Basics of
SURFACE ELECTROMYOGRAPHY
Applied to Physical Rehabilitation and Biomechanics

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Introduction

This document was written to assist you in using surface electromyography for biomechanics applications and physical rehabilitation.

Surface **E**lectro**M**yo**G**raphy (SEMG) is a non-invasive technique for measuring muscle electrical activity that occurs during muscle contraction and relaxation cycles.

"Electromyography 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" (Basmajian, "Muscles Alive, Their Function Revealed by Electromyography").

Surface electromyography is widely used in many applications, such as:
- Physical Rehabilitation (physical therapy/physiotherapy, kinesitherapy, chiropractic and orthopedics)
- Urology (treatment of incontinence)
- Biomechanics (sport training, motion analysis, research)
- Ergonomics (studies in the workplace, job risk analysis, product design and certification)

SEMG is clinically indicated for:
- Biofeedback
- Relaxation
- Muscle re-education
- Treatment of incontinence

SEMG is also commonly used in psychophysiology.
"Psychophysiology involves the scientific study of the interrelationships of physiological and cognitive processes" (Mark S. Schwartz, 2003).

Whereas applications addressed here mainly focus on the **biomechanical aspects** of muscle activity, psychophysiology focuses on muscle activity **in response to emotions**. The assessment and treatment goals of these two approaches, and consequently their use of SEMG, are dramatically different.
Therefore psychophysiology is not addressed in this document, for the sake of clarity and in order to avoid misunderstandings in the field.

After you have become familiar with the key concepts, it is strongly recommended that you do hands-on training, before using them on a real examinee. **As simple it can be, it still requires practice.**

Note: This document is not intended to replace scientific and clinical literature. A bibliography of references is provided at the end.

Skeletal Muscle Properties

SEMG may be considered a "seductive muse because of its apparent simplicity" (De Luca). SEMG can be easily misinterpreted, so it is important to have a good understanding of what the signal indicates.

However, in order to understand SEMG, one must first understand muscle.

This chapter reviews the main anatomical and physiological concepts that must be kept in mind when interpreting SEMG.

Types of Fibers

Skeletal muscles contain two main types of fibers: Slow-twitch fibers (type I) and fast-twitch fibers (type II).
Type II fibers are further divided in two groups: Type IIa and IIb (sometimes a third group is mentioned: type IIx).

Type I fibers are small, fire slowly and use the aerobic metabolism to produce energy. They can work for long periods and are very resistant to fatigue.

Type IIa fibers are intermediate fast-twitch fibers. They are of a medium size and can use both aerobic and anaerobic metabolisms to produce energy. They fire faster than the Type I fibers and can generate faster contractions. They can work for no more than 30 minutes, as they fatigue faster than the Type I fibers.

Type IIb fibers are the classic fast-twitch fibers. They are big and use the anaerobic metabolism to produce energy. They fire faster than the type IIa fibers but are able to work only for a few minutes.

Their proportions in the muscle vary with the type of muscle and the condition of the examinee (injured, normal or athlete).

Types of Contractions

There are three types of contractions:

- **Concentric:** The muscle shortens. This happens when the tension is greater than the load.
- **Isometric:** The muscle stays the same (no movement). The tension is equal to the load.
- **Eccentric:** The muscle lengthens. The tension is less than the load.

Types of Contributions to a Movement

Muscles are divided in three groups according to their contribution to a movement:

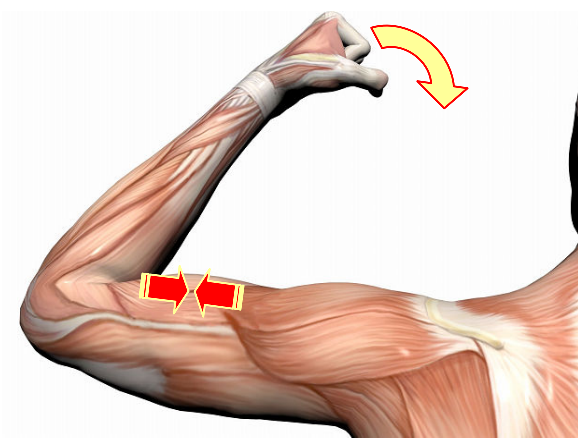
- **Agonist muscles:** The first movers, they initiate the movement; they generate most of the force.
- **Synergist muscles:** Assist the agonist muscles; they generate less force but contribute to the control of the movement.
- **Antagonist muscles:** Act in opposition to the movement; they provide a stabilizing force during the movement.

Examples of agonist/antagonist pairs:

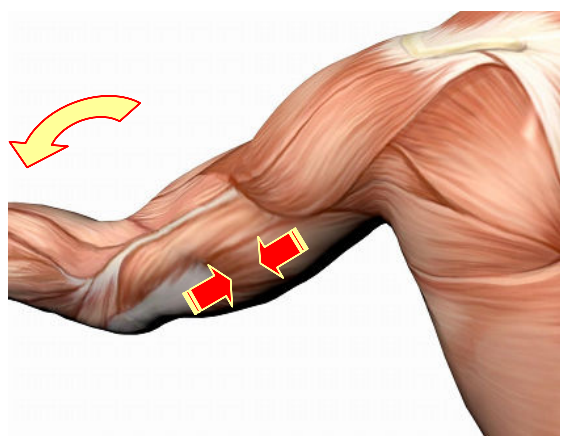
AGONIST	ANTAGONIST
Biceps	Triceps
Deltoids	Latissimus Dorsi
Pectorals	Trapezius/Rhomboids
Abdominals	Erector Spinae
Iliopsoas	Glueteus Maximus
Abductors	Adductors
Quadriceps	Hamstrings
Gastrocnemius/Soleus	Tibialis Anterior

Note that the contribution of a muscle, and consequently its assignment to a group, depends on the movement performed. Each movement has its antagonistic movement, which moves the limb in the opposite direction:

- Flexion ⇔ Extension
- Abduction ⇔ Adduction
- Inversion ⇔ Eversion
- Pronation ⇔ Supination
- Elevation ⇔ Depression
- Protraction ⇔ Retraction
- Plantarflexion ⇔ Dorsiflexion
- Left lateral flexion (spine and neck) ⇔ Right lateral flexion
- Left rotation (spine and neck) ⇔ Right rotation
- Lateral rotation (extremities) ⇔ Medial rotation



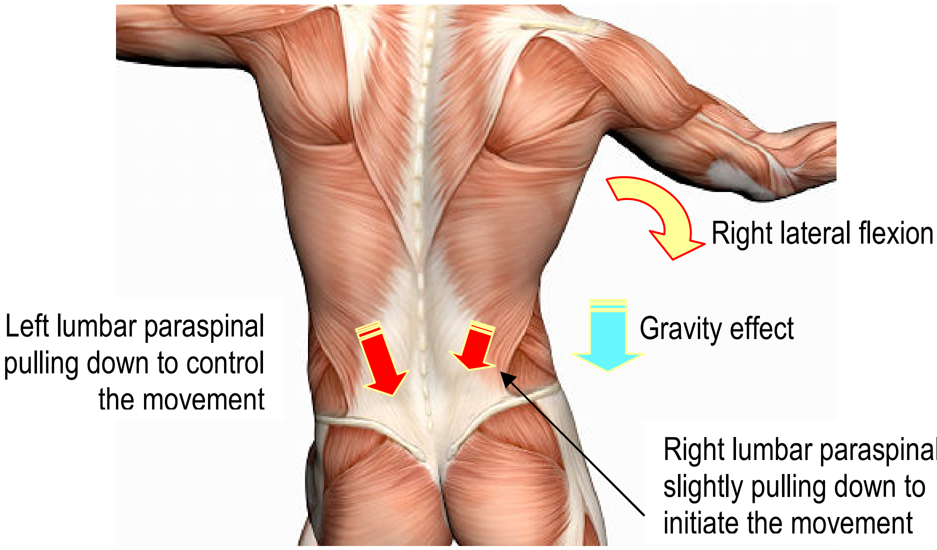
Elbow flexion: the biceps is the agonist and shortens (concentric contraction), which makes the elbow flex. The triceps is the antagonist. It lengthens (eccentric contraction) and its only function is to stabilize the movement by providing a force in opposition to the biceps and gravity.



Elbow extension: similarly, the triceps is now the agonist and shortens, which makes the elbow extend. The biceps then becomes the antagonist and stabilizes the movement by providing a force in opposition to gravity and the triceps.

A movement occurs when the agonist and synergists contract while the antagonist is relaxing. However, gravity can also play a proactive role and be the greatest contributor to the movement, in term of force. For instance, in the case of a right lateral flexion of the back in standing position, the agonist muscle (right lumbar paraspinal) only initiates the movement, gravity generating most of the force.

Therefore the antagonist muscle (left lumbar paraspinal) is more involved than the agonist, but still plays its role of control of the flexion and is not the initiator of the movement: **a muscle can only pull, it cannot push**.



Right lateral flexion of the back in standing position

The movement pattern can be altered by muscle imbalance (agonist vs. synergists or antagonist), or disturbance in the sequence of firing.

Movement pattern disturbances may find their origins in the following phenomenons:

- **Hyperactivity:** when a muscle contracts too early, too fast or too much.
- **Hypoactivity:** when a muscle contracts too late, too slow or not enough.

- **Hypotonicity:** a diminution of the muscle tone marked by a diminished resistance to passive stretching.
- **Hypertonicity:** excessive muscle tone marked by an increased resistance to stretching and heightened reflexes.

- **Substitution:** normal muscles take over a parallel one, to protect it and unload it when injured, weak or fatigued. Note that a substitute muscle may also become fatigued and become hypotonic (muscle shutdown).

- **Co-contraction:** co-contraction is the abnormal symmetrical activation of homologous muscles during asymmetrical movements, such as rotation or lateral bending, or more generally the over-activation of the antagonist muscle in order to protect the agonist (also called muscle bracing; pain is usually observed).

- **Spasm:** a spasm is a sudden, involuntary contraction of a muscle or a group of muscles.

- **Trigger-point:** a trigger-point is a hyperirritable spot in the muscle, a spasm at the cellular level.

- **Emotional arousal (or stress):** can increase the tonus of a muscle and change timing and coordination.

Muscles Involved in Movements

Shoulder

Movement	**Abduction**	**Adduction**
Involved Muscles	Supraspinatus (initiates motion) Deltoid (continues motion) Biceps brachii	Latissimus dorsi Teres major Triceps brachii Coracobrachialis Pectoralis minor
Movement	**Flexion**	**Extension**
Involved Muscles	Coracobrachialis Anterior deltoid Pectoralis major Biceps brachii	Posterior deltoid Latissimus dorsi Teres major Triceps brachii
Movement	**Lateral Rotation**	**Medial Rotation**
Involved Muscles	Posterior deltoid Infraspinatus Teres minor	Anterior Deltoid Latissimus dorsi Pectoralis major Subscapularis Teres major

Elbow

Movement	**Flexion**	**Extension**
Involved Muscles	Biceps brachii Brachialis Brachioradialis	Triceps brachii Anconeus
Movement	**Pronation**	**Supination**
Involved Muscles	Pronator teres Pronator quadratus Anconeus Brachioradialis	Supinator Biceps brachii

Wrist

Movement	Flexion	Extension
Involved Muscles	Flexor carpi radialis Flexor carpi ulnaris Palmaris longus Flexor digitorum superficialis Flexor digitorum profondus	Extensor carpi radialis brevis Extensor carpi radialis longus Extensor carpi ulnaris Extensor digitorum Extensor pollicis longus Extensor indicis
Movement	**Radial Deviation (Abduction)**	**Ulnar Deviation (Adduction)**
Involved Muscles	Extensor carpi radialis brevis Extensor carpi radialis longus Flexor carpi radialis Extensor pollicis brevis	Extensor carpi ulnaris Flexor carpi ulnaris

Hip

Movement	Flexion	Extension
Involved Muscles	Adductor brevis Adductor longus Iliacus Pectineus Psoas major Rectus femoris Sartorius Tensor Fascia latae	Adductor magnus Biceps femoris Gluteus maximus Semimem branosus Semitendinosus
Movement	**Abduction**	**Adduction**
Involved Muscles	Gemellus inferior Gemellus superior Gluteus maximus Gluteus medius Gluteus minimus Piriformis Tensor fascia latae	Adductor brevis Adductor longus Adductor magnus Biceps femoris Gluteus maximus Gracilis Pectineus Psoas major
Movement	**Medial Rotation**	**Lateral Rotation**
Involved Muscles	Gluteus medius Gluteus minimus Tensor fascia latae	Adductor brevis Adductor longus Adductor magnus Biceps femoris Gemellus inferior Gemellus superior Gluteus maximus Gluteus medius Obturator externus Obturator internus Piriformis Quadratus femoris Sartorius

Knee

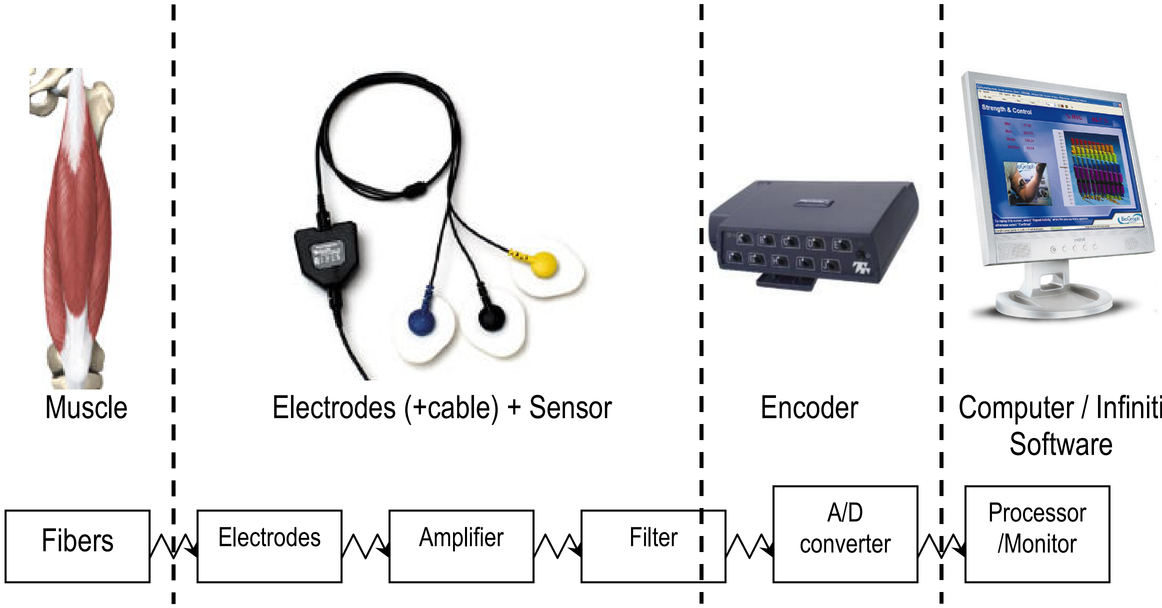
Movement	Flexion	Extension
Involved Muscles	Biceps femoris Gastrocnemius Gracilis Popliteus Sartorius Semimembranosus Semitendinorus	Rectus femoris Tensor Fascia latae Vastus intermedius Vastus lateralis Vastus medialis
Movement	**Medial Rotation**	**Lateral Rotation**
Involved Muscles	Gracilis Popliteus Sartorius Semimembranosus Semitendinorus	Biceps femoris

Ankle

Movement	Dorsiflexion	Plantarflexion
Involved Muscles	Extensor digitorum longus Extensor hallucis longus Peroneus tertius Tibialis anterior	Flexor digitorium longus Flexor hallucis longus Gastrocnemius Peroneus brevis Peroneus longus Plantaris Soleus Tibialis posterior
Movement	**Eversion**	**Inversion**
Involved Muscles	Extensor digitorum longus Peroneus brevis Peroneus longus Peroneus tertius	Flexor digitorum longus Tibialis anterior Tibialis posterior

Detection of SEMG signal

The SEMG signal generated by the muscle fibers is captured by the electrodes, then amplified and filtered by the sensor before being converted to a digital signal by the encoder. It is then sent to the computer to be processed, displayed and recorded by the Infiniti software.



A/D Converter (Encoder)

Thought Technology's A/D converters are called "encoders".

- **ProComp5 Infiniti** has 2 channels (A and B) sampling at 2048 samples per second and 3 channels (C to E) sampling at 256 samples/second.
- **ProComp Infiniti** has 2 channels (A and B) sampling at 2048 samples per second and 6 channels (C to H) sampling at 256 samples/second.
- **FlexComp Infiniti** has 10 channels (A to J) sampling at 2048 samples per second.

ProComp5 Infiniti

ProComp Infiniti

FlexComp Infiniti

Telemetric card for wireless transmission

The **sample rate** (for instance, 2048 samples per second) is the number of measures (samples) per second taken from the continuous signal (analog signal). In this case, the analog signal is the SEMG signal captured by the electrodes and amplified by the sensor. The series of samples constitutes the digital signal.

A **raw SEMG** signal has to be sampled at a minimum of 1000 samples per second and an **RMS SEMG** signal has to be sampled at a minimum of 32 samples per second (see definition of raw SEMG and RMS SEMG in section "The SEMG signal").

Amplifier (Sensor)

Thought Technology's EMG sensors are differential amplifiers. This means that whatever electrical activity is common to both sites is rejected, and what differs is amplified. It allows the rejection of the common mode between electrode pairs.

The EMG sensors for ProComp5, ProComp and FlexComp Infiniti are:

- **MyoScan (SA9503M)** and **MyoScan-Z (SA9503Z)** which amplify and output **raw SEMG**.
- **MyoScan-Pro (SA9401M)** which amplifies raw SEMG and converts it to **RMS SEMG**.

MyoScan (SA9503M)
MyoScan-Z (SA9503Z)

MyoScan-Pro (SA9401M)

Note: MyoScan-Z is an EMG sensor with built-in impedance check

Therefore, MyoScan and MyoScan-Z sensors are used on channels A and B of ProComp Infiniti and ProComp5 Infiniti and all channels of FlexComp Infiniti, whereas MyoScan-Pro is used on channels C to H of ProComp Infiniti and on channels C to E of ProComp5 Infiniti.

ProComp5	**A** 2048samp/s	**B** 2048samp/s	**C** 256samp/s	**D** 256samp/s	**E** 256samp/s
MyoScan or MyoScan-Z	☑	☑			
MyoScan-Pro			☑	☑	☑

ProComp	**A** 2048samp/s	**B** 2048samp/s	**C** 256samp/s	**D** 256samp/s	**E** 256samp/s	**F** 256samp/s	**G** 256samp/s	**H** 256samp/s
MyoScan or MyoScan-Z	☑	☑						
MyoScan-Pro			☑	☑	☑	☑	☑	☑

FlexComp 2048samp/s	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
MyoScan or MyoScan-Z	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
MyoScan-Pro										

MyoTrac Series: A/D Converter + Amplifier

Thought Technology also manufactures devices dedicated to SEMG:

- **MyoTrac Infiniti** has 2 built-in **raw SEMG** sensors sampled at 2048 samples/second.
- **MyoTrac3** has 2 built-in **RMS SEMG** sensors sampled at 20 samples/second..

MyoTrac Infiniti **MyoTrac3**

MyoTrac Infiniti can also, in certain configurations, have two electro-stimulation channels (NMES). These devices are usually used in muscle rehabilitation and incontinence treatment.

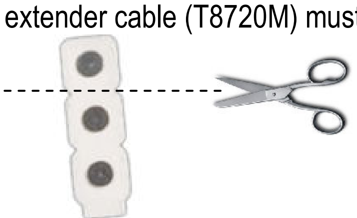
Surface Electrodes & Cables

The silver-silver chloride electrodes are the part of the instrument that is in contact with the skin. They make electrical contact between the skin and the sensor. The electrodes are either directly connected to (or “snapped on”) the sensor, or indirectly connected via an extender cable. Thought Technology provides various types of electrodes.

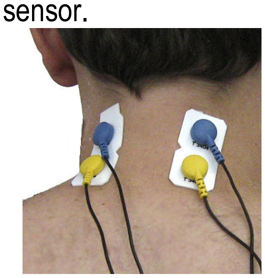
T3402M – Triode electrode (single use): The triode should be your first choice. It can be snapped directly on the sensor head, which makes it very easy to use and quick to position. The signal is then amplified right on the muscle site, which dramatically increases the SNR (Signal-to-Noise Ratio) and therefore limits pollution of the SEMG signal by surrounding electromagnetic fields and movement artifacts generated by wires being pulled.

The distance between the electrodes is optimal for avoiding or limiting muscle crosstalk.
However, its size does not make it suitable for long and thin muscles with great deformation while contracting, or for wider placements. In this case, the choice of another electrode type should be considered.

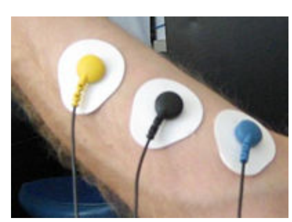
T3404 - Single strip electrodes (single use): The single strip electrodes are the perfect choice for long and thin muscles that do not offer enough space on the belly for a triode, and/or for muscles requiring a slightly wider distance between active electrodes. Here the reference electrode is placed between the active ones, which reduces the width of the electrode area in comparison to a triode and prevents them from peeling off. An EMG extender cable (T8720M) must be connected between the electrodes and the sensor.



These electrode strips can also be cut apart, which gives total freedom in term of placement. It is ideal for a wider placement or in order to put the reference electrode at a different place.



T3425 - UniGel electrodes (pre-gelled, single use): The UniGel electrodes provide total freedom in term of placement. Their small size also allows placement on very tiny muscles (such as SCM). They are not attached together, which



prevents them from moving on the skin when positioned on muscles with great deformation while contracting. These electrodes are pre-gelled and so do not require the addition of conductive gel, which reduces the time of preparation for this type of electrodes. An EMG extender cable (T8720M) must be connected between the electrodes and the sensor.

SEMG Vaginal Probes - T6050 / SEMG Rectal Probes - T6051 (re-usable for a single client only): These probes are used for monitoring of the pelvic floor muscles. They feature a vertical electrode configuration to ensure measurement along the direction of the muscle group. The T-bar ensures repeatability of measurement with respect to orientation and depth placement between uses. The small overall size and bulb configuration enable comfortable and secure seating of the sensor in a number of client positions including walking, standing or prone.

SEMG/Stim Rectal St-Cloud - SA9571 / Vaginal Femelex Probes - SA9572: The St-Cloud/Femelex probes are used vaginally or in the rectum to stimulate or sense the pelvic floor muscles. The same electrodes may be used for sensing or stimulating the pelvic floor muscles.

Typical Electrode Placements

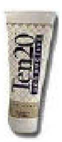
Skin Preparation

Proper skin preparation is important to get a good signal and avoid artifacts.

Before applying electrodes, make sure the skin surface is clean and dry:
Abrade the skin with an abrasive cream, such as NuPrep, to remove dead skin.
Alternatively, you can also clean skin with an alcohol wipe and let it dry, but this is not as efficient as the abrasive cream.
If necessary, shave excess body hair.

General Recommendations for Positioning Electrodes and Cables

If you use single electrodes with an extender cable, start by snapping the electrodes on the cable connectors. Once the electrodes are positioned on the skin, this action may be more difficult or uncomfortable for the examinee.

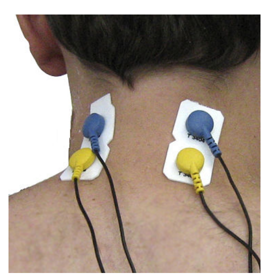


It may be recommended to put conductive electrode paste or cream (such as Ten20) on the center of electrodes (grey area only) before applying them to the skin. Only a small amount is necessary.

Place the active electrodes first (blue and yellow) on the examinee. The active electrodes should be placed in line with the muscle fibers, unless specified otherwise. Then place the reference electrode (black connector) anywhere on the body.

Make sure the electrodes are placed firmly on the skin and that there is good contact between the skin and electrodes.

Electrode Site



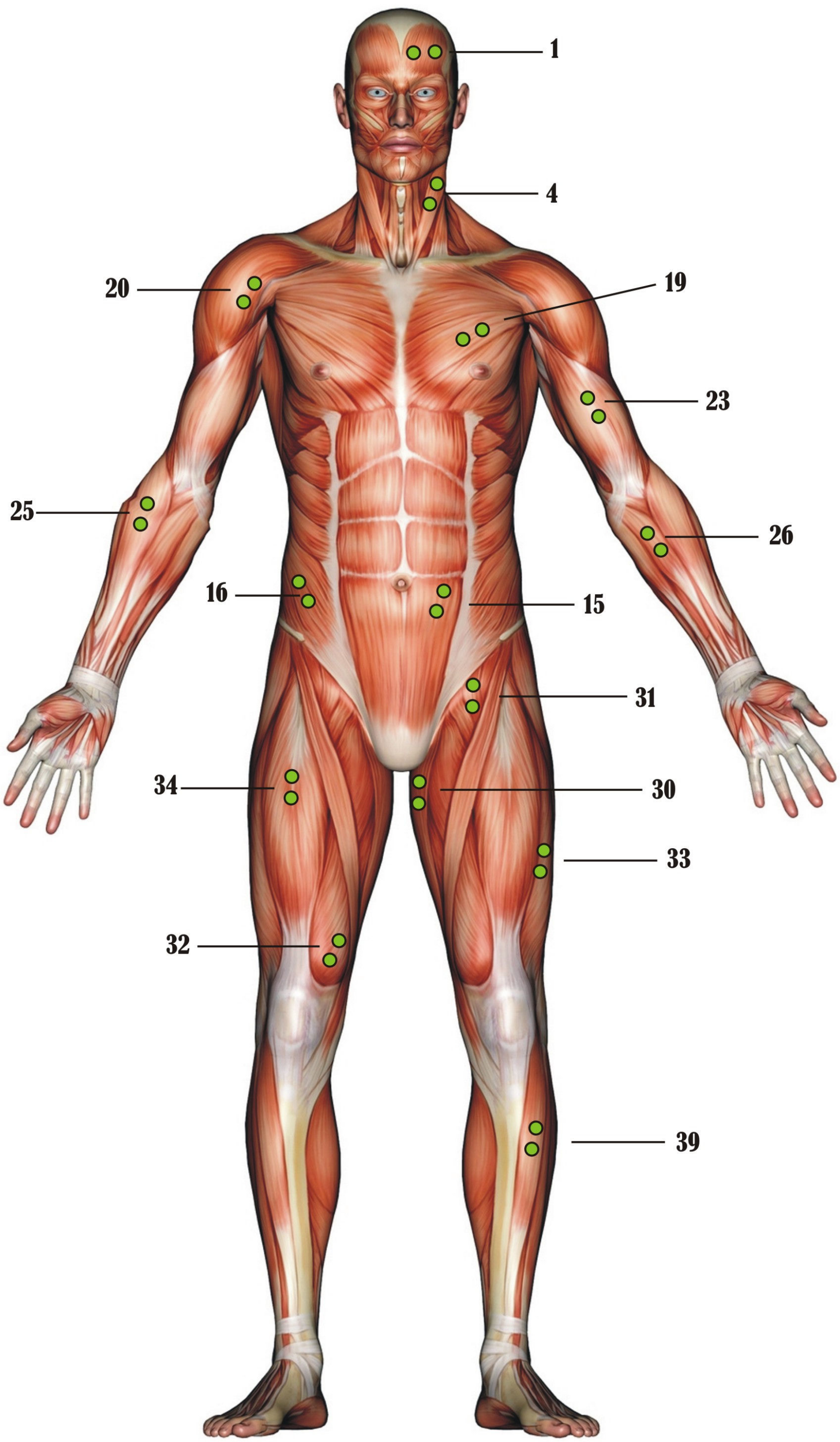
Active electrodes

Reference electrodes

Immobilize the cables with tape, straps or an elastic band to prevent them from being pulled or shaken.

The following pages show electrode placement on the different body areas. For clarity, only the active electrodes are shown.

SEMG Electrode Sites – Front View



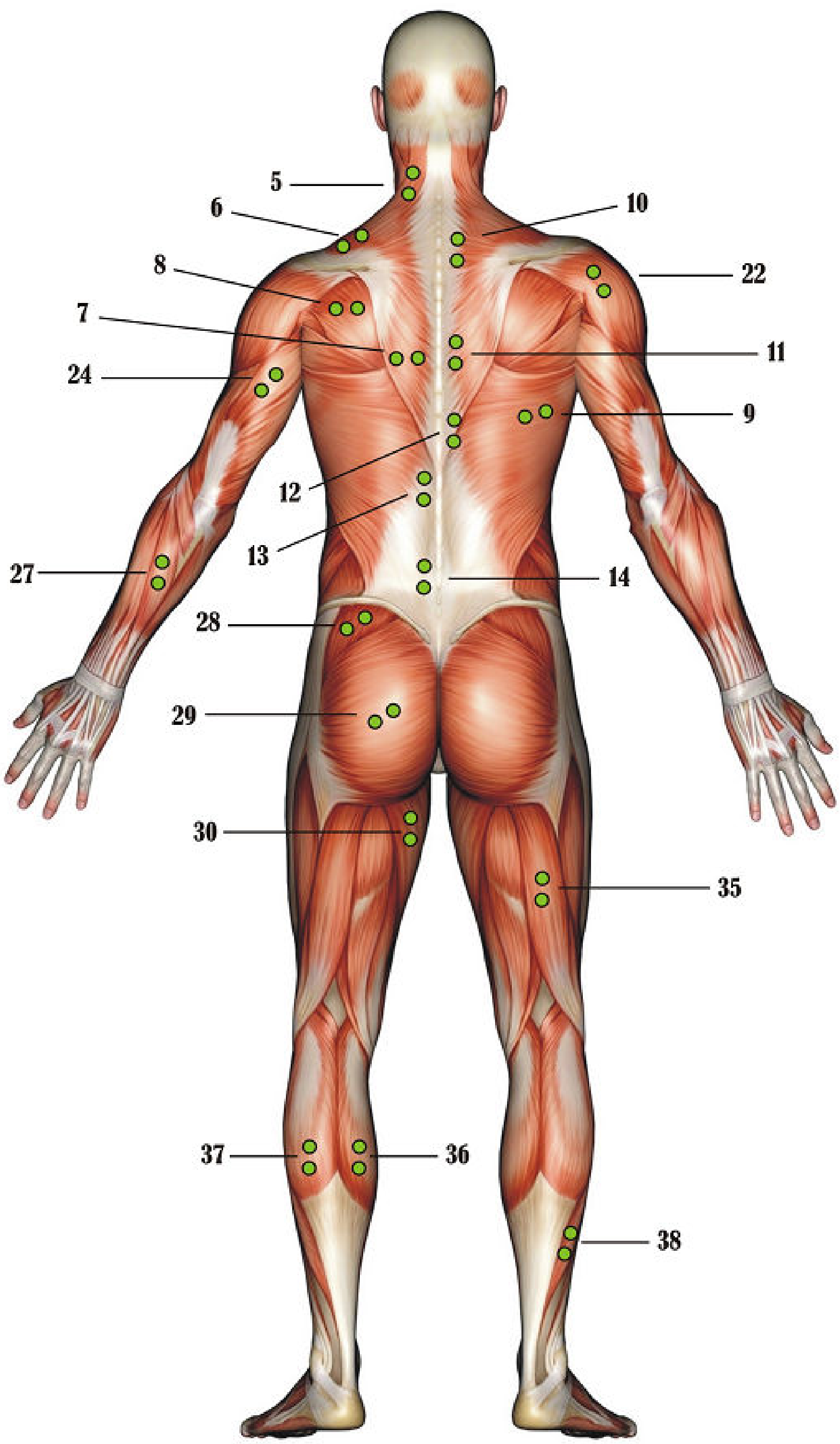
Head and Neck
1. Frontalis
2. Temporalis
3. Masseter
4. Sternocleidomastoid (SCM)
5. C4 Cervical Paraspinals (CP)

Trunk
6. Upper Trapezius
7. Lower Trapezius
8. Infraspinatus
9. Latissimus Dorsi
10. T2 Paraspinals
11. T8 Paraspinals
12. T10 Paraspinals
13. L1 Paraspinals
14. L5 Paraspinals
15. Rectus Abdominal
16. Abdominal Oblique
17. Internal Oblique
18. Serratus Anterior
19. Pectoralis Major

Arm
20. Anterior Deltoid
21. Lateral Deltoid
22. Posterior Deltoid
23. Biceps Brachii
24. Triceps Branchii
25. Brachioradialis
26. Wrist Flexor
27. Wrist Extensor

Leg
28. Gluteus Medius
29. Gluteus Maximus
30. Hip Adductor
31. Hip Flexor
32. Vastus Medialis Oblique (VMO)
33. Vastus Lateralis (VL)
34. Quadriceps Femoris
35. Medial Hamstring
36. Medial Gastrocnemius
37. Lateral Gastrocnemius
38. Soleus
39. Tibialis Anterior

SEMG Electrode Sites – Back View



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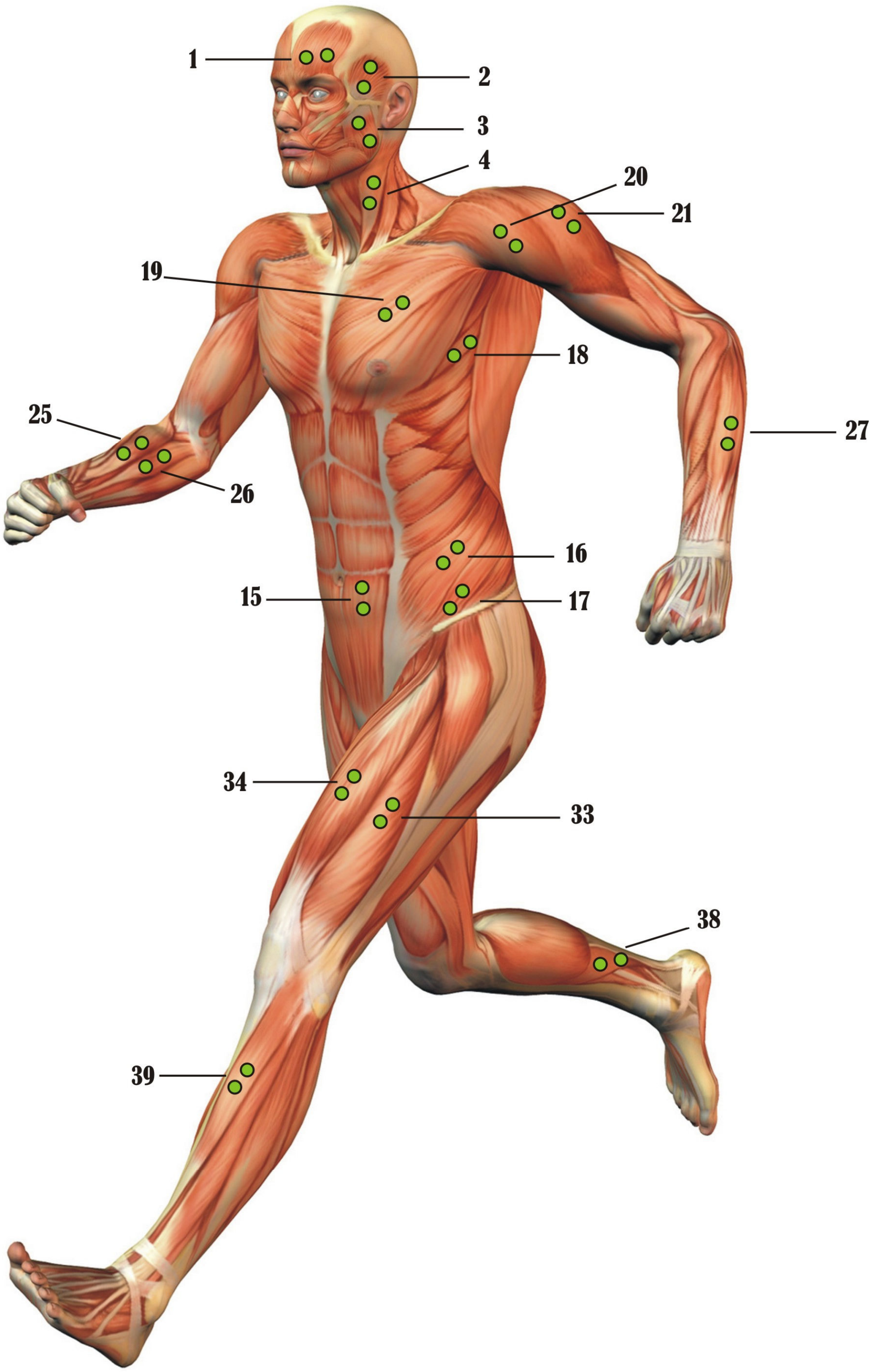
35. Medial Hamstring
36. Medial Gastrocnemius
37. Lateral Gastrocnemius
38. Soleus
39. Tibialis Anterior

SEMG Electrode Sites – Side View



Head and Neck

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37. Lateral Gastrocnemius
38. Soleus
39. Tibialis Anterior

The SEMG Signal

Physiological Basis of SEMG

To innervate a muscle fiber (stimulate it to contract), an electrical signal from the central nervous system must first reach an alpha motor neuron. These neurons are responsible for initiating muscle contractions.

As the contraction signal spreads from the alpha motor neuron across the muscle fiber, a series of electrophysiological and electrochemical processes takes place. This produces an electrically measurable depolarization and repolarization event known as the action potential.

SEMG looks at the action potential signals from a number of innervated muscle fibers located near the pickup electrodes. In the SEMG signal these action potentials from different muscle fibers appear together, all on top of each other.

Contraction intensity is controlled by how often the nerve impulse arrives and innervates the muscle fibers. Each action potential generates a certain amount of energy in the SEMG signal. So as the action potentials arrive more often, the muscle contracts harder and the SEMG signal level increases.

Signal Processing

Raw SEMG is the signal that is actually generated by the muscle. Figure 1 shows a raw SEMG signal.

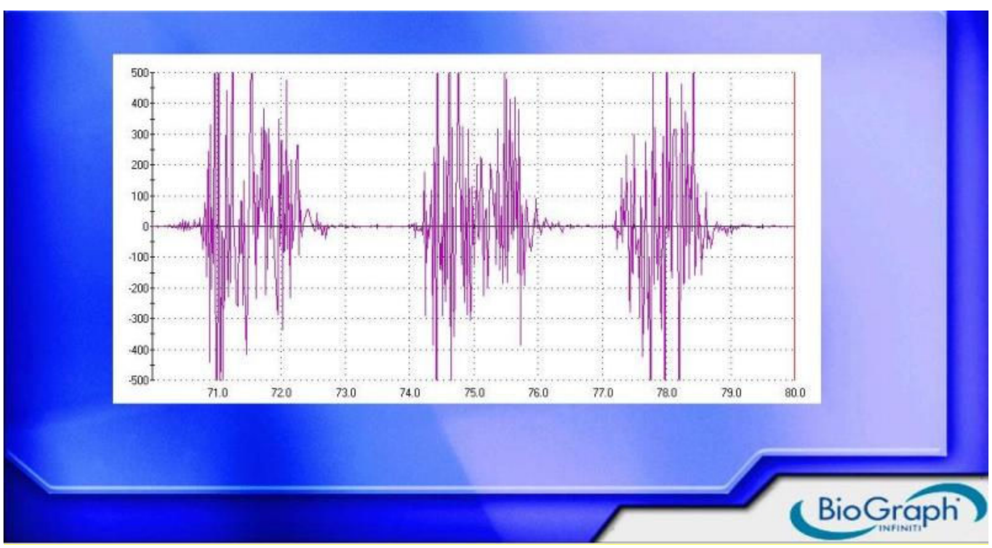


Fig. 1. Raw EMG (three contractions)

In the raw graph the X axis displays time and the Y axis displays amplitude in µV (micro-Volts), both positive and negative, about the axis which centers on zero. As the subject contracts the muscle the number and amplitude of the lines increase; as the muscle relaxes they decrease.

RMS or **R**oot **M**ean **S**quare is a technique for rectifying the raw signal and converting it to an amplitude envelope, to make it easier to view. It represents the mean power of the signal. Figure 2*a* shows an RMS signal.

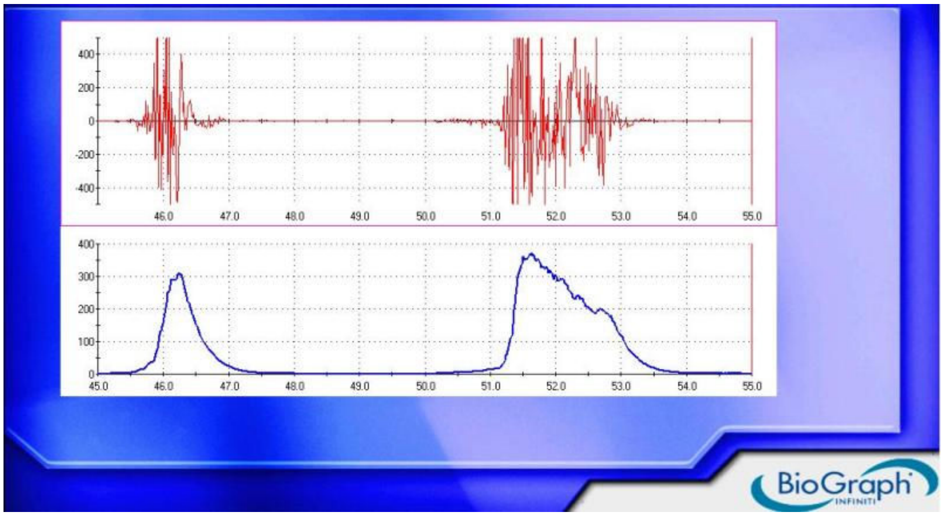


Fig. 2a. Raw EMG in red (top) and equivalent RMS EMG in blue (bottom)

The level of **smoothing** can be adjusted in the RMS signal. The smoother the signal is, the less "jitter" it has. But the smoother the signal is, the "slower" it is also. The ideal level of smoothing depends on the application. For biofeedback, for instance, the jitter should be limited. However it has to be balanced with the delay induced in the feedback.

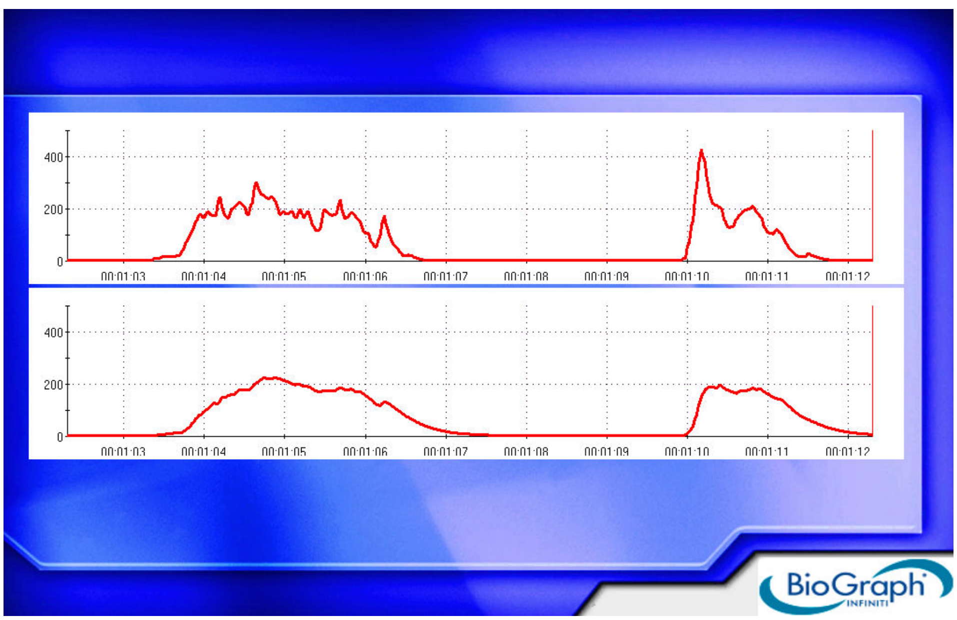


Fig. 2b. RMS EMG with low smoothing (top) and with high smoothing (bottom)

Frequency Domain: The raw and RMS displays both show the signal in the time domain. The signal can also be shown in the frequency domain. The signal is comprised of many electrical firings; these firings occur at different rates and the overall signal in the time domain is a composite of these multiple frequencies. Frequency is measured in Hertz (Hz) and is the number of events (firings, in this case) per second.

It is commonly accepted that relevant SEMG frequencies are between 20 and 500Hz. It is possible to display and represent the signal in its frequency domain by separating out the individual frequencies. It is interesting, for instance, to separate the activity of the slow-twitch fibers from the fast-twitch fibers. Publications generally say that slow-twitch fibers fire between 20 and 90Hz and fast-twitch fibers frequencies between 90 and 500Hz.

The raw signal is converted into the frequency domain by passing all the data points through a Fast Fourier Transform calculation (FFT); this mathematically isolates each of the frequency bands.

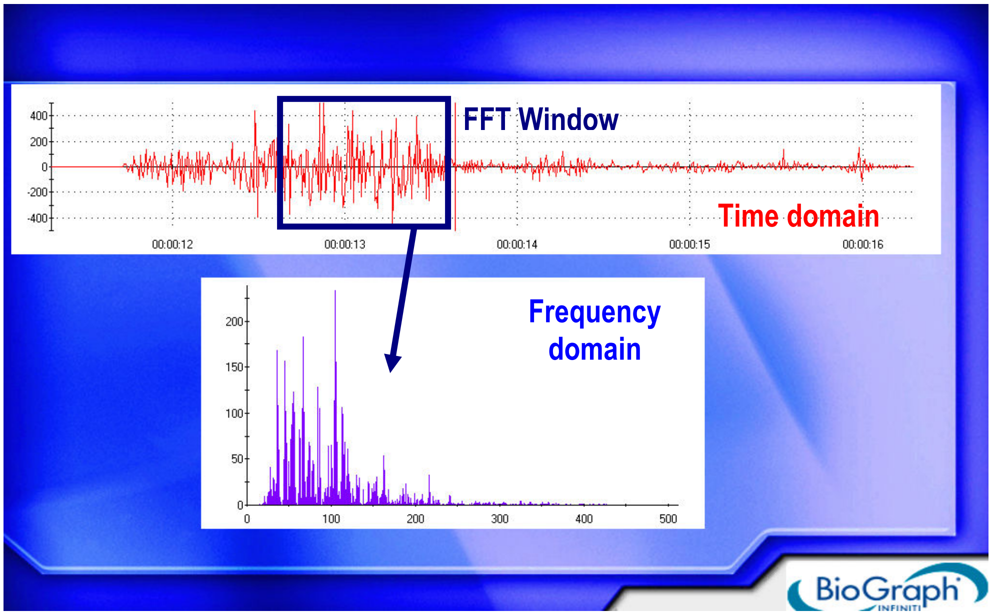


Fig. 3a. Time domain transformed into the frequency domain

The X axis displays frequency in Hz and the Y axis displays relative amplitude. Different information can be gathered from the frequency domain that is not as readily available from the time domain, such as muscle fatigue. As a muscle fatigues, the frequency of firings decreases, but total amplitude in the time domain can remain constant (so that the muscle fatigue cannot be seen in the time domain). The important measures for muscle fatigue are the **Median Frequency** indicated by the green bar in Figure 3b and the **Mean Frequency** denoted by the red bar.

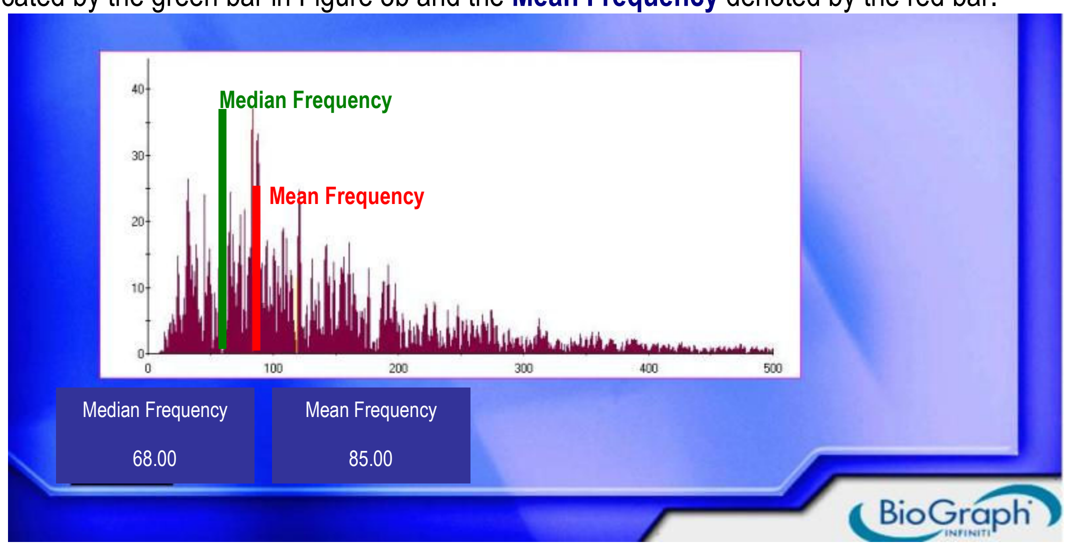


Fig. 3b. Frequency spectrum with mean and median frequencies

- The median frequency is the frequency that divides the power density spectrum into two sections with the same amount of power.
- The mean frequency is the frequency where the product of the frequency value and the amplitude of the spectrum is equal to the average of all such products throughout the complete spectrum.

As a muscle fatigues, the power density spectrum and the frequency spectrum shift to the left side of the frequency scale and, consequently, the median and mean frequencies decrease. Note that mean and median frequencies are relevant muscle fatigue indicators only for isometric contractions (sustained contraction with no movement).

- Uses of the different views of the SEMG signal:

- To measure the activation timing of a muscle: raw signal or RMS
- To verify the signal quality and detect the presence of artifacts (see next section): raw signal
- To measure the level of activation of a muscle: RMS
- To measure the resting level of a muscle: RMS
- For Biofeedback: RMS
- To measure the recruitment of the different types of fibers: raw signal or frequency/power spectrum
- To monitor the fatigue of a muscle: median frequency or mean frequency

- Uses of the EMG sensors for the different views:

	Raw	RMS	Power spectrum	Median frequency	Mean frequency
MyoScan or MyoScan-Z	☑	☑	☑	☑	☑
MyoTrac Infiniti	☑	☑	☑	☑	☑
MyoScan-Pro		☑			
MyoTrac3		☑			

SEMG Artifacts

Artifact is unwanted information contained within a signal. An EMG signal is very tiny and sensitive to artifacts. This section presents the different artifacts, how to detect them and how to prevent them.

- Line interference (50/60Hz noise):

This is the most common artifact. It comes from the power line and is transmitted by electrical devices (such as the computer) placed near the EMG data acquisition device (such as your Infiniti device). Figure 4 shows an example of line interference.

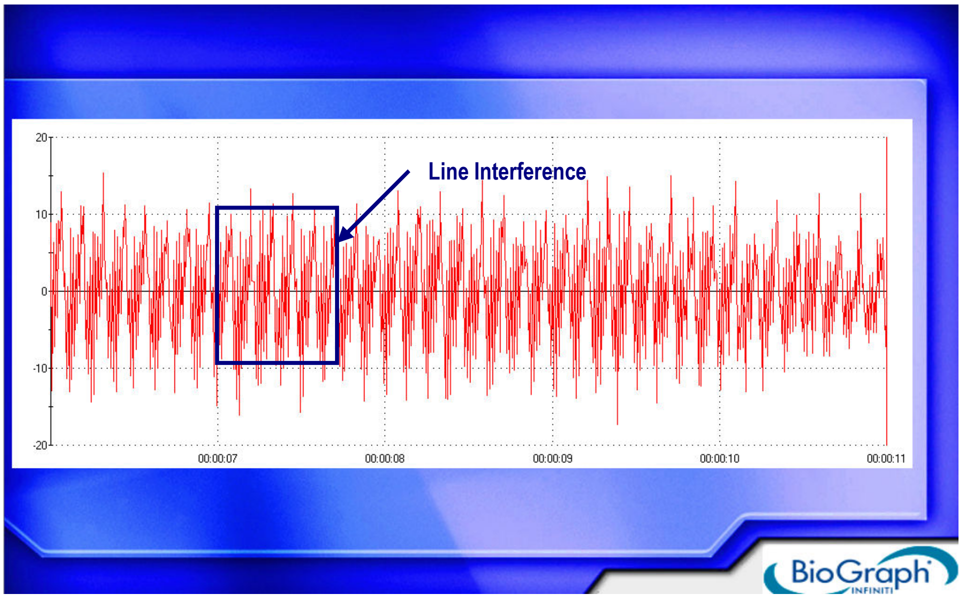


Fig. 4. Raw EMG signal with line interference

This problem can be fixed by applying a Notch filter to the signal, which will remove the 60/50Hz component of the signal. (The choice of 50 or 60Hz depends on the power transmission frequencies used in your region; you must configure your software accordingly.)

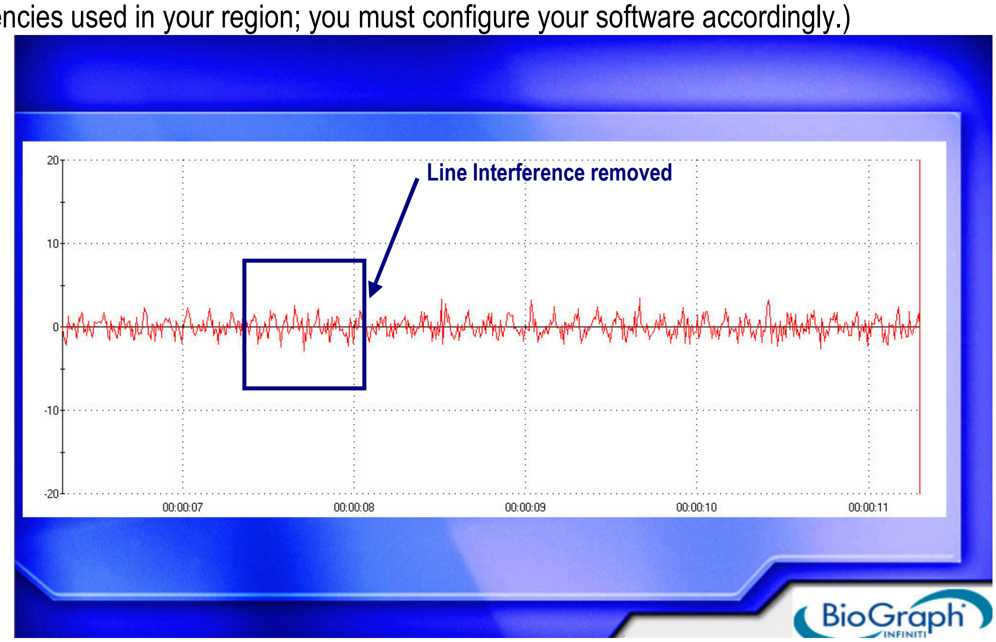


Fig. 5. Raw EMG signal with Notch filter

Electronic devices also generate their own frequencies that will not be removed by the Notch filter. Additional precautions must be taken, such as keeping the device 3 feet (1 meter) away from any electronic equipment and 10 feet (3 meters) away from any radio transmitting devices.

- EKG (ECG) artifacts:

EKG signal is generated by the heart. It can be picked up with the EMG signal. Figure 6 shows an example.

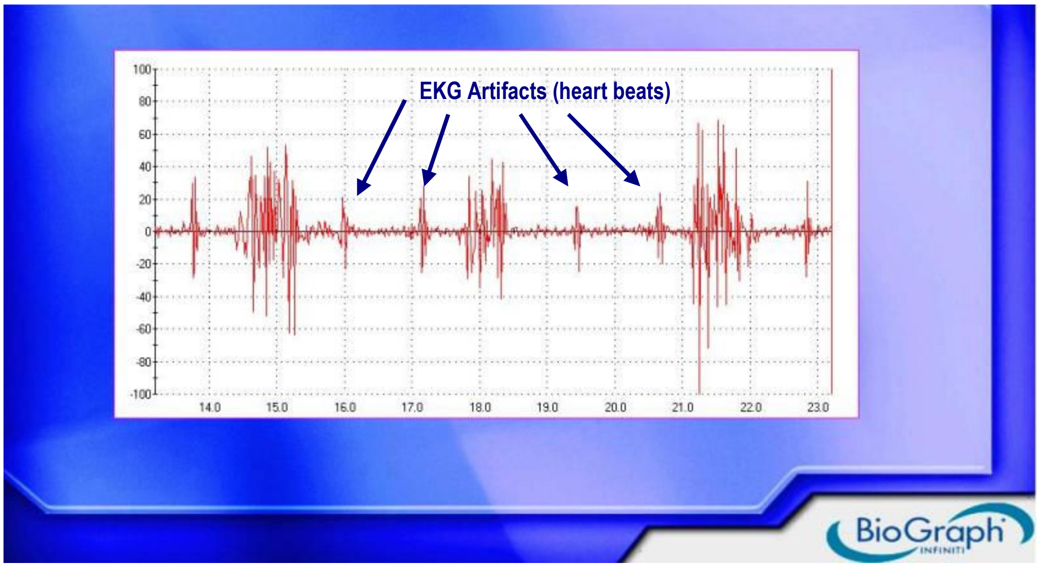


Fig. 6. Raw EMG signal with EKG artifact

EKG artifacts are very difficult to remove from the EMG signal. But they can be avoided by placing the electrodes so that they are not aligned with the axis of the heart activity (avoid transthoracic placement, for instance). Placing the electrodes on the same side of the body usually reduces or removes these artifacts.
If these precautions are not enough, a high-pass filter at 100Hz can be applied to the signal. However, this filters extremely low frequencies from the EMG signal and may remove important information.

- DC offset artifacts:

This is caused by the difference in the impedance between the skin and the electrodes. It adds an offset to the raw signal (which is normally centered on 0). Proper skin preparation and firm placement of electrodes on the skin generally prevent the problem. If necessary, conductive gel can be added.

- Muscle crosstalk:

Muscle crosstalk is caused by EMG signals coming from other muscles than the one being monitored. Crosstalk can be avoided by choosing the appropriate inter-electrode distance (around 2 centimeters) and by placing electrodes at the middle of the muscle belly.

- Movement artifacts:

During patient movements, the electrodes can move or the cables be pulled or be shaken, which may create artifacts in the EMG signal. An example can be seen in Figure 7.

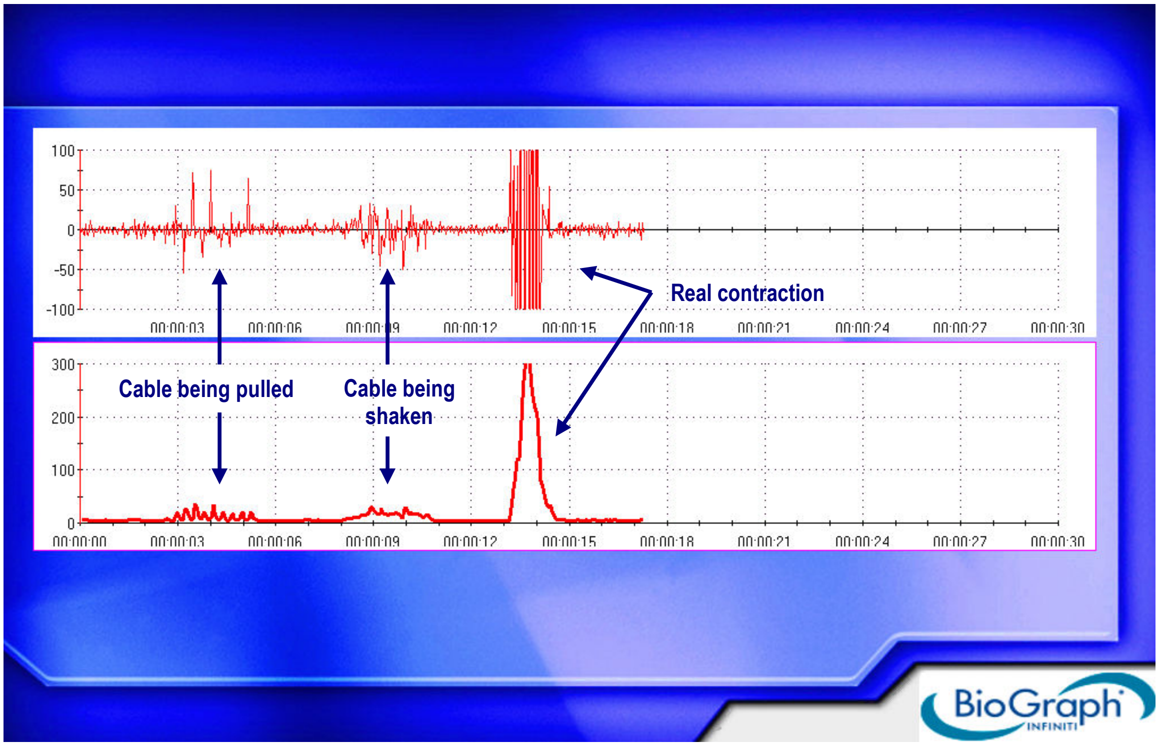


Fig. 7. Raw and RMS EMG signals with movement artifacts

An artifact caused by pulling or shaking can be avoided by using tape or an elastic band to fasten the cables. Electrode movement can be avoided by choosing the right electrode type and placing the electrodes firmly on the skin to avoid them peeling off. Inter-electrode distance must also be chosen so that electrodes do not push against each other during movement.

A high-pass filter at 20Hz can be applied to the signal (hardware or software) to remove the residual artifact.

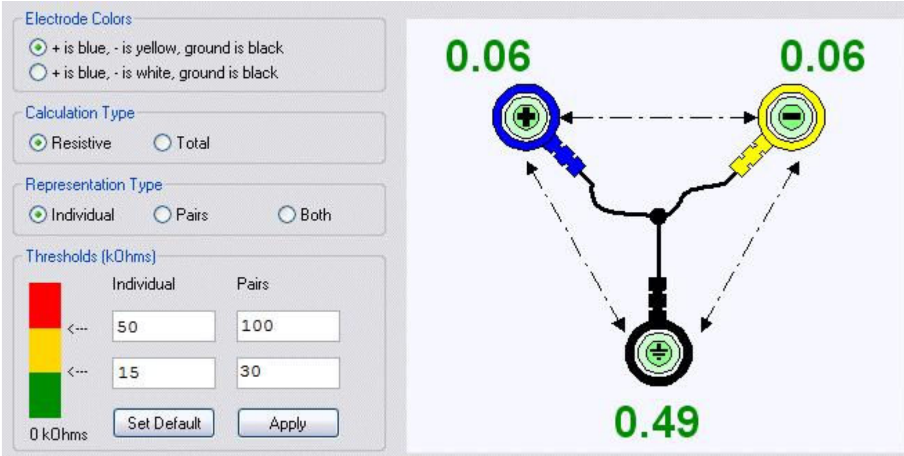
These artifacts can also be manually removed from the statistics calculation during the review of the session.

Impedance Check

Good preparation of the skin for contact is necessary for accurate results and prevention of artifacts. Measuring the impedance between the electrodes is the recommended way to verify good contact.
This measure is performed with an impedance meter. The table below gives the recommended ranges.

(green)	0 to 15 kOhms	Recommended for assessment
(yellow)	15 to 50 kOhms	Acceptable for Biofeedback training but not recommended for assessment
(red)	> 50 kOhms	Not recommended

The impedance check can also be done with MyoScan-Z, our EMG sensor with built-in impedance check.



BioGraph Infiniti – Impedance Check Screen

The advantage of MyoScan-Z is that you do not have to handle the patient and the cables between the impedance check and the real session. You can also run an impedance check during the session without disconnecting any cable. This is faster and more reliable than using a regular impedance meter.

Signal Analysis

SEMG signals can be viewed in three different dimensions: amplitude, time and power spectrum. Important information can be gathered in each dimension. SEMG analysis can be then separated in three groups: amplitude analysis, temporal analysis and spectral analysis.

Amplitude analysis:

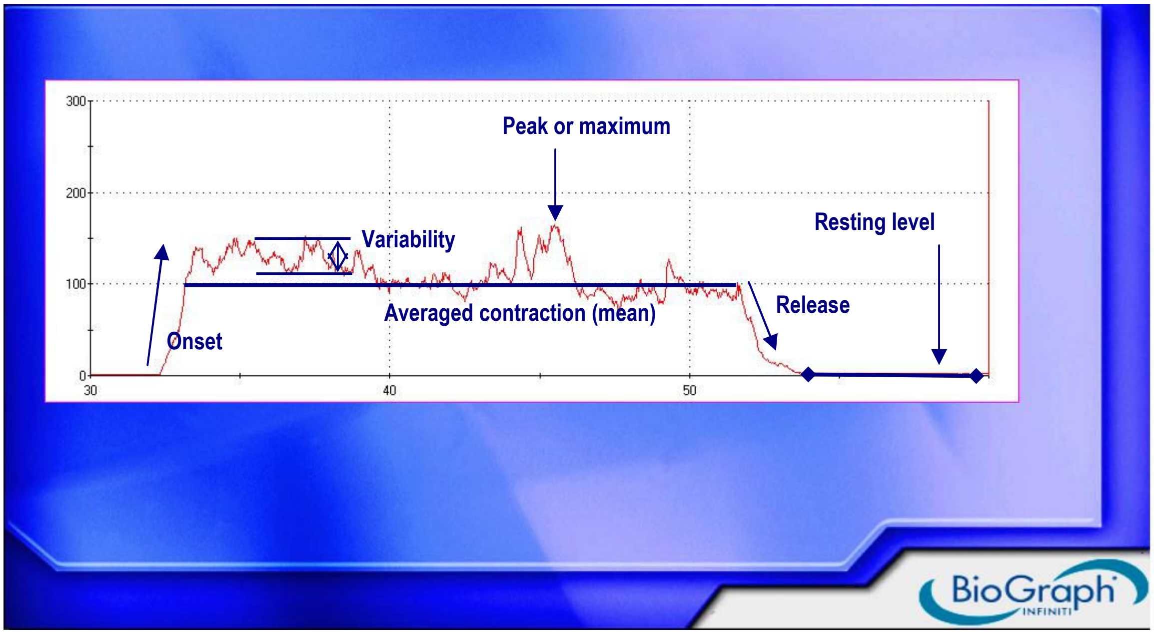
- Baseline or resting level: the level of SEMG when the muscle is totally relaxed. It is generally accepted that the SEMG of a muscle at rest should be below 5µV.
- Averaged contraction (mean of SEMG during contraction): this is a good indicator of the level of muscle strength and endurance **(while performing an isometric contraction)**.
- Peak or maximum: this is the maximum SEMG amplitude the muscle can generate.
- Variability: is a good indicator of the neuromuscular stability.
- Area or iEMG (integrated EMG): this is the mathematical integral of the EMG amplitude, which corresponds to the area under the curve, for a given period of time. It is a good indicator of the amount of energy produced during that period of time.

Temporal analysis:

- Onset time or activation time: the time it takes for the muscle to contract.
- Release time or deactivation time: the time it takes for the muscle to go back to rest.

Spectral analysis:

- Mean/Median frequencies: their rate of decrease is a good indicator of muscle fatigue **(while performing an isometric contraction)**.



SEMG Measures

Normalization Methods

SEMG measures must be compared to a reference in order to be meaningful. The drawback of SEMG measures is that they can vary significantly between subjects (age and type of skin), muscles, electrode placements (on the same muscle), and from day to day.

Several normalization methods exist; the most common ones are the following:

- Bilateral comparison: the involved site is compared to the uninvolved site.
- MVC-normalization: MVC is **M**aximum **V**oluntary **C**ontraction. The amplitude is compared to MVC and can be rescaled to % of MVC. MVC is obtained by recording several isometric contractions in the muscle test position (at least three repetitions are required). The maximum values of each repetition are averaged to give the MVC.

Summary of Recommendations

Here is a summary of recommendations to ensure proper use of SEMG and the capture of a good quality signal:

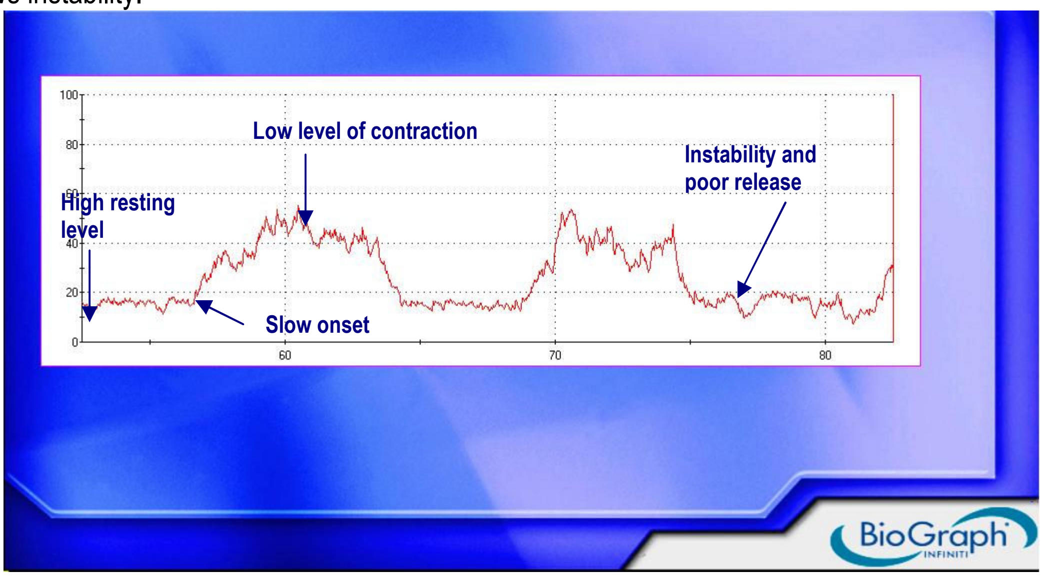
- Good skin preparation
- Impedance check
- Fixed electrode spacing (ideally 0.75 in or 2cm) between bilateral sites and from time to time
- Fixed location from time to time (ideally at the middle of the muscle belly)
- Notch filter enabled at the proper frequency (50Hz or 60Hz)
- Signal filtered between 20Hz and 500Hz
- Electromagnetic interferences minimized: keep the device 3 feet (1 meter) away from any electronic equipment and 10 feet (3 meters) away from any radio transmitting devices
- SEMG view properly chosen (raw, RMS, power spectrum etc …) for the intended use
- Consistency in the selection of hardware and software settings (signal processing settings, selected normalizations and statistics) from time to time.

Examples of Use

SEMG Biofeedback

SEMG Biofeedback is a powerful rehabilitation tool and is very popular in **physical therapy**. SEMG biofeedback involves measuring the patient's muscle tension and conveying it into an easily comprehensible visual and/or audio feedback. This raises their awareness and conscious control of their muscles, and creates an objective interaction between the patient and the SEMG signal. SEMG biofeedback motivates the patient to play an active role in the rehabilitation process. It also aids the therapist to instruct the patient more efficiently.

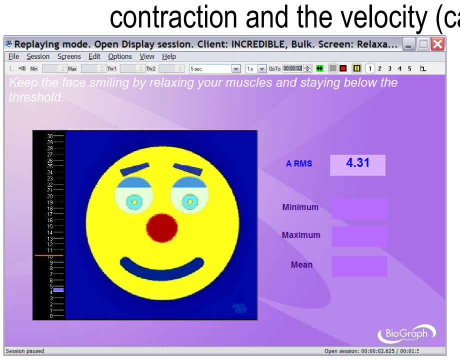
For instance, SEMG was recorded while a patient was performing few contractions. We can see on the figure below that the resting level is too high, the level of contraction is very low and the muscle shows instability.



EMG activity of an untrained muscle

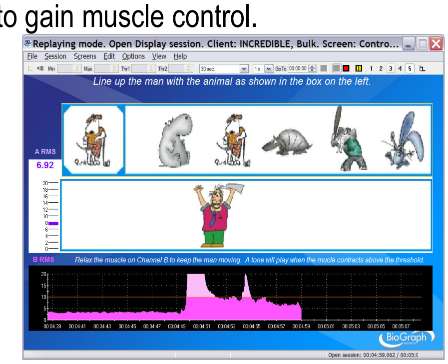
The high resting level indicates a higher muscle tone which, in most cases, will lead to muscle fatigue and/or muscle pain (the muscle never rests). In this case, the patient should first be trained to relax the muscle. If the patient has poor subjective recognition of the sensation of tension, biofeedback should be used to improve kinesthetic awareness.

Once the muscle is able to rest, the patient should progressively be trained to increase the level of contraction and the velocity (called "uptraining"), and finally be trained to gain muscle control.



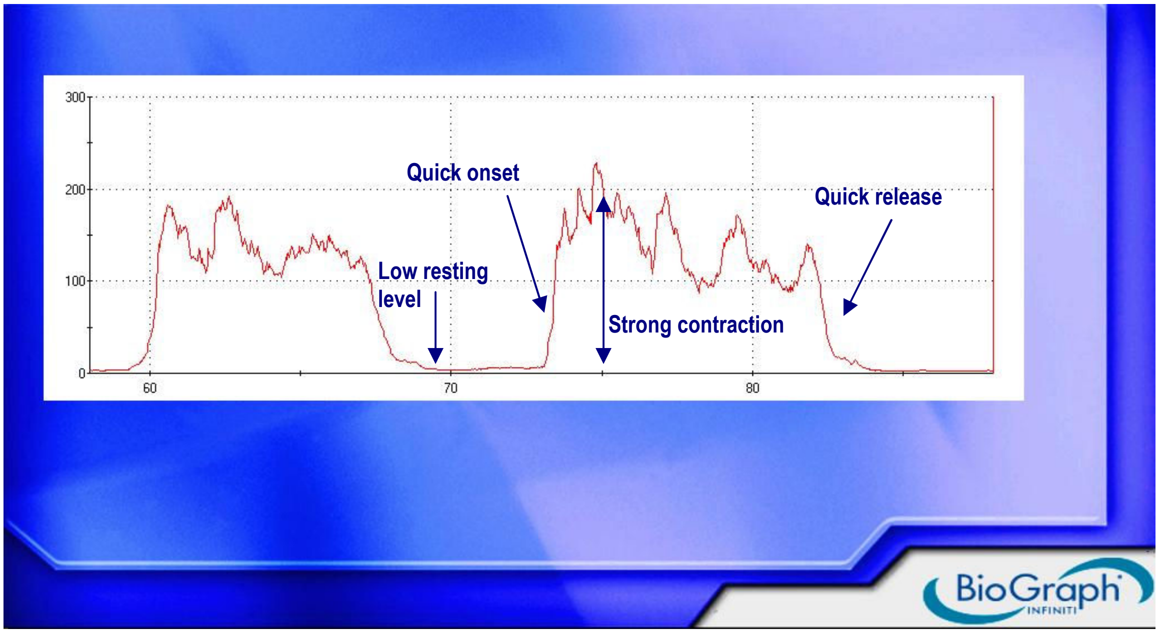
Relaxation: The face smiles when the EMG goes down.

Uptraining: The ball climbs the tubes when the signal goes up.



Control: The cartoon man must be lined up with the animal in the blue square.

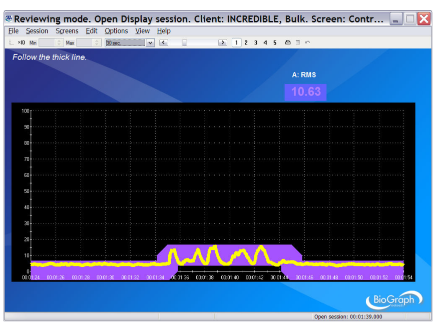
The next figure shows an SEMG recording of the same muscle after several sessions of biofeedback training. Resting level is low, onset and release are quick and the contraction is high.

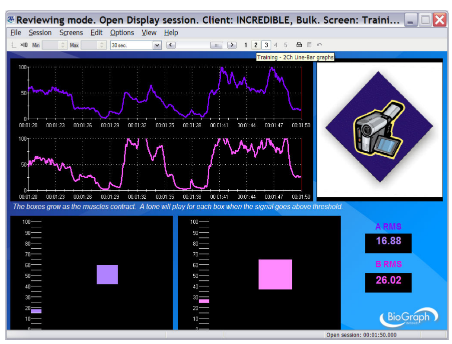


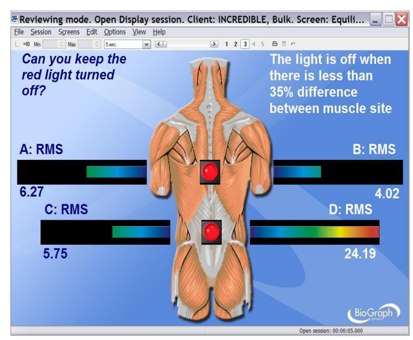
EMG activity of a trained muscle

Note: This is just an example for illustration and is not intended to be a norm for treatment.

Recovery of sensation, downtraining of hypertonic muscle, uptraining of hypotonic muscle, control/coordination of movements and improvement of posture are some of the numerous training exercises involving SEMG biofeedback. They usually require the monitoring of one to four muscle sites, but typically two, one for the agonist and one for the antagonist.







Recovery of sensations **Coordination Training** **Postural Training**

SEMG Biofeedback Screens from Thought Technology's Rehab Suite

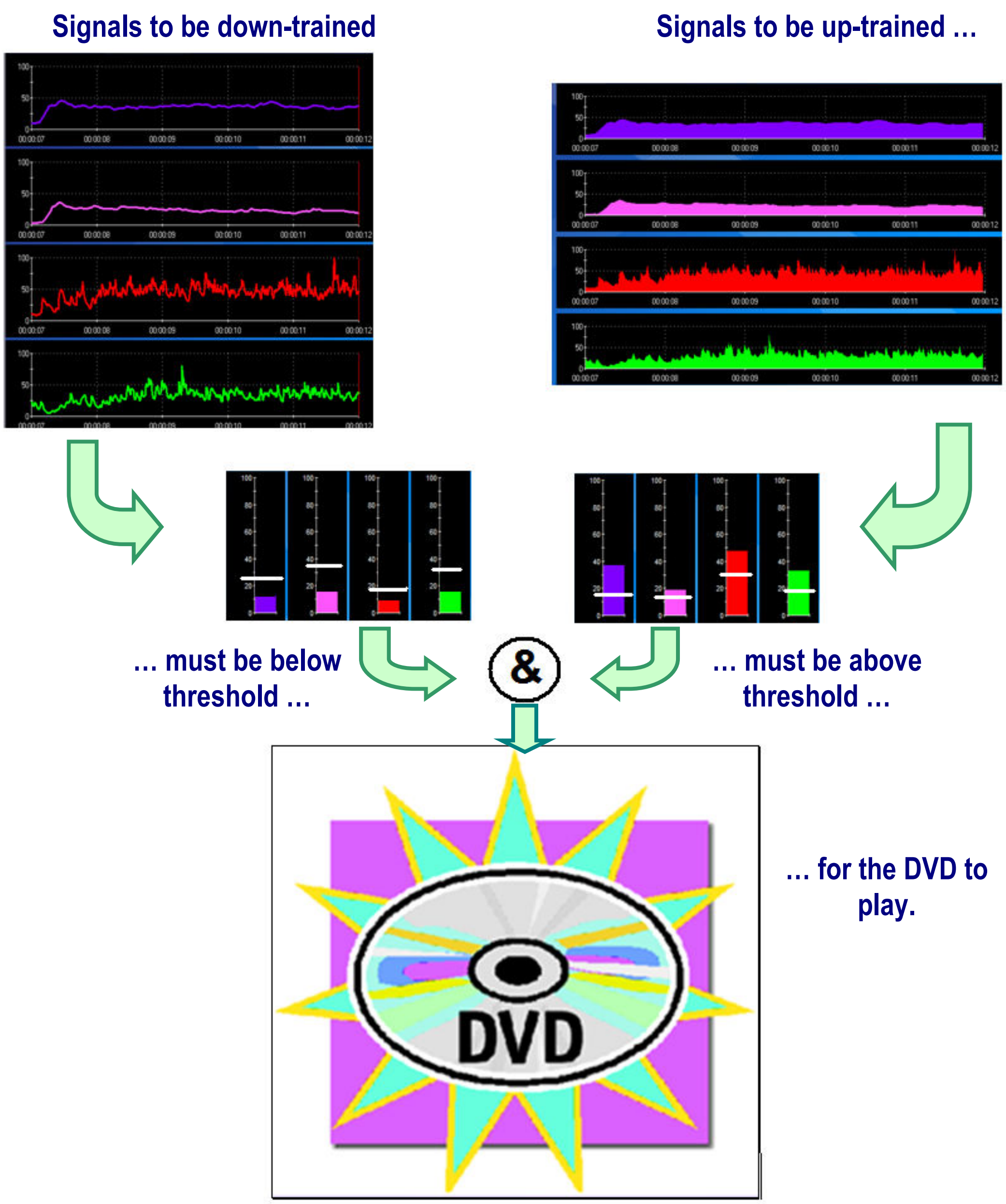
SEMG biofeedback is used in an advanced way in the **restoration of motor function**.

Motor function involves a group of numerous muscles working together in order to perform the movement. Providing independent feedback on each signal is acceptable when there are only a few (generally up to four). When the number of signals becomes significant, as in motor re-education, the patient may feel overwhelmed by the numerous graphs they have to look at and discouraged by the challenge they have to face.

Here, the feedback is given on the ensemble of the signals. The patient gets a reward only if all the muscles simultaneously follow their correct activation pattern. The muscles and their corresponding signals are sorted into two groups: the up-trained and the down-trained. The up-trained muscles are the ones that will be encouraged to fire, such as the agonist and synergists. The down-trained muscles are the ones that will be discouraged to fire, such as the antagonist or substitutes.

"The patient works to master the "feel" of the muscles when the video is on. Such a task is impossible if the patient needs to rely on watching the jumble of activity of 14 muscle readings on a monitor". (Dr Jeffrey Bolek, Cleveland Clinic Children's Hospital for Rehabilitation, 2007).

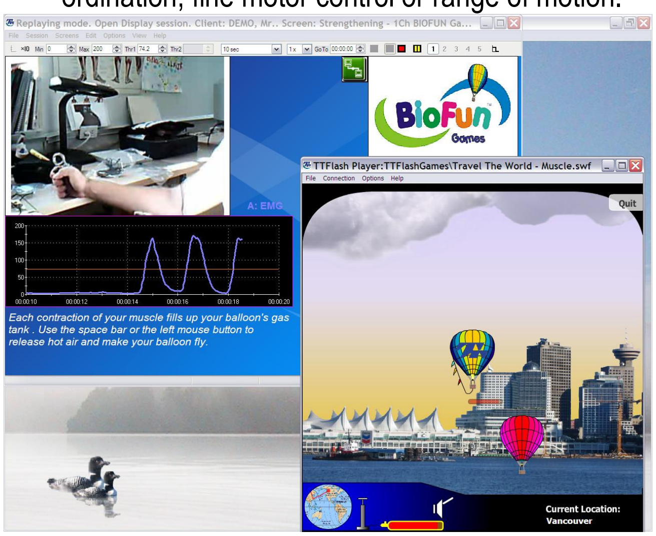
When the EMG of the up-trained muscles goes above a threshold and the EMG of the down-trained muscles goes below a threshold, the patient gets a reward. The reward must be motivating and varied.



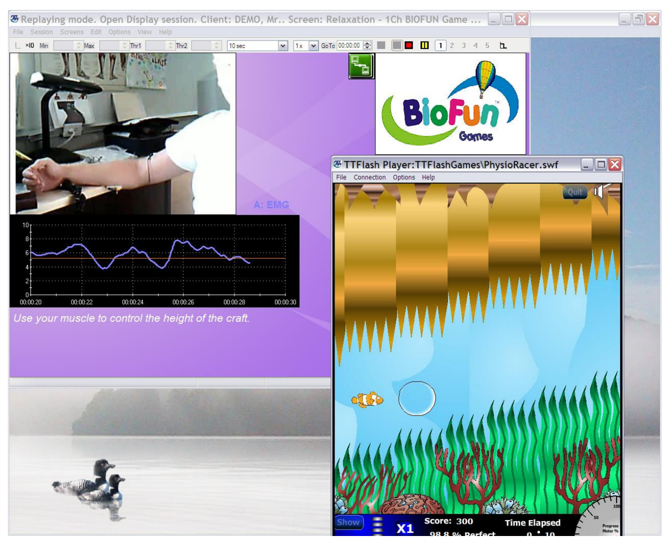
Example with 4 signals (screen from Thought Technology's Rehab Suite)

The above screen shows that the patient must relax the muscle connected to signal D (red bar at the bottom-right corner) to perform the correct movement. But the patient does not have to focus on "getting this red bar green, while keeping the 3 green bars green". They only need to focus on finding the way to get the DVD (firemen) to resume.

SEMG Biofeedback constantly evolves in order to increase patient's involvement in the therapeutic process. Physical rehabilitation is often seen as tedious, repetitive, difficult and boring. This may affect the patient's motivation and ultimately the effectiveness of the treatment. Video games are the latest feature added to biofeedback. The idea is that while the patient enjoys the game, they are getting their exercise. With these games, patients can improve muscle tension, strength, co-ordination, fine motor control or range of motion.



In this game, each successful repetition adds to fuel to the balloon tank. The patient can use this fuel to fly the balloon around the world and compete with the red balloon.



In this game, the patient controls a fish by contracting their muscle. While guiding it safely through the cave, the patient gains muscle control. They even can improve their fine motor control by catching bubbles on their way.

SEMG biofeedback is also used in **sports** to enhance the athlete's performance and Thought Technology's systems have a long and successful history in sports:

India's Olympic Gold Breakthrough

"I used the Infiniti System to train Abhinav for the air rifle competition in Beijing - India's first ever Olympic Gold. Shooting is a unique sport due to the lack of movement, and air rifle is the most precise and exacting of the shooting sports. I chose the Flex-Comp because it allowed me to move seamlessly between training modalities, and the BioGraph software because of its ability to measure and provide accurate biofeedback."

Timothy Harkness - Sports Psychologist

Italy's World Cup Winner - AC Milan

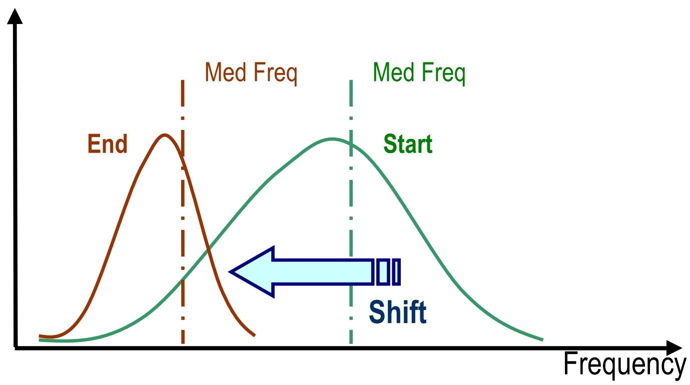
"Thought Technology's FlexComp Infiniti, ProComp Infiniti and BioGraph Infiniti are an essential component of the sports science in AC Milan's Milan Lab. Our ability to monitor muscle fatigue, as well as the psychological and physiological preparedness of our athletes in the Mindroom have allowed them to perform at their peak, and enabled he team to decrease injuries by 90%".

Bruno De Michelis Ph.D - Milan Lab AC Milan"

For more information, see: www.thoughttechnology.com/thewall1.htm.

SEMG & Muscle Fatigue Monitoring

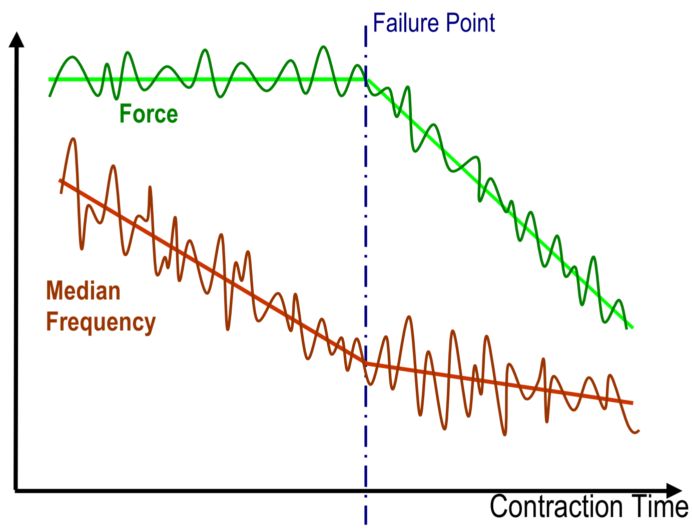
SEMG can be used as an indicator of muscle fatigue.
During **isometric submaximal contraction**, muscle fatigue is accompanied by a decrease in motor unit firing rate and conduction velocity.



EMG Power Spectrum over time

Thus the EMG power density spectrum shifts to the lower frequencies and, consequently, the median frequency and mean frequency decrease.

Median and mean frequencies are therefore considered as good indicators of muscle fatigue.
Median vs. Mean: Median frequency is found less sensitive to noise and signal aliasing and more sensitive to biomechanical and physiological factors, but more variable at lower frequencies (De Luca).

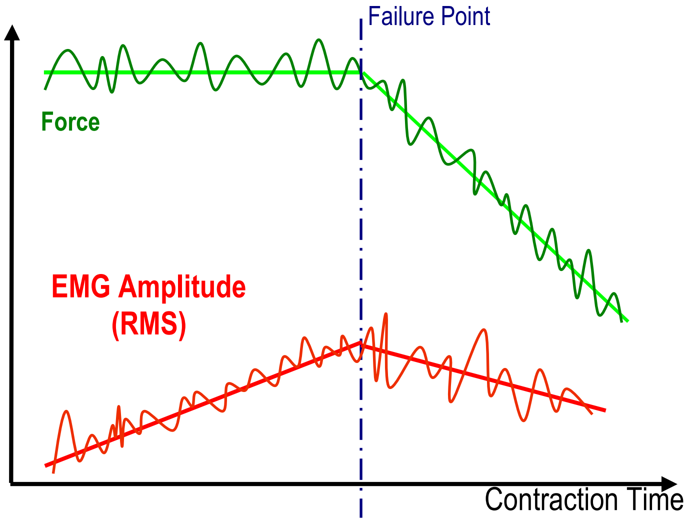


Contractile fatigue (force) vs. metabolic fatigue (EMG median frequency)

With EMG, fatigue can be detected **before** the failure point, at which the contractile force can no longer be maintained. While force remains constant, the median frequency starts decreasing. Force monitors the contractile fatigue, EMG monitors the metabolic fatigue.

This is a very important control parameter for **prevention of injury or re-injury** in clinical, ergonomics and sports applications.

As the muscle fatigues, additional fibers must be recruited in order to generate the same force. This results in an increase of the EMG amplitude.

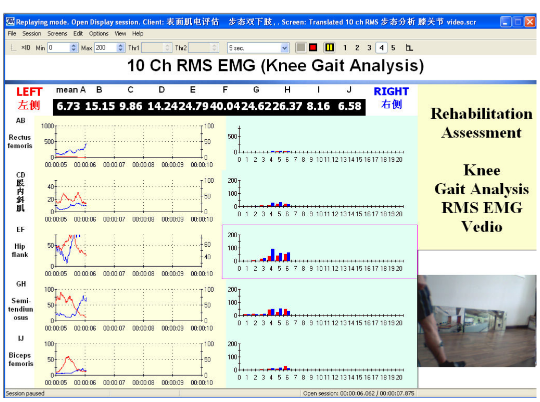


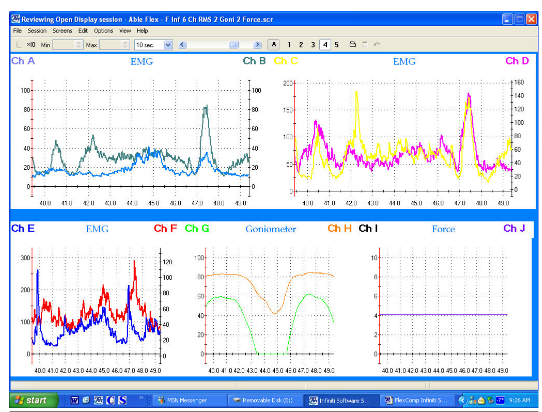
EMG amplitude increasing with fatigue

EMG amplitude as a fatigue indicator is used when movement is required, such as in fitness exercises. Note that fatigue is not always something that we want to prevent. For instance, in muscular training, short-term fatigue is a necessity for muscle growth and is actually looked for.

SEMG & Joint Motion

SEMG is used in gait analysis for describing the relation between muscle activity and the mechanical aspect of the joint motion.
Angular motion is monitored with goniometers (usually hip, knee or ankle), gait phases (swing and stance) are marked with foot switches on heel and toe.
Video cameras are also used to record and mark the different events of the motion.





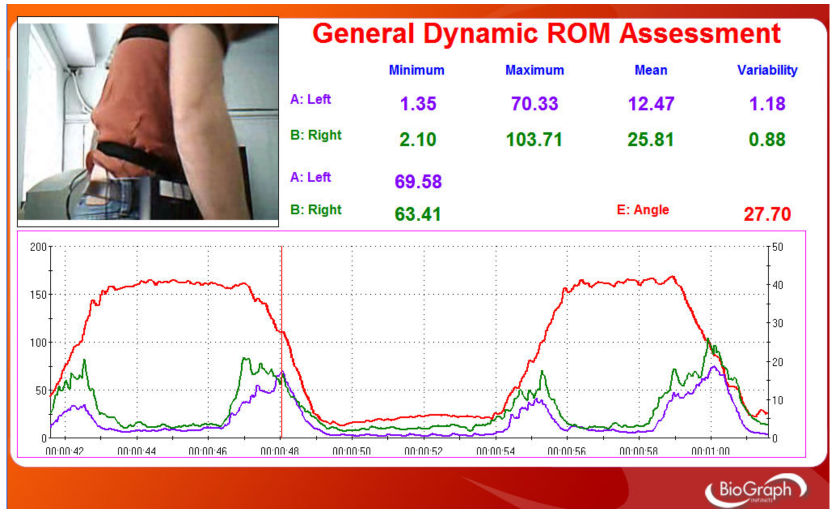
Screen from Thought Technology's DynaMap Suite

Thought Technology's adapter for Biometrics' torsiometers and goniometers

SEMG in Range of Motion Assessment

In range of motion assessment, the combination of inclinometry and SEMG allows the examiner to assess the contribution of the muscles at every phase of the movement: it highlights hesitation in the movement, and how and when the muscles fire.


Thought Technology's dual-inclinometer



Inclinometry (red line) with 2 SEMG and video for lumbar flexion/extension (screen from Thought Technology's Rehab Suite)

SEMG in Muscle Testing

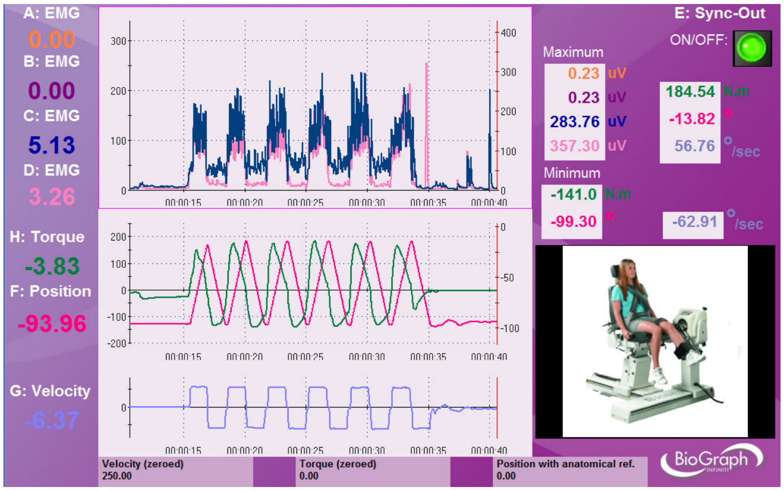
In muscle testing, it can help the examinee to perform the right movement by providing feedback on unwanted muscle activation. It can also help the examiner to document potential muscle substitution.

Muscle testing with SEMG biofeedback (screen from Thought Technology's Rehab Suite)


Thought Technology's muscle tester

SEMG with Isokinetic Dynamometers

Its use in conjunction with isokinetic dynamometers has become very popular in research as well as in clinical settings.



Biodex System interfaced with Thought Technology's Infiniti hardware and BioGraph Infiniti software

Real-time physiology monitoring (such as SEMG, heart rate and respiration) is an important asset to the data provided by the isokinetic machine (position, torque and velocity).

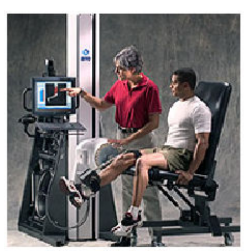
It provides the examiner physiological data to validate the effectiveness of the training and helps the examinee to modify their physiology (breathing patterns, muscle activation patterns …) in real time during the training.

Regarding SEMG, it allows the evaluation of the activity of muscles or muscle groups during the movement (contraction intensity, timing, sequence of firing and local muscle fatigue) and to correlate them to the phases of the exercise (isometric, isokinetic, isotonic, concentric or eccentric). SEMG biofeedback motivates the patient to play an active role in the rehabilitation process.

The following isokinetic machines can be interfaced with SEMG: Biodex System 3 & 4, LimbGym, CSMI Humac/Cybex Norm, BTE Technologies and Con-Trex.

Biodex System 4

CSMI Humac/Cybex



BTE Technologies

Con-Trex

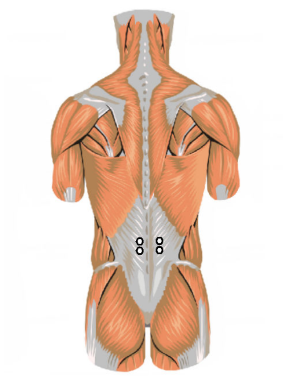
LimbGym

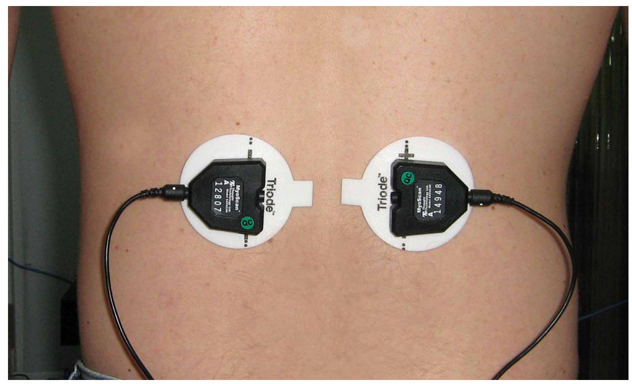
SEMG with MyoRack System

MyoRack System

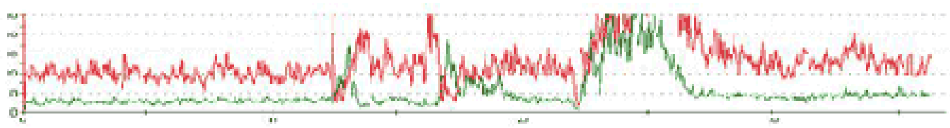
The MyoRack was developed to assist the rehabilitation, maintenance and enhancement of the musculoskeletal system of a human lower back via stretching, strengthening and silencing (relaxing) the muscles. This machine is used by trained personnel to treat existing back problems, strengthen people at risk for back problems and to enhance physical performance.

SEMG uses electrodes placed on the skin to measure the electrical activity of the muscles when contracting.





This form of treatment is used to document muscle function in the assessment and treatment sessions.

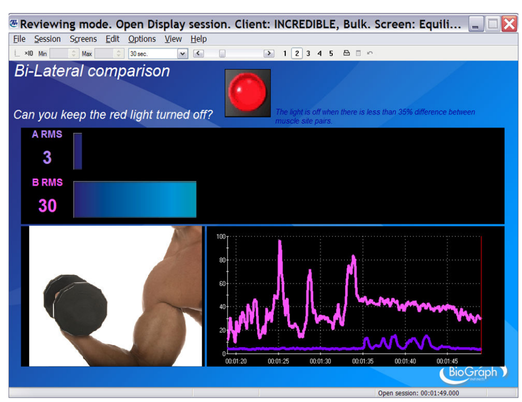


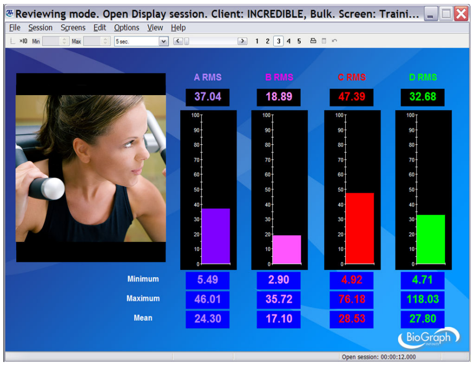
SEMG for Fitness Training

If well understood, SEMG is a valuable asset to strength and conditioning by providing unique information regarding muscle activity.

SEMG allows the examination of muscle fatigue before the force generated by the muscle decreases.

It may also be useful to monitor changes in activation/co-activation during strengthening programs (for instance, increased activation of the agonist and decreased activation of the antagonist).





SEMG Biofeedback can be used to ensure that the trainee maintains a good posture during the exercise. For instance, feedback could be given on bilateral difference or muscles that should be activated very little or not at all.

SEMG can also be used to examine muscle coordination and timing during multi-joint exercises.

SEMG in Ergonomics

SEMG is one of the methods used to assess a workplace and the effects of a task or position on the worker's muscles for optimization of the task and prevention of injuries. It is also used for tool design.

The most common use of SEMG is the evaluation of the on-off state of the muscle throughout the task, for different speeds of movement and various experimental conditions.
SEMG shows which muscles are being recruited at every phase of the task.

The level of recruitment (amplitude) of each muscle can also be of interest of the ergonomics researchers. SEMG is usually normalized to MVC.

Muscle fatigue assessment has lately become very popular and showed very good results in ergonomics studies.

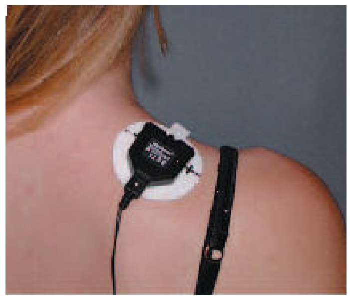
Example: Repetitive Strain Injury, Computer User Injury With Biofeedback: Assessment and Training Protocol *by Erik Peper, Ph.D.San Francisco State University,San Francisco, CA*

Biofeedback machine attached to her right arm, staff member Sarah Chaput listens as Erik Peper describes proper posture for healthful computing

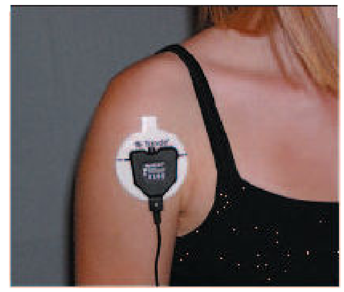
Improper work habits, poor workstation ergonomics, and environment can lead to physiological dysregulation such as muscle soreness, fatigue, and injury (Grandjean, 1987). Some workers develop chronic neck and upper limb pain also known as repetitive strain injury. (RSI), cumulative trauma disorder (CTD) or overuse syndrome, from long hours of repetitive tasks at personal computer workstations. Workers with RSI suffer loss of productivity and income with increasing medical costs. RSI accounted for forty percent of workers compensation cases in 1990. Discomfort and injury can shape the way PC users feel about their job and computers.

Computer users can learn preventative skills to sense muscle tension and incorporate relaxation and regeneration of muscles during data entry and mouse use. SEMG can be used to monitor specific muscle sites and to warn the user of excessive strain or overuse habits that can lead to chronic pain or injury. Mastering this process reduces the risk of RSI.

Forearm extensors



Upper Trapezius



Anterior-medial Deltoid

Illustration of the three common electrode locations - Courtesy of Erik Peper

About Research …

SEMG has not yet revealed all its benefits and Thought Technology supports research projects all over the world.

Thought Technology is the proud sponsor of the **Biofeedback Foundation of Europe**, which manages numerous research and educational projects throughout the world.

See www.bfe.org for more information.

Astronaut Ron Garin wearing the FlexComp Infiniti™ photographed by Canada's Dave Williams during the NEMO NINE undersea mission.

For decades, **NASA** has been studying astronauts' physiological responses to zero gravity, to living in outer space and to staying in a space vehicles and space stations for extended periods of time. NASA recently conducted underwater research since the environment provides some useful similarities to working in space, using off the shelf technology, developed by THOUGHT TECHNOLOGY LTD of Montreal.

NASA's Toscano commented on the extreme research environment and air pressure, "at 65 feet is about 2.65 atmospheres) -- different from at the surface. There were questions of whether the instrument would function, would it work? And it did, with flying colours!"

See www.thoughttechnology.com/nasa.htm for more information.

A Typical Procedure

Preparing the Examining Room

Electromagnetic Interferences

The EMG sensors are capable of detecting very tiny electrical signals (millionths of a Volt) generated by the human body. Therefore they are very sensitive to electromagnetic fields generated by other devices in the exam room, such as radio transmitting devices, computer monitors, medical devices (for example x-ray machines), and fluorescent, halogen or neon lights.

These devices should be turned off, if they are not needed for the examination. If the situation arises, keep the instrumentation 10 feet away from radio transmitting devices and 3 feet away from electronic devices (including monitors) and fluorescent, halogen or neon lights.

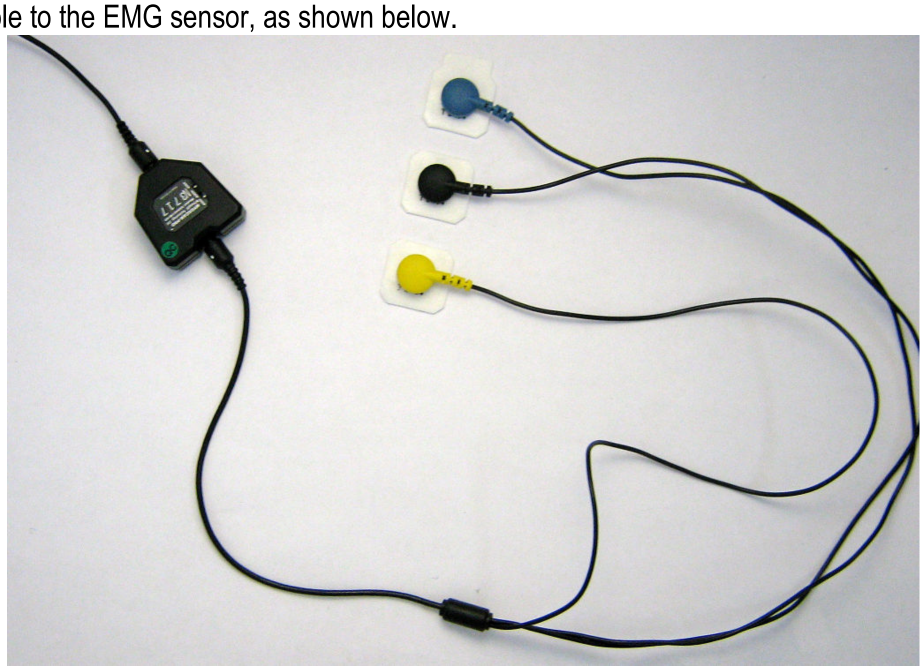
Disconnect all the unused sensors from the encoder. If not connected to the examinee, they may act as antennas and capture unwanted signals that would corrupt the EMG signal.

Electrostatic discharges

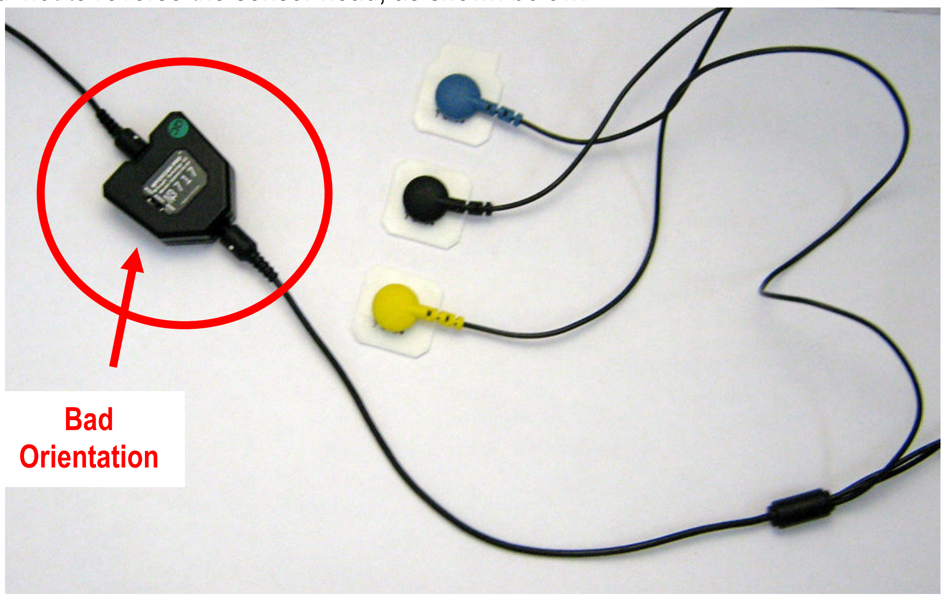
To prevent static discharge from damaging the sensor and/or encoder, use anti-static mats or sprays in your working area. A humidifier may also be used to help prevent static environments by conditioning hot, dry air.

Preparing the Examinee

- Explain the procedure to the examinee.
- Identify the muscle sites you want to monitor.
- Abrade the skin. Make sure the skin surface is clean and dry. If necessary, shave excess body hair.
- If you use an EMG extender cable, snap the electrodes on it. Then connect the extender cable to the EMG sensor, as shown below.



Be careful not to reverse the sensor head, as shown below:

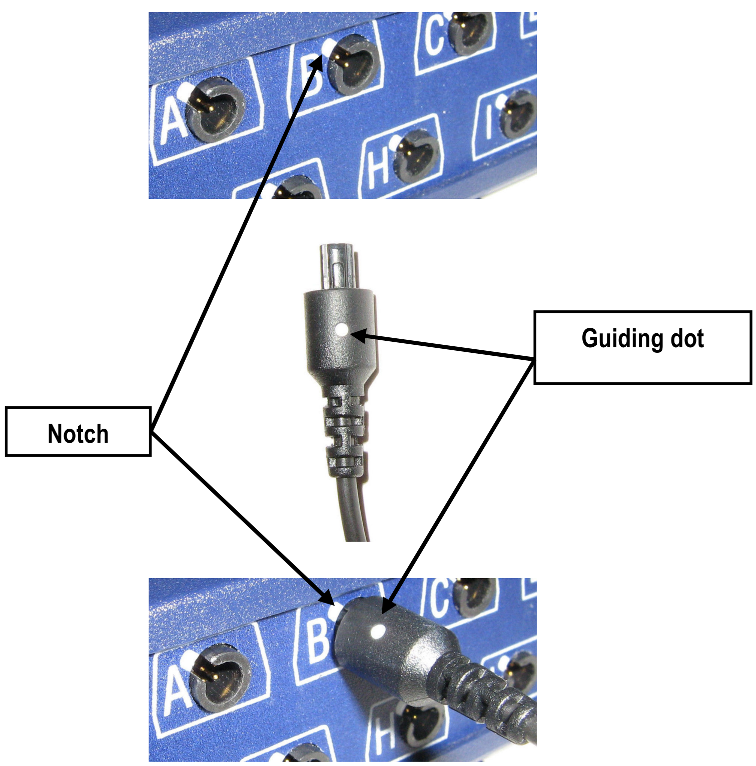


Incorrect hook-up

- Place the electrodes on the examinee.

Connecting the Sensors to the Encoder

When connecting an EMG sensor to the encoder, make sure to properly line up the guiding dot on the top of the plug with the notch in the device's input socket.



Forcing the plug into the jack in any other position may damage your equipment.

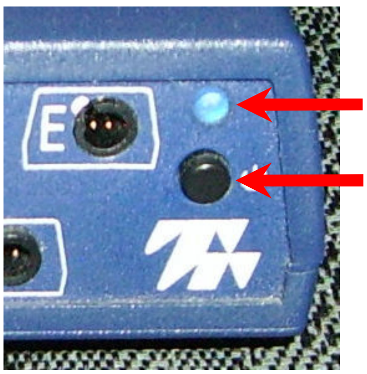
Starting a Session

Before You Start

Open BioGraph Infiniti, and select your client and your screen/script.
When you are getting ready to launch a recording, you may want to perform one or more of the following functions:

- Edit a display screen with the Screen Editor: *Screens* menu
- Verify the battery level: *Options* menu
- Check the electrode impedance (MyoScan-Z users only): *Options* menu
- Zero your sensor(s) (MyoScan-Pro users only): *Options* menu
- Predefine the statistics for an open display session: *Edit* menu

Checking the electrode impedance (MyoScan-Z users only)



From the **Options** menu of the Recording Screen, select **Impedance Check**. This opens the **Impedance Check** window.

Then, trigger impedance checking from your encoder. To do this:

- Ensure that the encoder's **power light** is on.

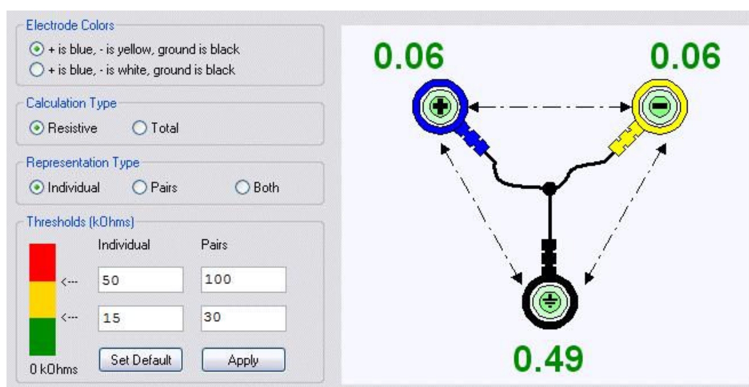
- Press and hold down the **power button** for about 3 seconds, or until the power light starts blinking.

When the power light begins to blink, impedance checking mode is active.

The graphic display shows the impedance values of the selected sensor in green, orange or red.

- Green indicates a low value.
- Orange indicates a medium value.
- Red indicates a high value.

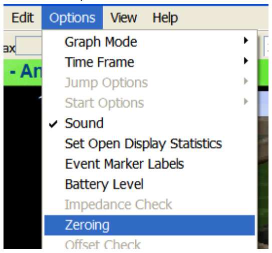
Ideally, all three measurements should display in green.
For more information about impedance checking, press F1 to consult the on-line help.



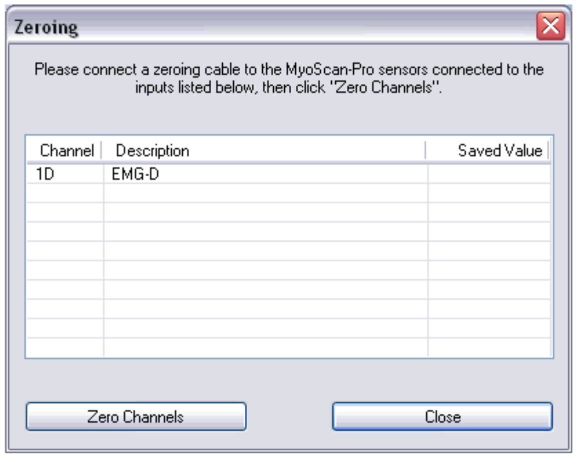
To exit impedance checking mode, press the power button down for about 3 seconds, or until the power light stops blinking.

Zeroing MyoScan-Pro Sensor

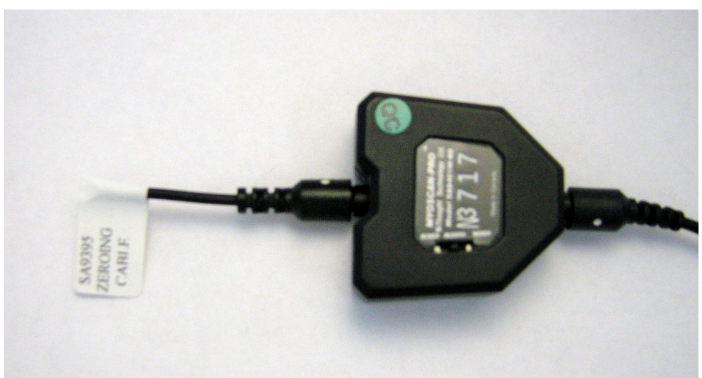
When using MyoScan-Pro sensors, it is a good idea to zero their physical channels every few weeks, in order to make sure that you get the most reliable EMG measurements possible.



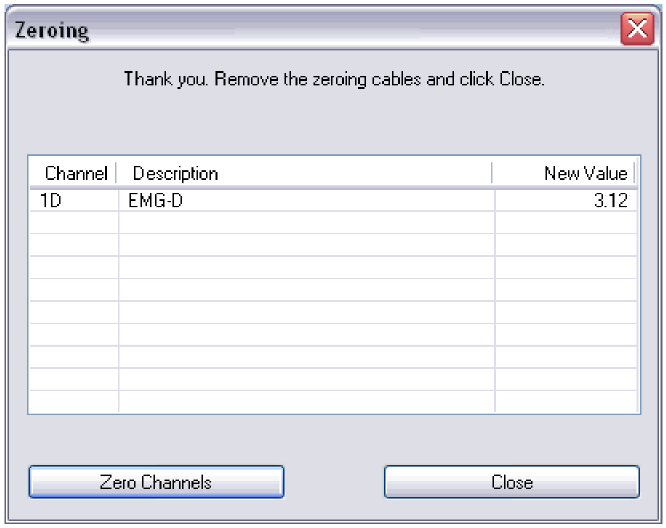
When you click on the *Zeroing* item from the *Options* menu, the program opens this dialog box and asks you to connect a zeroing cable onto each MyoScan sensor before you click on the *Zero Channels* button:



The zeroing cable (or zeroing clip) is a small plug with a short piece of cable coming out of it. (It is included as a component of the MyoScan-Pro sensor package.) It connects to the extender cable socket, on the sensor, as shown below. When it is connected to the sensor, the sensor should read zero microvolts.



When all the sensors have a zeroing cable connected, click the *Zero Channels* button. Within a few seconds, the program shows a *New Value* column, where the *Saved Value* was and the message, at the top of the dialog box, confirms that all sensors have been zeroed and reminds you to remove the zeroing cables and click *Close*:

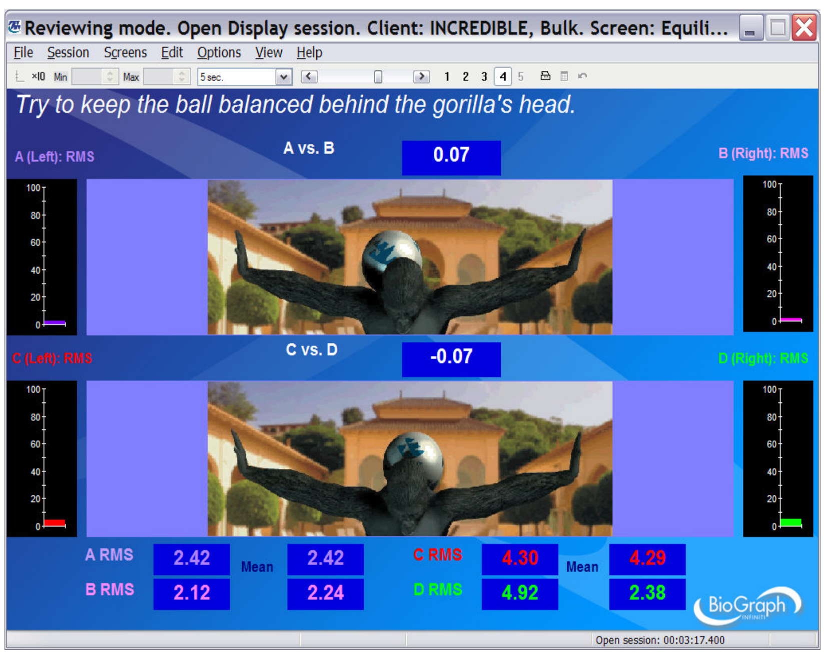


The zeroing information is saved as part of the channel set data, so the sensors do not have to be zeroed for every screen of a given channel set, **as long as you always connect the same sensor to the same encoder input**. If you have several MyoScan-Pro sensors, it might be best to label each one with the corresponding encoder Input letter. If you use screens that use other channel sets, then, of course, you have to zero the channels of this channel set as well.

Disconnect the Zeroing Cable before using the sensor.

Recording

From the Main Frame Screen, you can then start recording a session by clicking on the *Start* button:



SEMG Biofeedback Screen from Thought Technology's Rehab Suite

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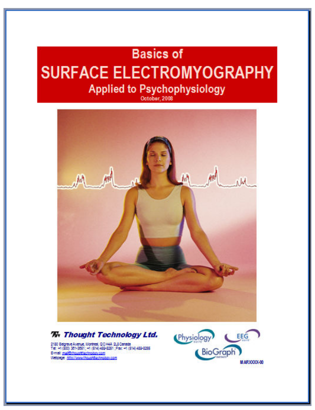

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Web Sites

- **Biofeedback Foundation of Europe (BFE)**: www.bfe.org
  The Biofeedback Foundation of Europe sponsors education, training and research activities in biofeedback. The BFE is entirely supported by fees and gifts from corporate and non-profit members and from revenues generated by the sale of conferences, workshops, internet courses, courseware and books. The BFE supports activities in Europe, North & South America, Asia and Africa.

- **SENIAM project:** www.seniam.org
  The SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) is a European concerted action in the Biomedical Health and Research Program (BIOMED II) of the European Union.

- **International Society of Electrophysiology and Kinesiology (ISEK):** www.isek-online.org
  The International Society of Electrophysiology and Kinesiology (ISEK) is a multidisciplinary organization composed of members from all over the world in health-related fields and basic science with a common desire to study human movement and the neuromuscular system.