, the alpine ski slope, the swimming pool and the ice rink, demands a specific technological and methodological approach, adaptable to both the field and the sport circumstances [52]. Sport movement techniques and skills, training approaches and methods, ergonomic verification of the human-machine interaction have, amongst others, a highly specialized muscular activity in common. The knowledge of such muscular action in all its aspects, its evaluation and its feedback should allow for the optimization of movement, of sports materials, of training possibilities and, in the end, of sports performance [52]. Drawing conclusions from a review of the EMG research of 32 sports, covering over 100 different complex skills, including methodological approaches, is an impossible task. EMG and sports is a vast area and a complete review is impossible, as information will be found scattered in many different journals, including those on the sports sciences, ergonomics, biomechanics, applied physiology, in different congress proceedings, and so on [52].

sEMG refers to surface electromyography and measures muscle activity in microvolts. This form of feedback allows us to determine if muscles not involved in a particular skill need to be relaxed and those muscles involved in a skill need to fire in the right sequence and with the right amplitude. In addition to using sEMG feedback for training purposes, the information can also provide insight into the athlete's strength and conditioning or the effects of an injury rehabilitation program [53].

EMG can also be used to examine the activation characteristics of specific muscle groups.

Amplitude and power spectrum of sEMG are commonly used to quantify neuromuscular activity and fatigue [54].

3.1.1. The limitations of sEMG

Because of the characteristics of 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 simultaneously [55,41]. 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 MUAPs is a limitation in those cases where this particular type of examination is of specific interest [41].

Another limitation is the fact that in some dynamic actions there can be displacement and modification of the volume of the muscle being analyzed. 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 affect 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 [5,56,57,11].

The majority of activities in sport and occupational settings involve complex movement patterns often complicated by external forces, impacts and the equipment used during the movement. An electromyogram is the expression of the dynamic involvement of specific muscles within a determined range of that movement. The integrated EMG of that same pattern is the expression of its muscular intensity. However, intensity is not always related to force [12].

Mostly sEMG is used to investigate the activity of a series of muscles. The majority of scientists working in sports and occupational contexts measure EMG using surface electrodes [12,15]. Skeletal muscles do not always stay in the same place during complex dynamic movements and the entire muscle belly may not be fully under the skin, but covered by parts of other bellies or tendons and subcutaneous adipose tissue. It needs to be emphasized that the selection of muscles for EMG measurement requires careful consideration. Some of these choices can lead to erroneous registration, sometimes without being noticed by peer reviewers [12].

Many factors may affect the quality of EMG signals; they can be divided into physiological, physical, and electrical types. Some factors can be controlled by the investigator [58].

3.2. Origin of the EMG signal

Muscle tissue produce electrical potentials due to action potentials. With electrodes placed on surface or in muscle tissue, muscle action potentials can be determined. Several events must occur before contraction of muscle fibers. Central nervous system activity initiates a depolarization in the motoneuron [59,60]. The depolarization is conducted along the motoneuron to the muscle fiber's motor end plate. At the endplate, a chemical substance is released that diffuses across the synaptic gap and causes a depolarization of the synaptic membrane. This phenomenon is called muscle action potential. The depolarization of the membrane spreads along the muscle fibers producing a depolarization wave that can be detected by recording electrodes [60].

3.2.1. Skin preparation

Preparation of the skin is essential to avoid artifacts and receive an appropriate signal. Before placing the electrodes on skin, it must be ensured that the skin is clean and dry. The skin must be cleaned by using gel, cream or alcohol and then it should be dried [61,62,25]. If necessary, shave excess body hair. Cleansing of the skin is useful to provide EMG recordings with low noise levels. Appropriate preparation of the skin assures the removal of body hair, oils and flaky skin layers and, consequently, reduces the impedance in the electrode-gel-skin interface. Shaving, wetting and rubbing with alcohol, acetone or ether, are often considered for the cleansing of the skin [25].

Proper skin preparation and electrode positioning are essential elements in acquiring EMG measurements of high quality. Two key strategies govern electrode preparations (1) electrode contact must be stable (2) skin impedance must be minimized. While there are no general rules for skin preparations, the type of application and signal quality sought usually determines the extent of the skin preparation [43]. For example, given a targeted test condition if the movement is somewhat static or slow moving and only qualitative reading are desired, a simple alcohol swab around the area of interest is sufficient [43]. However, if dynamic conditions present risk of the introduction of movement artifacts like in walking, running or other planned accelerated movements, a thorough preparation is required. Some EMG systems have built in impedance checking circuit that sends an imperceptible burst of current through the electrodes and controlled measurements are correlated to a known impedance level to indicate the quality of the electrode contacts [43].

3.2.2. Electrode material, size, montage and positioning

Surface EMG is a helpful technique for the analysis of muscle activity. However, its efficacy is related to the correct electrode positioning, the adequate skin preparation and opportune recording instrumentation. In addition, it is mandatory to recognize artifacts which may alter EMG signals and choose a particular filtering procedure before any additional analysis [63].

Surface electrodes are usually made of silver/silver chloride (Ag/ AgCl), silver chloride (AgCl), silver (Ag) or gold (Au). Electrodes made of Ag/AgCl are often preferred over the others, as they are almost nonpolarizable electrodes, which mean that the electrode-skin impedance is a resistance and not a capacitance [25]. Therefore, the surface potential is less sensitive to relative movements between the electrode surface and the skin. Additionally, these electrodes provide a highly stable interface with the skin when electrolyte solution (for example gel) is interposed between the skin and the electrode [25]. Such a stable electrode-skin interface ensures high signal to noise ratios (for example the amplitude of EMGs exceeds fairly the noise amplitude), reduces the power line interference in bipolar derivations and attenuates the artifacts due to body movements [64,25]. The electrode should be placed between a motor point and the tendon insertion or between two motor points, and along the longitudinal midline of the muscle. The longitudinal axis of the electrode should be aligned parallel to the length of the muscle fibers. When an electrode is placed on the skin, the detection surface comes in contact with the electrolytes in the skin [65]. A chemical reaction takes place which requires some time to stabilize, typically in the order of a few seconds if the electrode is correctly designed. But, more importantly, the chemical reaction should remain stable during the recording session and should not change significantly if the electrical characteristics of the skin change from sweating or humidity changes. Given the high performance and small size of modern day electronics, it is possible to design active electrodes that satisfy the above requirements without requiring any abrasive skin preparation and removal of hair [65].

In localizing the site of detection of the electrode on the skin, a variety of approaches has been applied: (1) over the motor point; (2) equidistant from the motor point; (3) near the motor point; (4) on the mid-point of the muscle belly; (5) on the visual part of the muscle belly; (6) at standard distances of osteological reference points and (7) with no precision at all with respect to its placement [12].

4. Analysis of a movement

EMG enables us to record muscular activity, and it is often advisable to carry out a synchronized cinematic measurement at the same time. In this way, the two types of data can be contrasted and it is possible to establish:

Figure 2. A research of lower extremity muscle groups [66] (Photograph shot during a study by Sozen H. et al.).

- 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 [41].

The analysis of movement usually includes cinematic and kinetic study [52,47,41]. 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. A kinetic study determines the internal or external forces involved [41].

4.1. Evaluating sports performance

Surface EMG is commonly used to quantify the magnitude and timing of muscle activation during various physical tasks, that has broad application in sport science research [44]. The fact that sEMG can analyze dynamic situations makes it of special interest in the field of sports [11]. The improvement in the efficiency of a movement involves the correct use of the muscles, in terms of both economies of effort and effectiveness, as well as in the prevention of injury.

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In a training process, improvements in these parameters can be sought, follow-up carried out and corrective measures or steps for improvement determined [5,13].

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 [9]. It has to be remembered that the EMG does not provide us with muscular force parameters, although it is an indicator of the muscular effort made in a particular action [67,12-57,11]. In relation to this, it is important to stress that the relationship between EMG activity and effort is only qualitative [5]. Recently, experiments have also been carried out in the sports area on applications for purposes such as the evaluation of the type of muscle fiber and the characterization of muscles [15,14].

4.2. Relationships between muscular force and EMG

Muscular force is the amount of force a muscle can produce with a single maximum effort. Enhanced muscular force can lead to improvements in the areas of performance, injury prevention, body composition, self-image, lifetime muscle and bone health, and chronic disease prevention [16]. There are many cases in which knowledge of the relationship between EMG and force is desired. If the relationship between force and EMG amplitude is simply linear, a direct regression equation yields a relatively simple technique to control prosthetic limb function [19].

Ergonomists could assess the load on various muscles by monitoring the EMG activity. The relationship between EMG and force also seems to depend on the nature of the muscle studied, since some investigators have reported a linear relationship for the adductor pollicis and first dorsal interosseous and soleus, and a nonlinear relationship for the biceps and deltoid [68]. There have been other, numerous examples of observations of nonlinear relationships between force and EMG amplitude [69,70].

It is clear that when considering the possible shape of the EMG force relationship, one needs to consider various features of the movement, such as the type of muscle contraction; the size and location of the active muscles; their role as agonists, synergists, or antagonists; air temperature [71,19] and the numerous other physiological and technical factors that affect the electromyogram [19].

4.3. Examples of current EMG studies in sciences of sports

EMG has been a subject of laboratory research for decades. Only with recent technological developments in electronics and computers has surface EMG emerged from the laboratory as a subject of intense research in particularly kinesiology, rehabilitation and occupational and sports medicine. Most of the applications of surface EMG are based on its use as a measure of activation timing of muscle, a measure of muscle contraction profile, a measure of muscle contraction strength, or as a measure of muscle fatigue [72]. Only a handful of research articles using EMG techniques were published in the early 1950s. Today, over 2500 research publications appear each year. The growth of the EMG literature and the availability of appropriate instrumentation and techniques might suggest that our understanding of the procedures used to record the EMG signal and the relevant analysis methods must be complete. Yet the interpretation of the signal remains controversial; and there are few sources available to help the novice electromyographer understand the physiological and biophysical basis of EMG, characteristics of the instrumentation, signal analysis techniques, and appropriate EMG applications [19].

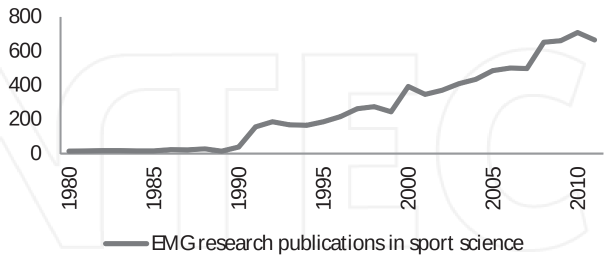

Figure 3. The growth in the number of EMG related publications in sport science since 1980s (drawn by Sözen H. based on data from Thomson ISI).

Sports science studies on exercise equipment often use electromyography. A study carried out by Sözen H. et al compared the muscle activation during the exercise on elliptical trainer, treadmill and bike equipment which are frequently used in the fields of rehabilitation and sport science. Determing the muscles used predominantly during the exercise on these three equipments may contribute to the regulation of available performance tests or the tests scheduled to be performed on these equipments. Besides, detemining in which muscle groups the equipments are used more efficiently for rehabilitation and treatment may help treatment be more successful. According to studies' results; it was found out that elliptical trainer equipment activated upper extremity muscles more when compared to treadmill and bicycle equipment. But, in the activation of lower extremity muscles, treadmill and elliptical trainer equipments are more advantageous compared to bike. As a result; elliptical trainer equipment is more advantageous to activate different muscle groups compared to treadmill and bicycle equipments. By more muscles groups' involving in action, more cardiorespiratory output, accordingly more energy consumption and production can be provided as a response to the exercise on elliptical trainer [1].

The studies that use surface EMG in sciences of sports are mostly related with determination of the mechanism of contraction and relexation of muscles while also dealing with evolution of injuries. The data obtained from these studies can be used in the following areas:

a. the evaluation of the technical development

b. the establishment of the suitable exercise programs

c. follow up of the development of the sportsmen

d. the choice of skills [34].

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5. Conclusions

When the research in sciences of sports is thoroughly investigated, it is seen that usage of electromyography is rapidly increasing. Research and applications of such kind unite medical and sports sciences and thus help us understand the movement physiology of the human body.

Surface EMG, though often used for diseases of locomotion and movement disorders, may also be a tool for evaluation of performances of sportsmen. By this way the functional capacity of muscles which play the most active role in movement may be determined and this approach also yields designation of exercise programs and skill analysis that play an important role in success in various fields of sports.

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