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ORIGINAL RESEARCH

SURFACE ELECTROMYOGRAPHY IN BIOMECHANICS: APPLICATIONS AND SIGNAL ANALYSIS ASPECTS

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Abstract. Surface electromyography (SEMG) is a technique for detecting and recording the electrical activity of the muscles using surface electrodes. The EMG signal is used in biomechanics mainly as an indicator of the initiation of muscle activation, as an indicator of the force produced by a contracting muscle, and as an index of the fatigue occurring within a muscle. EMG, used as a method of investigation, can tell us if the muscle is active or not, if the muscle is more or less active, when it is on or off, how much active is it, and finally, if it fatigues. The purpose of this article is to discuss some specific EMG signal analysis aspects with emphasis on comparison type analysis and frequency fatigue analysis.

Keywords: electromyography, signal, biomechanics, applications, sport

REZUMAT. *Electromiografia de suprafață în biomecanică: aplicații și aspecte ale analizei de semnal.* Electromiografia de suprafață (SEMG) este o tehnică de detecție și înregistrare a activității electrice a mușchilor cu ajutorul electrozilor de suprafață. Semnalul electromiografic este folosit în biomecanică în principal ca un indicator al inițierii activării musculare, ca un indicator al forței produse de un mușchi în contracție și, nu în ultimul rând, ca un index al oboselii musculare. Electromiografia, folosită ca metodă de investigație, ne poate spune dacă mușchiul este activ sau nu, dacă este mai mult sau mai puțin activ, când este activ și când nu, cât de mult este activ și dacă este obosit. Scopul acestui articol este acela de a discuta câteva aspecte specifice analizei de semnal electromiografic, punând accentul pe analizele comparative și pe cele de frecvență-oboseală.

CUVINTE CHEIE: electromiografie, semnal, biomecanică, aplicații, sport

Introduction

Electromyography (EMG) is a technique for detecting and recording the electrical activity of the muscles (Strungaru, 1982). The instrument used to detect the electrical potential generated by the muscle cells when they contract or are at rest is called an electromyograph. The record produced by an electromyograph is known as an electromyogram or a myogram. The signal recorded as a myogram is the result of superimposed motor unit action potentials (MUAPs) from several motor units. A motor unit has, as a central element, one motor neuron which innervates several muscle fibers. The impulse generated by a firing motor unit is called an action potential and it is carried down the motor neuron to the muscle. The neuromuscular junction is the area

where the nerve contacts the muscle. Once the action potential is transmitted across the neuromuscular junction, an action potential is elicited in all of the innervated muscle fibers of that particular motor unit. The sum of all this electrical activity is known as a *motor unit action potential* (MUAP) (Wikipedia).

The raw EMG signal looks like the one presented in Figure 1. The amplitude of the signal can range from 0 to 10 mV (peak-to-peak). The usable energy of the signal ranges between 0 and 500 Hz, with the dominant energy being in the 50-150 Hz range (De Luca, 2002). When analyzed, the EMG signal is rarely used as a raw one. Typically, the information derived from a raw EMG signal is limited to a frequency analysis. In order to interpret the amplitude and time characteristics, the EMG signal must be processed. In most cases, the steps followed in processing the raw EMG signal are rectification, smoothing and digital filtering (Konrad, 2005).

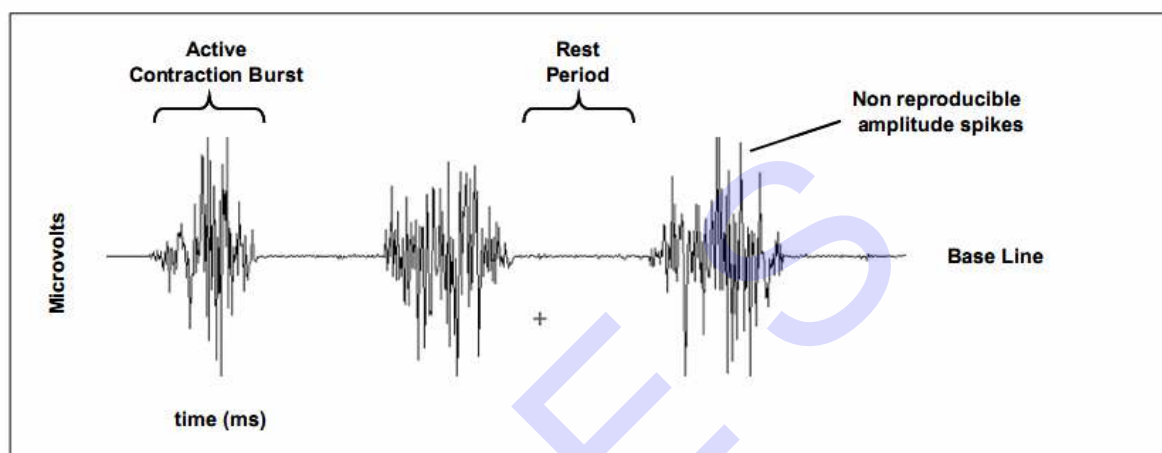


Figure 1. The raw EMG signal (Adopted from Konrad, 2005)

Surface electromyography (SEMG) is mainly used in kinesiological studies because of its non-invasive character. It implies the detection of the myoelectric signal with surface electrodes. The main drawback of SEMG is the fact that only surface muscles can be investigated.

Electromyography was initially used in neurology as an analyzing method of the muscle response at an artificial electrical stimulus. Nowadays, EMG is used in medical research, ergonomics, rehabilitation and sports science. In kinesiology, EMG is described as “the study of the neuromuscular activation of muscles within postural tasks, functional movements, work conditions and treatment/training regimes” (Konrad, 2005).

SEMG in biomechanics

In the world of biomechanics, electromyography has the role of evaluating the neuromuscular activation within any type of physical activity. Aside Anthropometry, Kinematics and Kinetics, Kinesiological EMG (Figure 2) is recognized as an objective measurement method (Konrad, 2005). The aims of kinesiological EMG are to analyze the function and coordination of muscles during any kind of physical performance, in both healthy and disabled subjects.

The research areas of kinesiological EMG include studies of normal muscle function during different types of contraction; studies of muscle activity in sports, occupational activity and rehabilitation; evaluation of functional anatomical muscle activity; coordination and synchronization studies; studies on how training affects muscle function; fatigue studies; muscle force and EMG; the influence of equipment on muscle activity, and so on (Clarys, 2000).

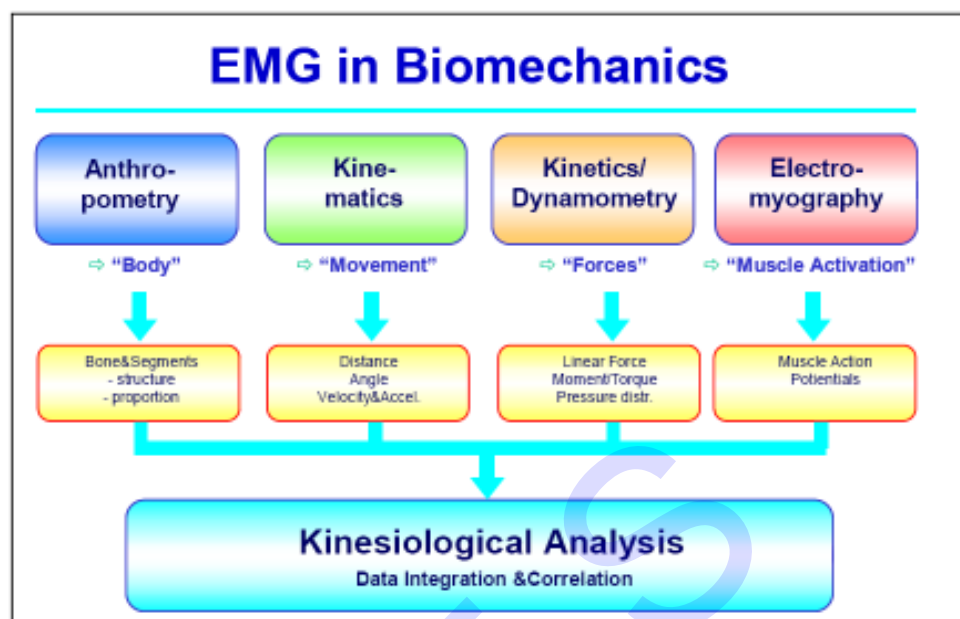


Figure 2. The 4 major areas of biomechanical measurement methods (Adopted from Konrad, 2005)

Surface EMG signal is used in biomechanics mainly as an indicator of the initiation of muscle activation, as an indicator of the force produced by a contracting muscle, and as an index of the fatigue occurring within a muscle. When used as an indicator of the initiation of muscle activity, the SEMG signal provides the timing sequence of one or more muscles which contract with the purpose of fulfilling a task, such as bending forward from an upright position or maintaining the upright standing position (De Luca, 1997). Although the amplitude of the EMG signal does not necessarily reflect the value of the force generated by a contracting muscle, it is qualitatively related to the amount of torque (or force) measured about a joint. This is the reason why some amount of information regarding muscle force can be extracted from EMG data, but this process must be approached with caution (Royer, 2005). If we are interested in assessing the muscle fatigue, the EMG signal is a good information source. The frequency spectrum of the EMG signal, when correctly interpreted, reveals when the investigated muscles fatigue.

SEMG analysis issues

As we have seen so far, EMG focuses on muscles. To be more specific, it focuses on the electrical activity of the muscles. What exactly can EMG, used as a method of investigation, tell us about muscles? First and most important, EMG can tell us if the muscle is active or not. Then it can tell us if the muscle is more or less active, when it is on or off, how much active is it, and finally, if it fatigues (Konrad, 2005). In the following pages we will focus only on three of these issues. We will discuss why it is relevant to know if the muscle is active or not, if the muscle is more or less active, and if it fatigues.

The first question that EMG addresses ("Is the muscle active?") is a simple one. It takes no more than one minute for an EMG specialist to record the raw signal generated by a specific muscle and, thus, respond with Yes or No to the question. A more complex question would be "Is the muscle more or less active?". The answer implies comparison conditions, so the steps to be followed are preparation for recording, recording the signals, analysis of each recorded signal separately, and comparison of the analyzed recordings. Maybe the most complex question that EMG addresses is "Does the muscle fatigue?". As opposite findings were associated with fatigue tests, interpreting the fatigue analysis results is not an easy task. Fulfilling this task requires a great amount of expertise in the field.

There are five major categories of analysis question that EMG can answer. The first one, as we have already mentioned, is referring to whether the muscle is active or not. The answers are yes/no or on/off and they can be obtained by simply observing the raw EMG signal generated by the muscles. The flexion-relaxation phenomenon (Figure 3) exemplifies perfectly the on/off succession of the back muscles when bending forward

from an upright position (Konrad, 2005). At the most flexed position of the trunk, the back muscles (ch. 1 and 2 lumbar right and left; ch. 3 and 4 multifidii right and left) turn off. When slowly extending back, both muscles start firing again.

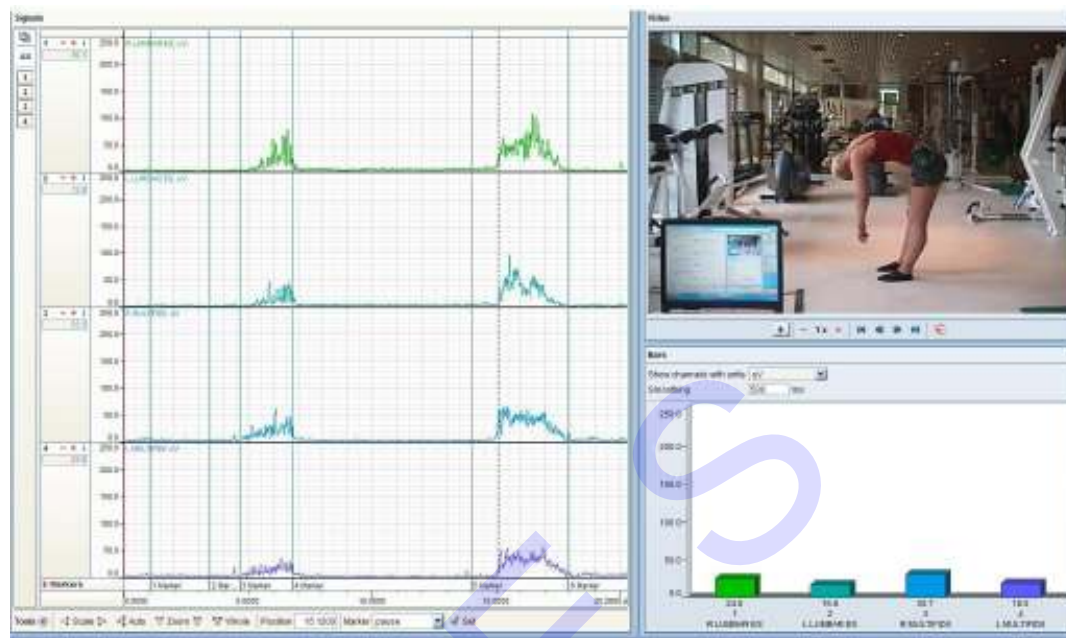


Figure 3. The flexion-relaxation phenomenon (Noraxon MyoResearch XP)

Another example could be the one presented in Figure 4, where a male subject performs 3 bicep curls with his right arm. The signal from the left biceps brachii is recorded on channel 1, and the signal from the right biceps brachii is recorded on channel 2. It can be clearly seen that no signal is recorded on channel 1 as the left biceps brachii is relaxed.

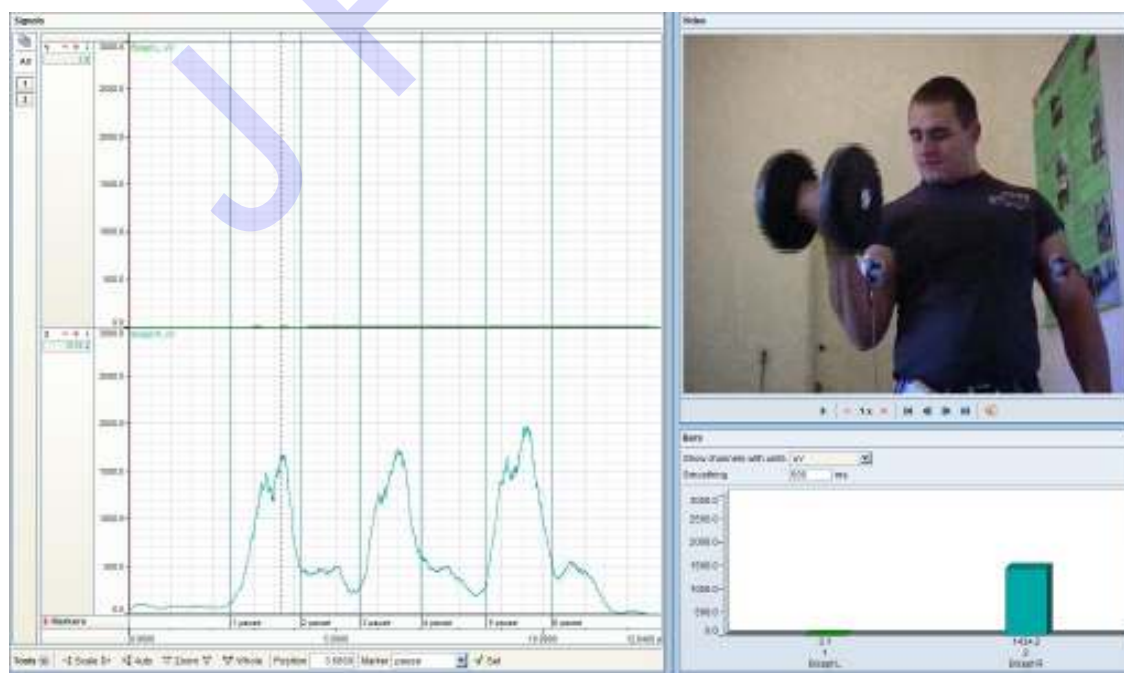


Figure 4. Biceps brachii flexion/extension (Noraxon MyoResearch XP)

At this point, one can argue: we know if one specific muscle is active or not at a given moment. What is the scientific relevance of that? A clinician can and will give a diagnosis based on the results of such a simple EMG analysis. A physical therapist can be provided with a starting point for a therapy regime by simply measuring which muscle of the patient is active in a given task. A training professional can make pertinent choices on the training methods he/she will use to achieve a specific goal by knowing the on/off succession of the muscles in an exercise. These are a few reasons why knowing if a muscle is active or not could be relevant.

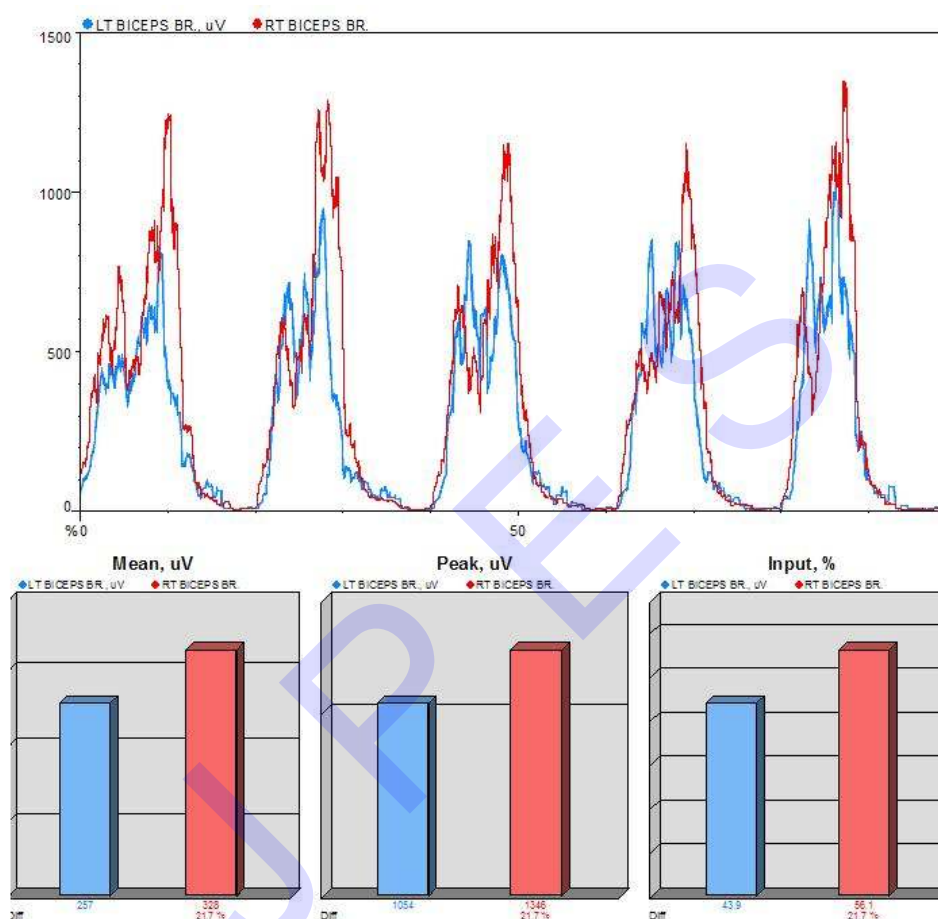


Figure 5. EMG analysis of the biceps brachii in left/right comparison (Noraxon MyoResearch XP)

The question “Is the muscle more or less active?” implies comparison conditions, like comparing the left and right side electromyogram, the pre and post test electromyogram, the subject’s and the normative electromyogram. The answer at this kind of question will be a qualitative one and the data resulted from the qualitative analysis will be presented as curves (Konrad, 2005). A more/less analysis is presented in Figure 5, where the curve with the higher amplitude values is the signal generated by the right biceps brachii of a subject performing 5 voluntary biceps curls, and the curve with the lower amplitude values corresponds to the left biceps brachii of the same subject. Symmetry reports are designed for records measuring the muscle activity in symmetrical, bilateral movements. Comparisons between each muscle pair (left vs. right) are based on EMG signals that are automatically rectified and smoothed online. The MyoResearch XP software’s report overlays the EMG patterns of each muscle pair for visual comparison of pattern, timing and amplitude. Corresponding statistics (mean and peak amplitudes) including the relative difference between each muscle pair are provided in both a bar graph and numerical format (MyoResearch XP, 2004). For the case analyzed in Figure 5, the right biceps brachii is clearly more active than the left one while performing the same task.

Another type of test to which the “more/less” analysis can address is the one presented in Figure 6. This is an ergonomics test and it takes place in an working environment. The muscles tested while the subject performs specific working activities are the lumbar region of the erector spinae (ch. 1), the multifidii (ch. 2), the internal oblique (ch. 3), and the upper trapezius (ch. 4).

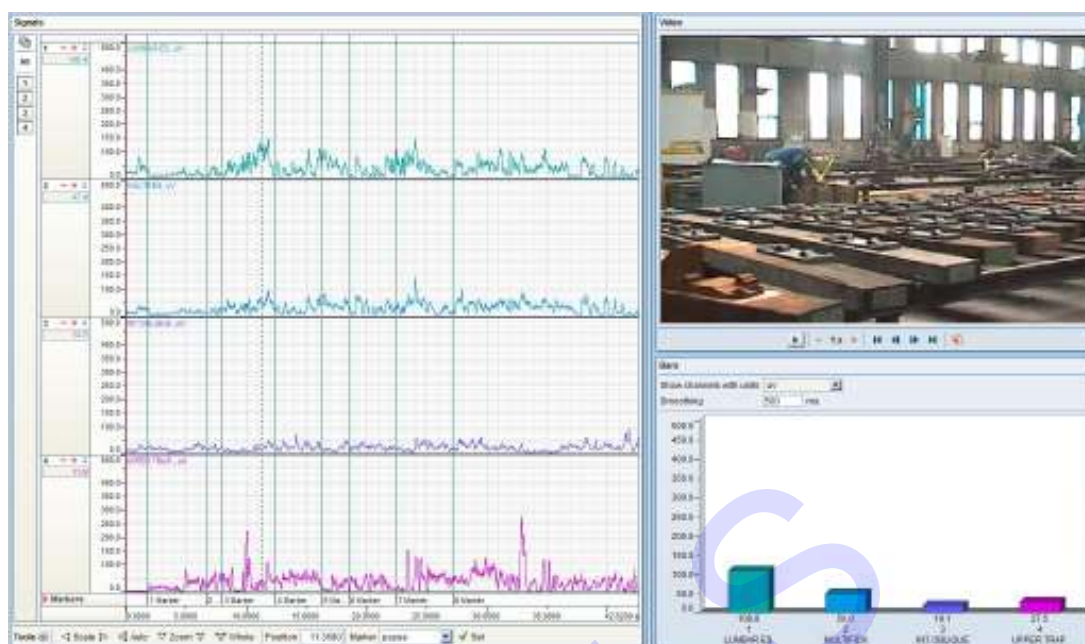


Figure 6. Video-based EMG recording of different work activities (Noraxon MyoResearch XP)

The analysis report corresponding to the EMG recordings from Figure 6 is the one presented in Figure 7. Four different work activities are selected from the whole record by using manual markers to indicate the beginning and the end of each activity. The MyoResearch XP software provides the mean and peak values of each activity for the analyzed muscles. Comparisons can then be made between muscles and work activities. We can find out which muscle is more or less active during a specific work activity by interpreting the bar graphs from Figure 7.

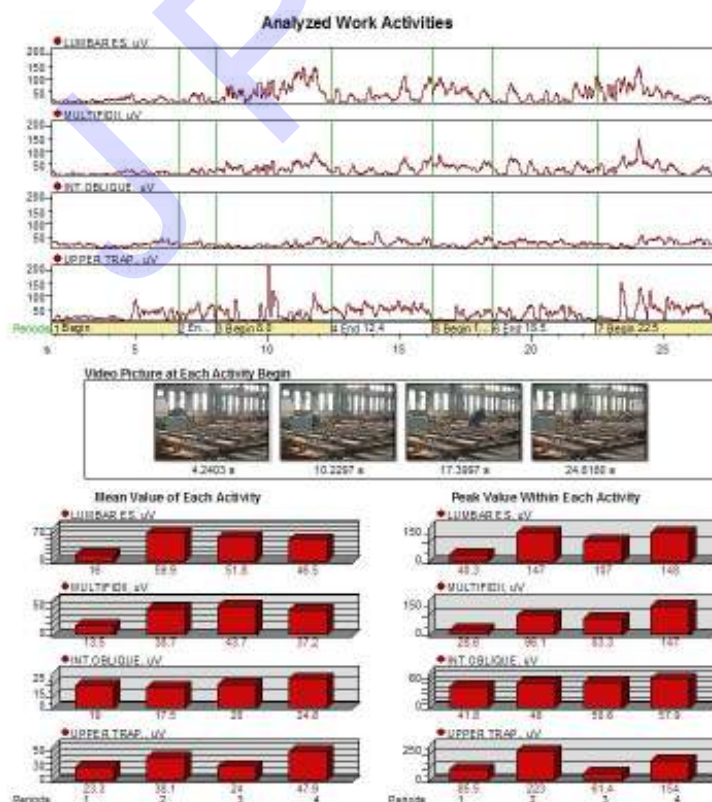


Figure 7. EMG analysis report of 4 different work activities (Noraxon MyoResearch XP)

When wanting to compare sides during the performance of an exercise like the lumbar extensions on a bench (Figure 8), Symmetry report is not the only option. The Average activation report is an excellent alternative.

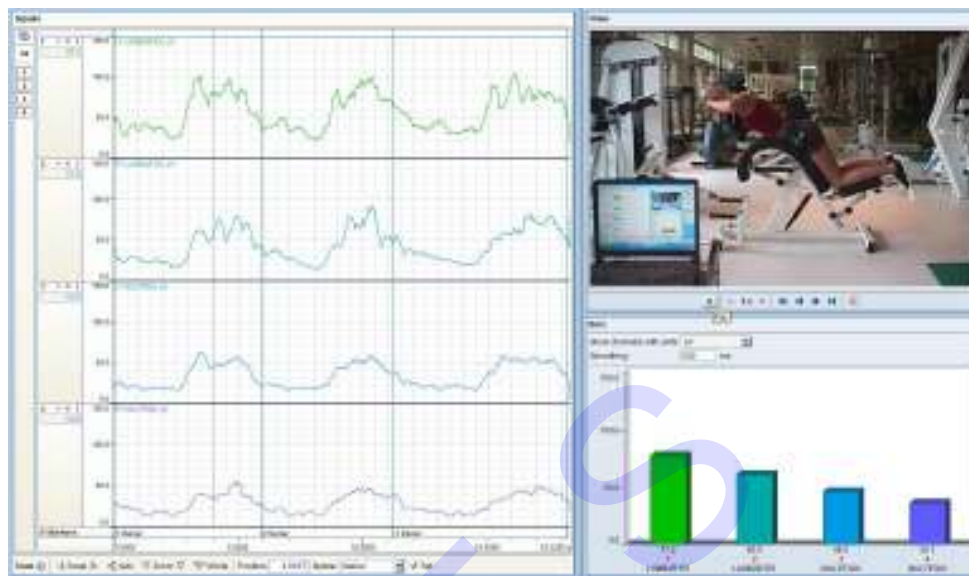


Figure 8. Video-based EMG recordings of lumbar extension exercise (Noraxon MyoResearch XP)

The Average activation report (MyoResearch XP software) is designed to provide time normalized average EMG patterns for repetitive movements (e.g. extension / flexion). The main purpose of averaged muscle activation profiles is to detect prototypical activation patterns and firing characteristics for two separate phases of a cyclic motion, such as extension/flexion, abduction/adduction, multi-joint up and down movements, cycling, walking and running etc. The averaging process requires a continuous, standardized repetition sequence. Typically a sequence of 3 to 6 repetitions is performed at a controlled movement velocity. The benefit of EMG averaging is increased reproducibility, the ability to create normative data records and the convenience of comparing EMG patterns between different activities. The report displays the average muscle activity profile (ensemble average) with a shaded area reflecting \pm one standard deviation around the mean (Figure 9). Mean and peak values of the ensemble averages are provided in both a bar graph and numerical format.

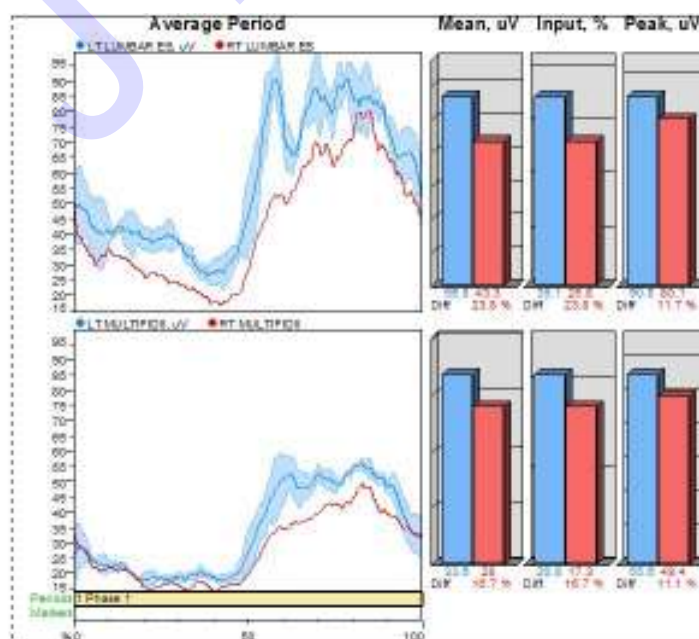


Figure 9. EMG average activation analysis report for 3 back extensions (Noraxon MyoResearch XP)

The primarily involved muscles in a lumbar extension are the lumbar erector spinae and the multifidii. Figure 8 presents four EMG signal recordings (left lumbar erector spinae on channel 1, right lumbar erector spinae on channel 2, left multifidii on channel 3, and right multifidii on channel 4) representing three back extensions. Manual markers were used to separate the three repetitions and an Average activation type analysis was performed with the Noraxon MyoResearch XP software. The results are presented in Figure 9, both as normalized curves and as bar graphs. The muscles on the left side of the investigated subject are about 20% more active when performing a back extension than the muscles on the right side.

Finally, the most complex question of all the questions that EMG can give an answer to is “Does the muscle fatigue?”. The classical fatigue test requires a constant load level at a well defined angle position/muscular length. Figure 10 presents a male subject performing an isometric contraction of the left biceps brachii. The raw EMG signal of the left bicept is recorded on channel 1 for 1 minute. This recording is then used to generate a Frequency fatigue report.



Figure 10. Video-based EMG recording of a static biceps brachii contraction (Noraxon MyoResearch XP)

The Frequency fatigue report is designed mainly for the purpose of tracking and analyzing fatigue related changes in the neuromuscular recruitment. Changes in the frequency and amplitude parameters can be used to determine local fatigue. Unfiltered raw EMG is analyzed step-wise in 1000 ms increments over the selected portion of the measurement (Figure 11). Median and mean frequency is calculated for each step using values based on the frequency power spectrum (calculated by a Prime Factor Fourier Transformation) (MyoResearch XP software).

Figure 11 presents the raw EMG signal recordings for the following fatigue test setup: holding the semi-squat position on one leg for 45 seconds. The EMG data was recorded from the right thigh muscles of a female subject (channel 1 – vastus lateralis; channel 2 – vastus medialis; channel 3 – rectus femoris; channel 4 – biceps femoris).

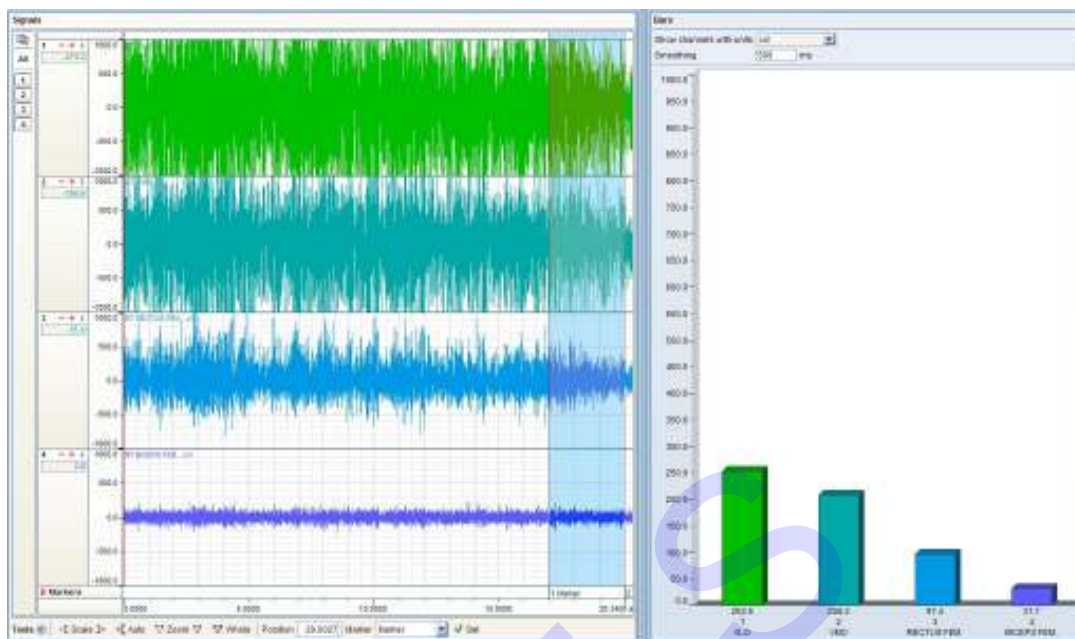


Figure 11. EMG recordings of a static semi-squat (right leg) (Noraxon MyoResearch XP)

The mean frequency diagram and the median frequency diagram resulted from analyzing the selected portion of the raw EMG signal from Figure 11 are presented below (Figure 12). As muscles fatigue, the frequency based mean or median frequency of the total power spectrum show a decrease over contraction time. The decline is present because the conduction velocity of the motor action potentials on the muscle membrane decreases (Konrad, 2005).

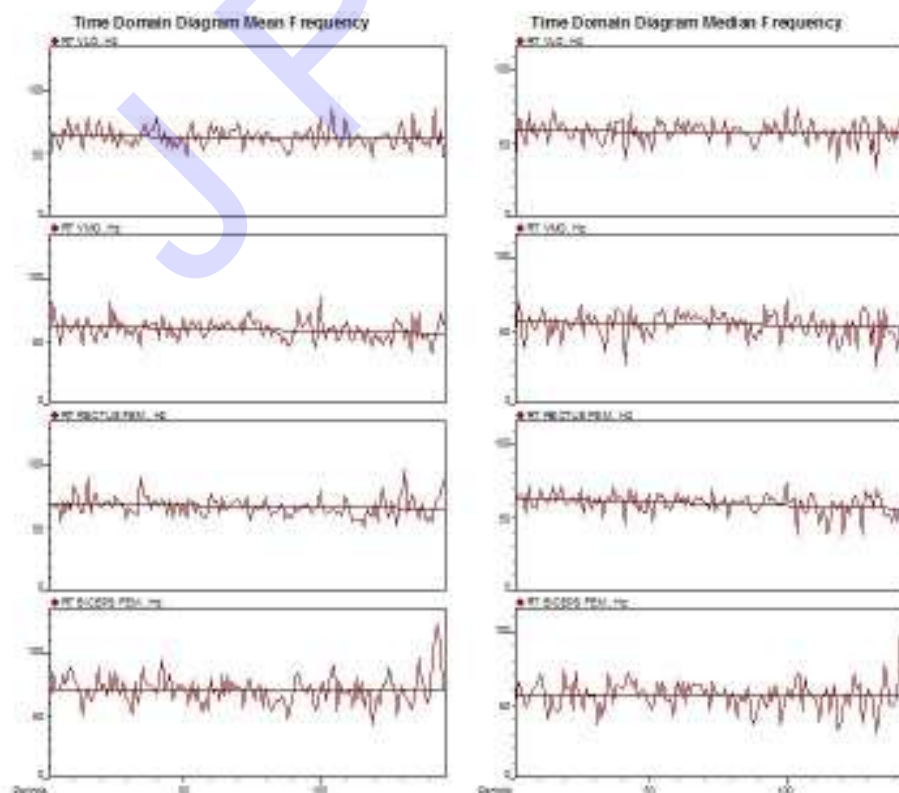


Figure 12. EMG frequency-fatigue analysis report for a static semi-squat recordings (right leg)

There are two major applications of the study of local muscle fatigue effects. First, it can be used to identify weak muscles. The most famous application of frequency shifts is in the analysis of low back pain patients. Second, it can be used to prove the efficiency of strength training exercises (Konrad, 2005).

Summary

Electromyography (EMG) is a technique for detecting and recording the electrical activity of the muscles (Strungaru, 1982). The instrument used to detect the electrical potential generated by the muscle cells when they contract or are at rest is called an electromyograph. The record produced by an electromyograph is known as an electromyogram or a myogram. The signal recorded as a myogram is the result of superimposed motor unit action potentials (MUAPs) from several motor units (Wikipedia).

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There are five major categories of analysis question that EMG can answer. The first one is referring to whether the muscle is active or not. The second one is about which muscle is more or less active than the one compared with. The third one is about the muscle timing (when is it on/off?). The fourth question is referring to the amount of muscle activity (more/less) in a given task and, finally, the fifth question is about muscle fatigue.

Due to its relative amplitude character which is influenced by local detection conditions and the lack of normative curves or activation levels, the comparison of EMG findings is the most important strategy to analyze and interpret EMG data. It is especially helpful to compare EMGs from the same muscle site in different movement phases, portions of the record or test activities. It is probably the most important EMG design at all (Konrad, 2005).

Interpreting the EMG findings is very demanding. A very good understanding of the neuromuscular system is required in order to do that. Then one must be aware of the real challenge that arises from the interpretation of EMG data: the re-integration of a certain finding from the neuromuscular system to the entirety of the human body (Konrad, 2005).

Although an EMG signal can give us very precise information regarding some aspects of the neuromuscular activation, it is rarely of much value by itself. Measuring instrumentation like the electrogoniometer, the isokinetic dynamometer, the force platform or the foot switches can provide joint-angle position, joint-torque, ground-reaction force, heel-strike and toe-off events which, synchronized with the EMG data, can give a more complex view on the activity of the muscles in different movement phases (Royer, 2005).

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