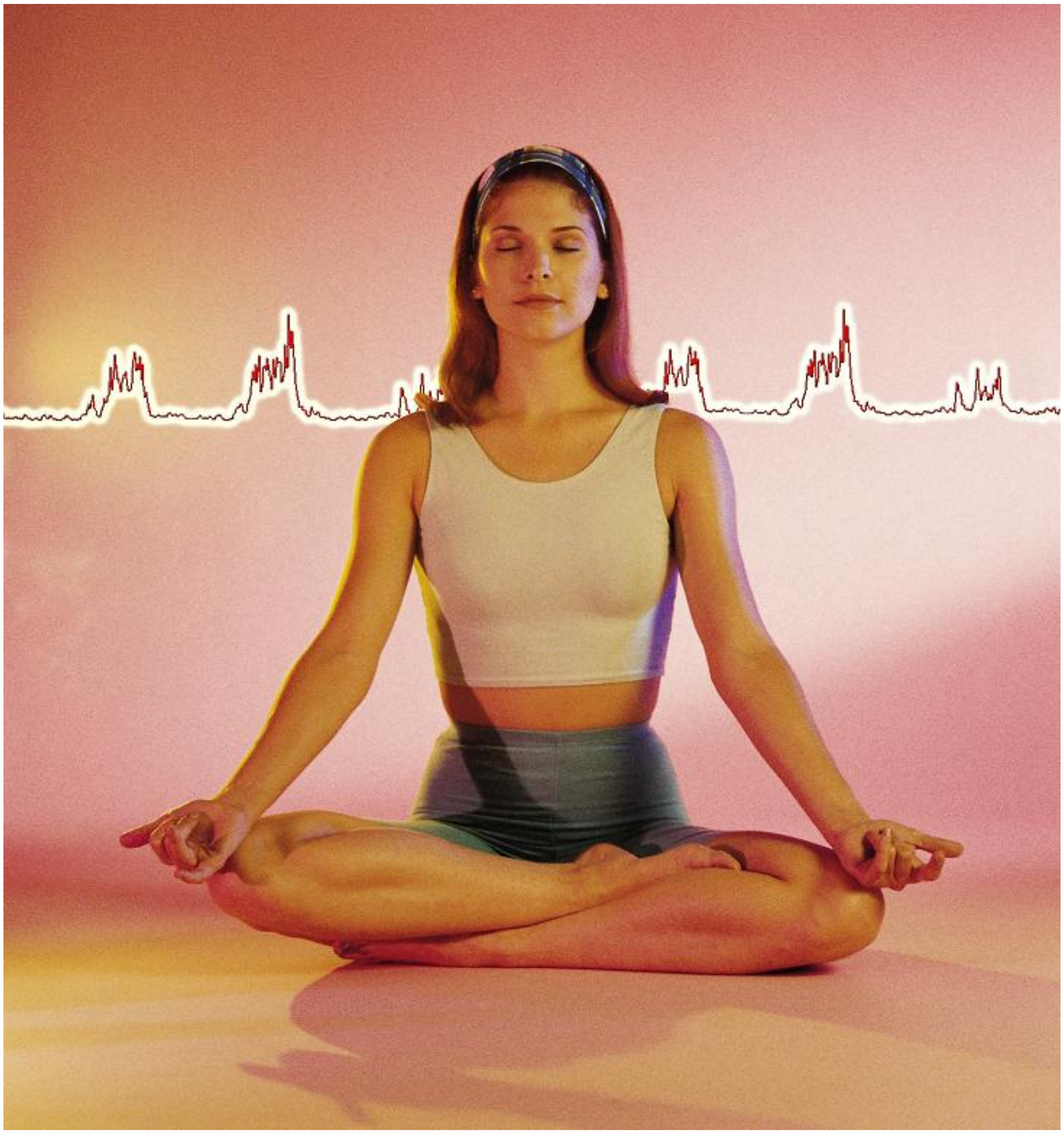
# Basics of
# SURFACE ELECTROMYOGRAPHY
## Applied to Psychophysiology

October, 2008



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# Table of Contents

# Introduction

This document was written to assist you in using of surface electromyography in clinical biofeedback as a form of **applied psychophysiology**.

**S**urface **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.

SEMG is clinically indicated for:

- Biofeedback
- Relaxation
- Muscle re-education

Surface electromyography is also widely used in many other applications, including other clinical biofeedback applications such as SEMG biofeedback in physical rehabilitation.
These applications are:

- 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)

"As Basmajian (1967) suggests the SEMG signal not only indicates the status of a muscle, but also tells us about the status of the nervous system serving the muscle" (Donaldson Stuart, Donaldson Mary & Snelling Leslie, 2003).
"Psychophysiology involves the scientific study of the interrelationships of physiological and cognitive processes" (Mark S. Schwartz, 2003).

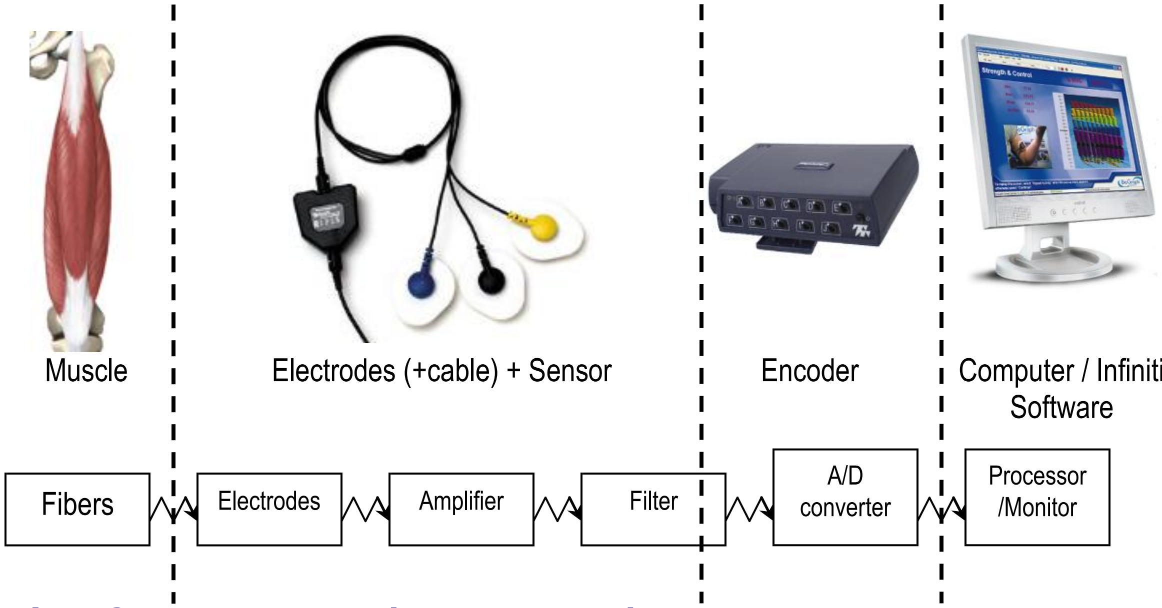
Whereas these applications focus on the **biomechanical aspects** of muscle activity, psychophysiology mainly focuses on the muscle activity **in response to emotions**. The assessment and treatment goals of these applications, and consequently, their use of SEMG, are dramatically different.
Therefore these applications are 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.

# 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".

- **ProComp2** has 2 channels (C and D) sampling at 32 samples per second and 2 channels (A and B) sampling at 256 samples/second.
- **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.

**ProComp2** **ProComp5 Infiniti** **ProComp Infiniti** **FlexComp Infiniti**

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 (amplifiers) are:

- **MyoScan (SA9503M)/ MyoScan-Z (SA9503Z)** which amplify and output **raw SEMG**.
- **MyoScan-Pro (SA9401M)** which amplifies raw SEMG and converts it to **RMS SEMG**. This is the sensor commonly used for applied psychophysiology.

**MyoScan (SA9503M)**
**MyoScan-Z (SA9503Z)**

**MyoScan-Pro (SA9401M)**

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, on channels C to E of ProComp5 Infiniti, and on channels C and D of ProComp2.

| **ProComp2** | **A** 256samp/s | **B** 256samp/s | **C** 32samp/s | **D** 32samp/s |
|---|---|---|---|---|
| **MyoScan or MyoScan-Z** | | | | |
| **MyoScan-Pro** | | | ☑ | ☑ |

| **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** | | | | | | | | | | |

Since MyoScan-Pro is the sensor commonly used in psychophysiology, the rest of the document will illustrate SEMG with MyoScan-Pro only.

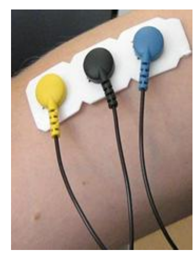
# Surface Electrodes & Cables

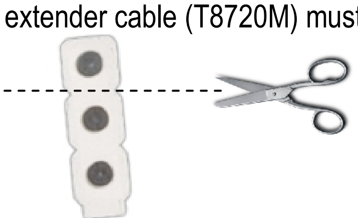
The silver-silver chloride electrodes are the part that is in contact with the skin and makes electrical contact between the skin and the sensor. The electrodes are either directly connected to (or "snapped on") the sensor, or indirectly connected via an extender cable. Thought Technology proposes various 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 the pollution of the SEMG signal by surrounding electromagnetic fields and movement artifacts generated by wires being pulled.

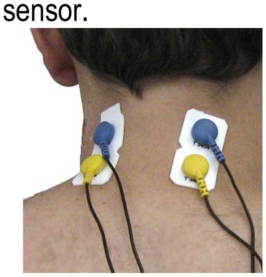

The distance between the electrodes is optimal for avoiding or limiting muscle crosstalk.
However, its size does not make it adequate for long and thin muscles with great deformation while contracting, or for wider placements. In this case, the choice of another electrode type should be considered.

**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 electrodes can also be cut, 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.



**SA2306 - EMG Headband (re-usable for a single client only):** the EMG Headband enables easy EMG measurement from the forehead (frontalis), which is one of the common EMG placements for stress/relaxation biofeedback. The headband has 3 snap electrodes (Ag-AgCl) that work with the EMG Extender Cables (T8720M).

# 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, or use an alcohol wipe and let it dry.
If necessary, shave excess body hair.

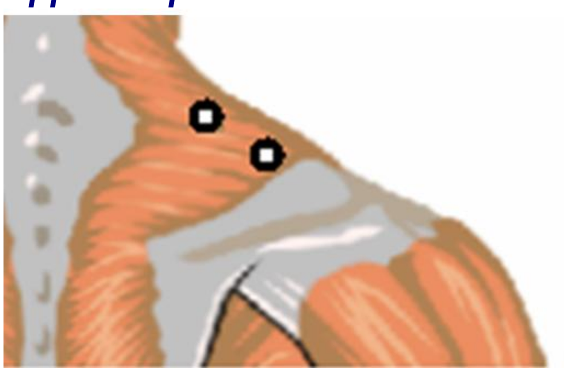
## *General Recommendations for Positioning the Electrodes*

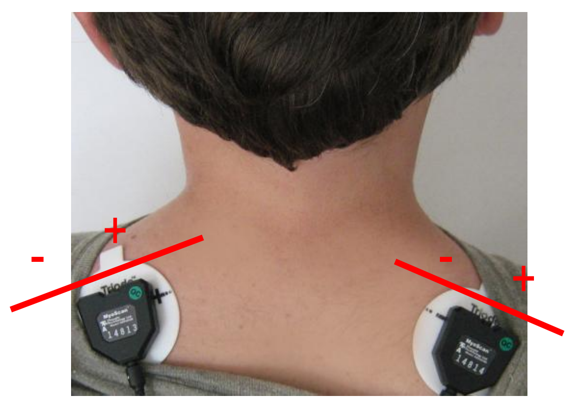
If you use single electrodes, place the active electrodes first (blue and yellow). Then place the reference electrode (black connector) anywhere on the body. The active electrodes should be placed in line with the muscle fibers, unless specified otherwise.

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


It may be recommended to put conductive electrode paste or cream on the center of electrodes (grey area only) before applying them to the skin.

## *Upper Trapezius Placement*



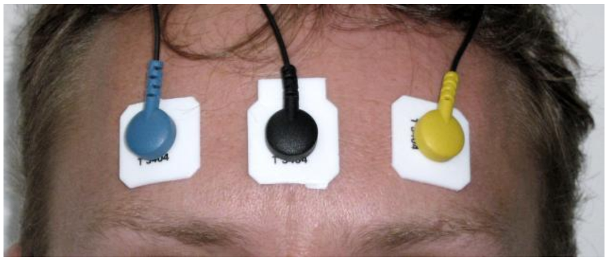



**Purpose:** monitoring of movements of the shoulders.

**Commonly used in psychophysiology for:** stress assessment, general relaxation, recording of activity related to headaches, prevention of repetitive strain injury.

**Location:** see pictures above.

## *Frontalis Wide Placement*



With single electrodes and extender cable

With EMG head band

**Purpose:** monitoring of facial muscle activity.

**Commonly used in psychophysiology for:** stress assessment, general relaxation.

**Location:** reference electrode in the center, active electrodes above the iris of the eyes.

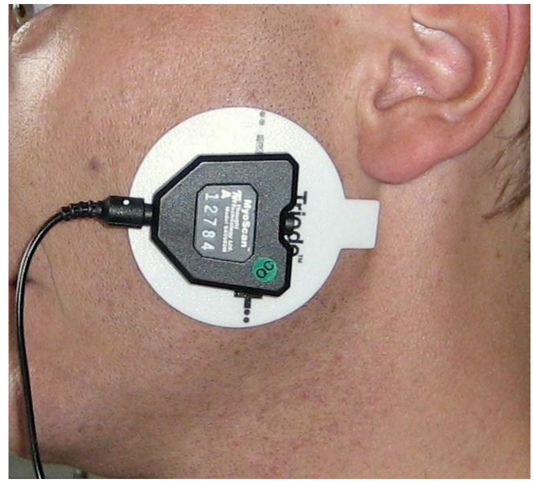
## *Frontalis Narrow Placement*

**Purpose:** monitoring of facial muscle activity.

**Commonly used in psychophysiology for:** recording of activity related to emotions.

**Location:** active electrodes half way between the eye and the hair line, reference electrode on top.

## *Masseter Placement*

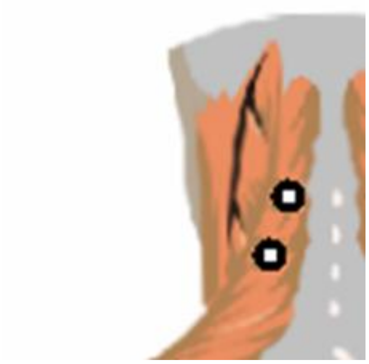


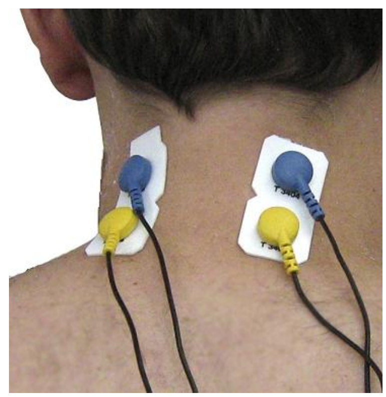
**Purpose:** monitoring of the grinding of the jaw.

**Commonly used in psychophysiology for:** stress assessment, recording of activity related to anxiety.

**Location:** see pictures above.

## *Cervical Paraspinal (CP) Placement*





**Purpose:** monitoring of neck muscle activity.

**Commonly used in psychophysiology for:** stress assessment, recording of activity related to headaches.

**Location:** see pictures above.

## *Forearm Extensor Placement*

*Courtesy of Erik Peper*

**Purpose:** monitoring of static muscle effort.

**Commonly used in psychophysiology for:** stress assessment, prevention of repetitive strain injury.

**Location:** see picture on the left.

## *Anterior Deltoid Placement*

*Courtesy of Erik Peper*

**Purpose:** monitoring of static muscle effort.

**Commonly used in psychophysiology for:** stress assessment, prevention of repetitive strain injury.

**Location:** see picture on the left.

**Erik Peper, Ph.D.,** International authority on biofeedback and self-regulation. He is Professor and Director of the Institute for Holistic Healing Studies at San Francisco State University and President of the Biofeedback Foundation of Europe, past President of the Biofeedback Society of America, now Association for Applied Psychophysiology and Biofeedback, and Biofeedback Society of California. He is co-author of Healthy Computing - a biofeedback software protocol to prevent the risk of injury from working with computers and the recent book ***Muscle Biofeedback at the Computer***.

# 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.

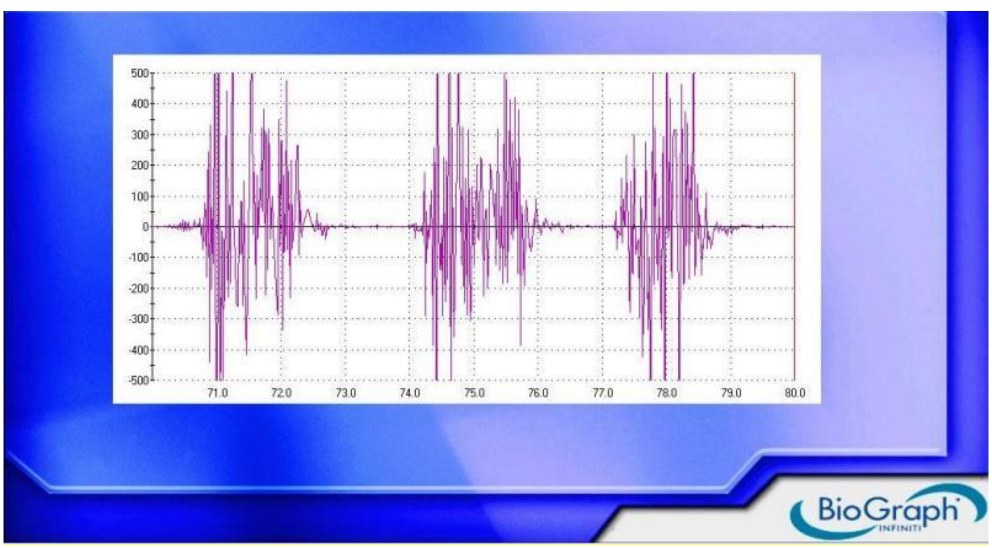



**Fig. 1. Raw EMG (three contractions)**

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.

The raw signal is then captured and rectified by the MyoScan-Pro sensor using RMS.

**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 shows an RMS signal.

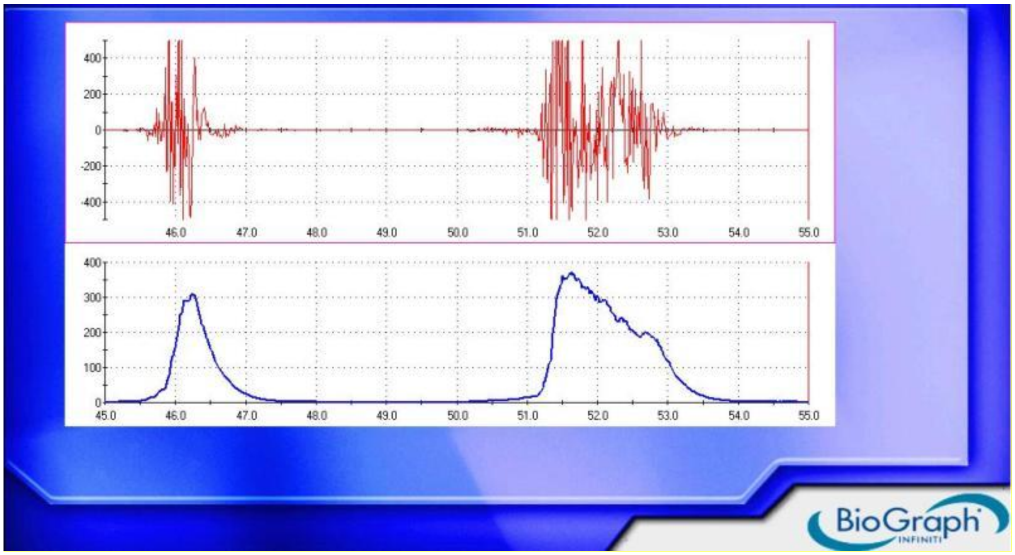



**Fig. 2. Raw EMG in red (top) and equivalent RMS EMG in blue (bottom)**

# 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.

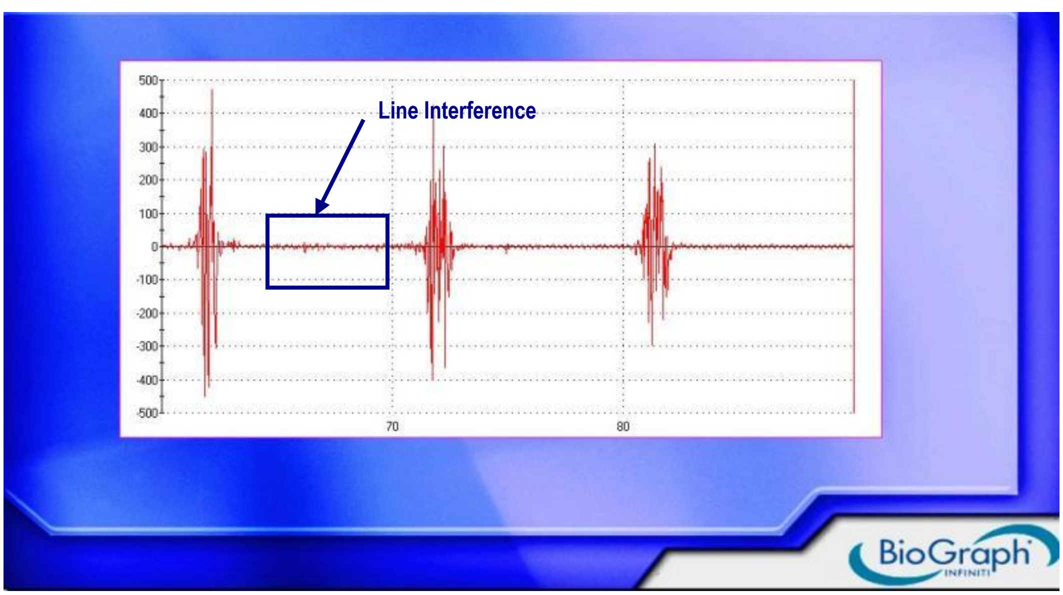



**Fig. 4. Raw EMG signal with line interference**

The MyoScan-Pro fixes the problem 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; The MyoScan-Pro is configured in factory for rejecting either 60 or 50Hz).

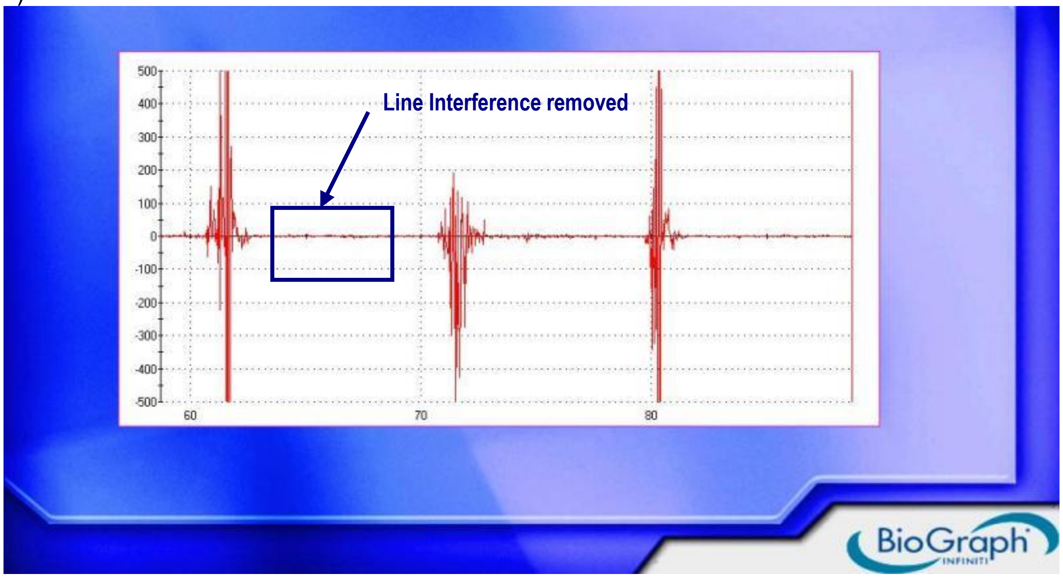



**Fig. 5. Raw EMG signal with Notch filter**

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. 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 SEMG signal.

### - EKG (ECG) artifacts:

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

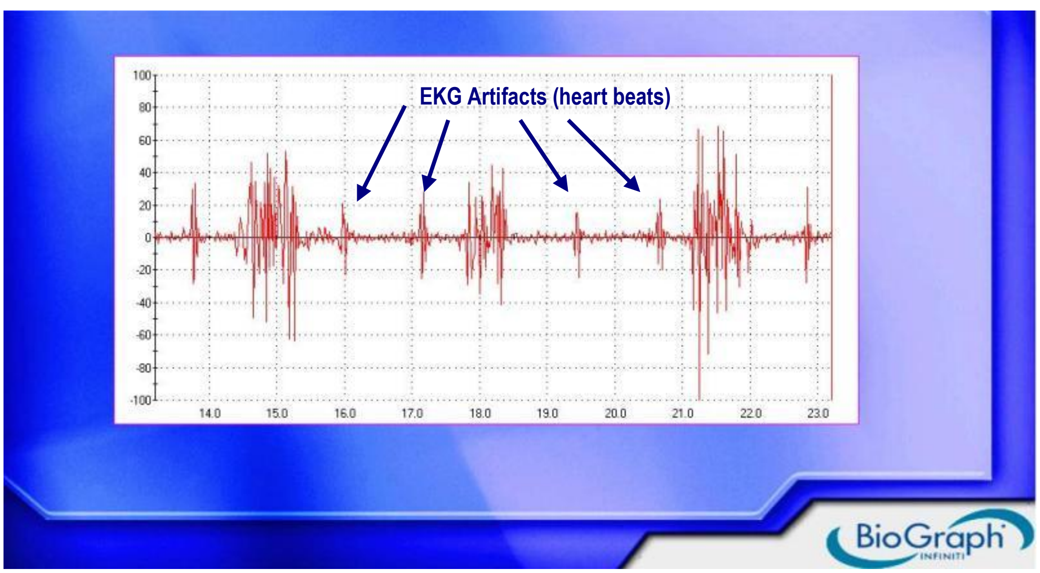



**Fig. 6. Raw EMG signal with EKG artifact**

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.

**- 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) that can be seen as high readings in the RMS signal. Proper skin preparation and firm placement of electrodes on the skin generally prevent the problem. If necessary, a small amount of conductive gel can be added.

**- Muscle crosstalk:**
Muscle crosstalk is caused by EMG signals coming from other muscles than the one(s) 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, which may create artifacts in the EMG signal. An example can be seen in Figure 7.

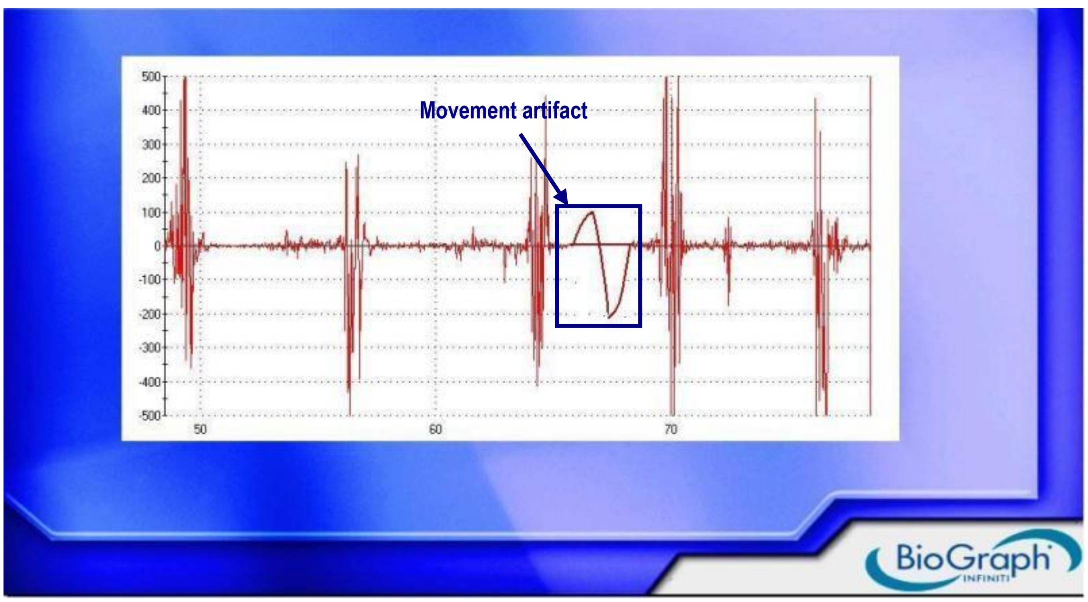



**Fig. 7. Raw EMG signal with movement artifact**

An artifact caused by pulling can be avoided by using tape or an elastic band to fasten the cables. Electrode movement can be avoided by placing 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 is applied to the signal (in MyoScan-Pro sensor) to remove the residual artifact.

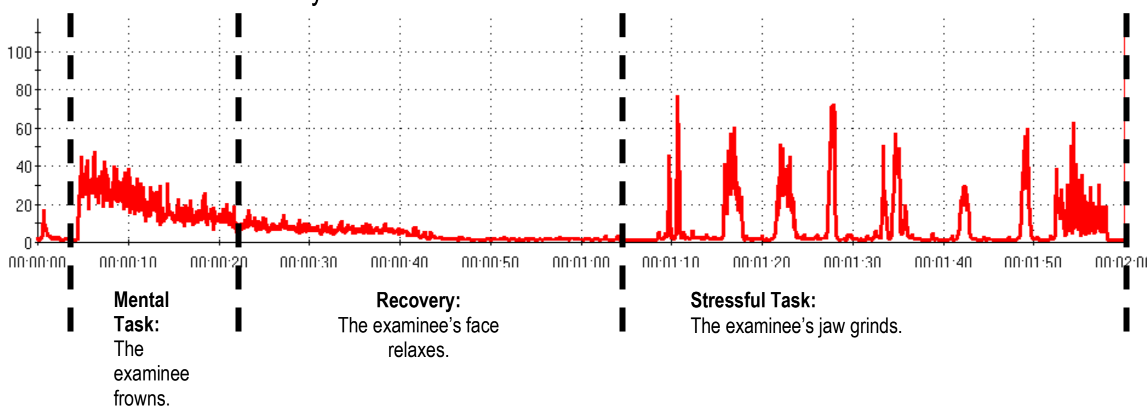
These artifacts can also be manually removed from the statistics calculation during the review of the session.

# Examples of Use

Among the features of the muscle (such as its role in motion or posture), emotional display is the one that is mainly exploited in psychophysiology.

SEMG is commonly used for **stress assessment** in conjunction with other physiological signals, such as skin conductance, skin temperature, respiration and heart rate (from BVP or EKG).
The stress assessment protocol usually guides the examinee through a succession of activities or tasks generating stress, alternated with periods of rest or recovery. The examinee's physiological signals are monitored and recorded during each activity.

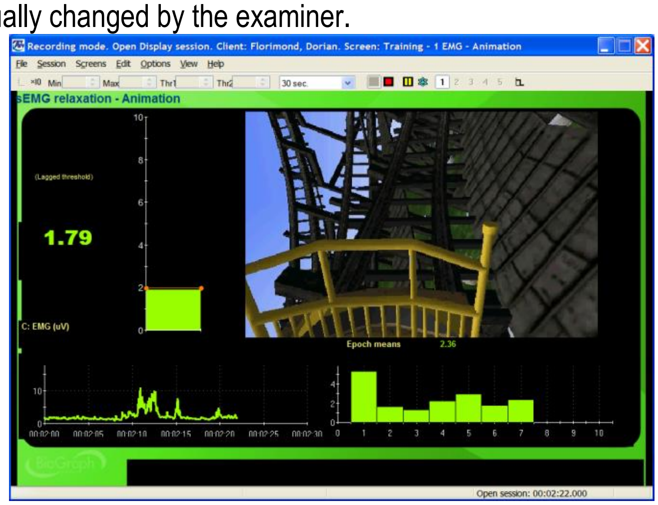
For instance, the SEMG electrodes are placed on the examinee's face. The movements of the facial muscles can be easily correlated to emotions.




***SEMG recorded with wide frontalis placement***

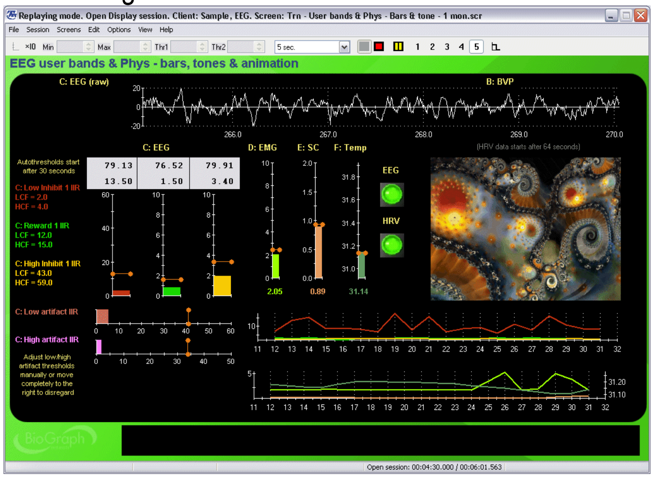
Thought Technology's **Physiology Suite** provides a series of stress assessment protocols.

SEMG can also be used for learning **relaxation** and stress control, helping teach awareness of head, neck and low back muscle tension, or training voluntary relaxation of specific muscle groups. The visual and/or audio feedback is usually based on a threshold. The examinee is taught to keep the signal below the threshold. The threshold can either automatically follow the examinee's reactions or be manually changed by the examiner.




***SEMG relaxation screen from Physiology Suite***

SEMG may also be used in **Neurofeedback**. SEMG is usually used to inhibit the audio and/or visual feedback when the signal goes above a threshold. It helps the examinee to stay relaxed and minimize their movements during the Neurofeedback session.




***Neurofeedback screen from EEG Suite***

It also allows the examiner to see physiological changes during Neurofeedback training.

"From 2001 I started using Thought Technology's Infiniti products for simultaneous multi-monitoring and training. Often it was clear, if a client was trying too hard to accomplish a task, they would also produce changes in one or more physiological channels other than EEG. Observed changes often included a rise in SC, SEMG, heart rate or respiration and a drop in peripheral temperature. Now I generally have my clients observe and/or train all parameters. It is part of my permanent arsenal, since it has led to faster training and client satisfaction."

Ray Pavlov MD., Ph.D, ND

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.

# About Research …

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

Biofeedback Foundation of Europe

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

See www.bfe.org for more information.

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 under water research since the environment provides some useful similarities to working in space, using off the shelf technology, developed by THOUGHT TECHNOLOGY LTD of Montreal.

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

NASA's Toscano commented on the extreme research environment and on the 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.
- Apply sensors to the examinee as follows:

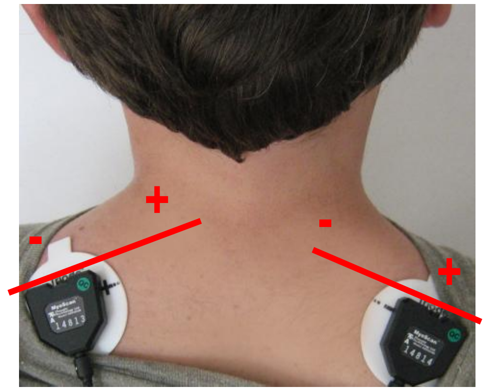
***Example with triodes on the upper trapezius:***

MyoScan-Pro Sensor

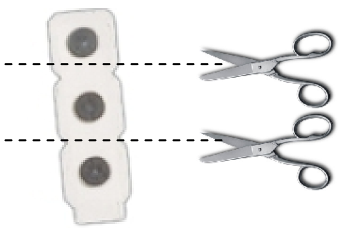

Triode

- Affix a triode on each MyoScan-Pro sensor.

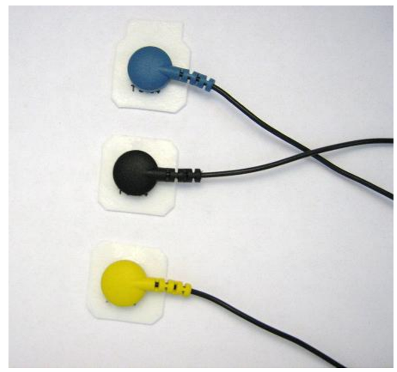
- The sensors should be placed on the trapezius muscles, in the orientation shown here.



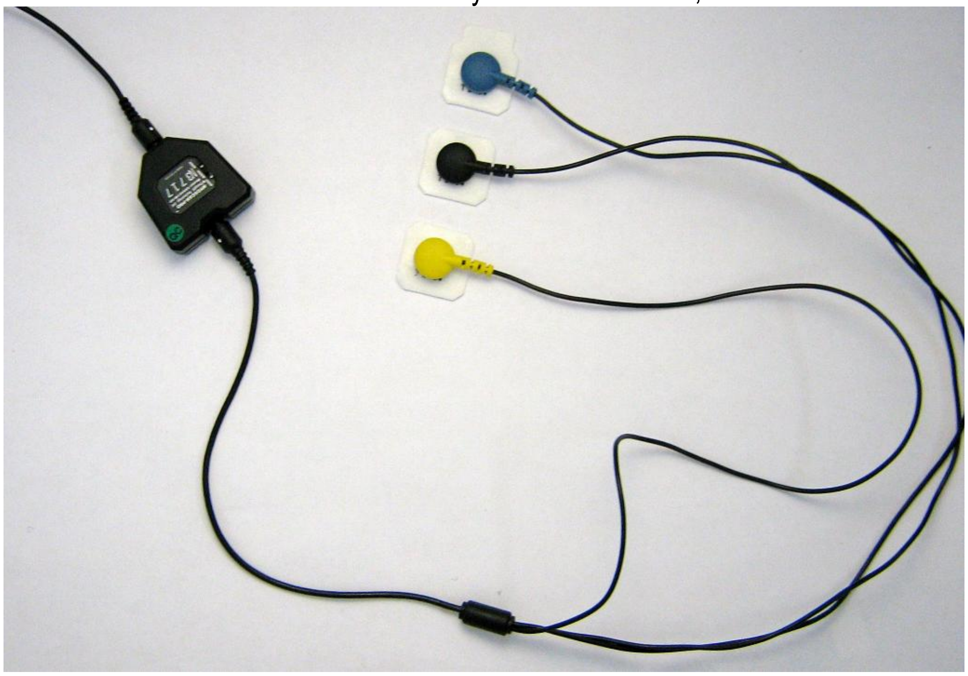
***Example with single electrodes on the frontalis:***



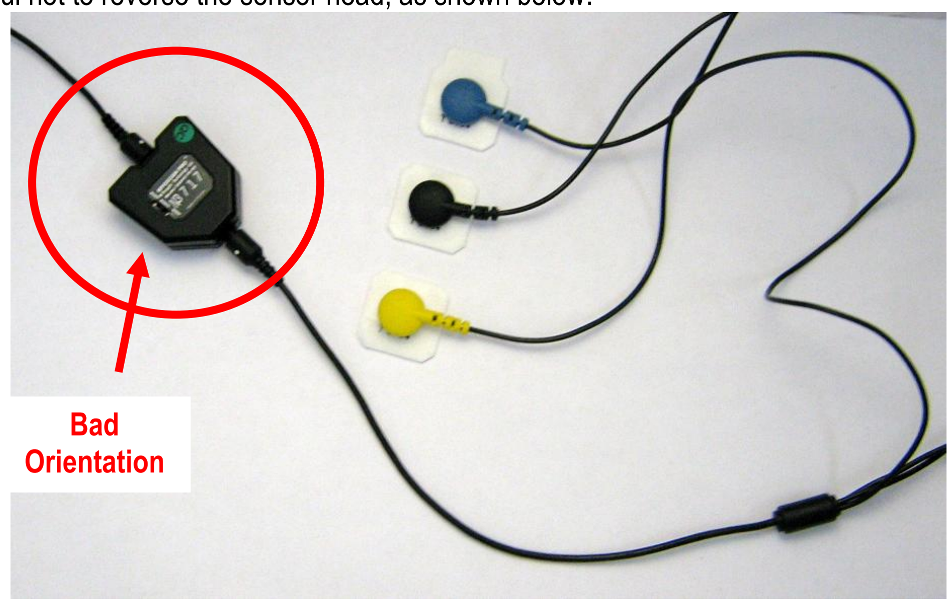
Cut the electrodes in three pieces and snap them on the EMG extender cable.



- Connect the EMG extender cable to the MyoScan-Pro sensor, as shown below.

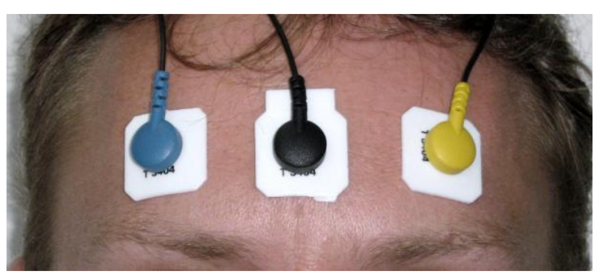


Be careful not to reverse the sensor head, as shown below:




**Wrong hook-up**

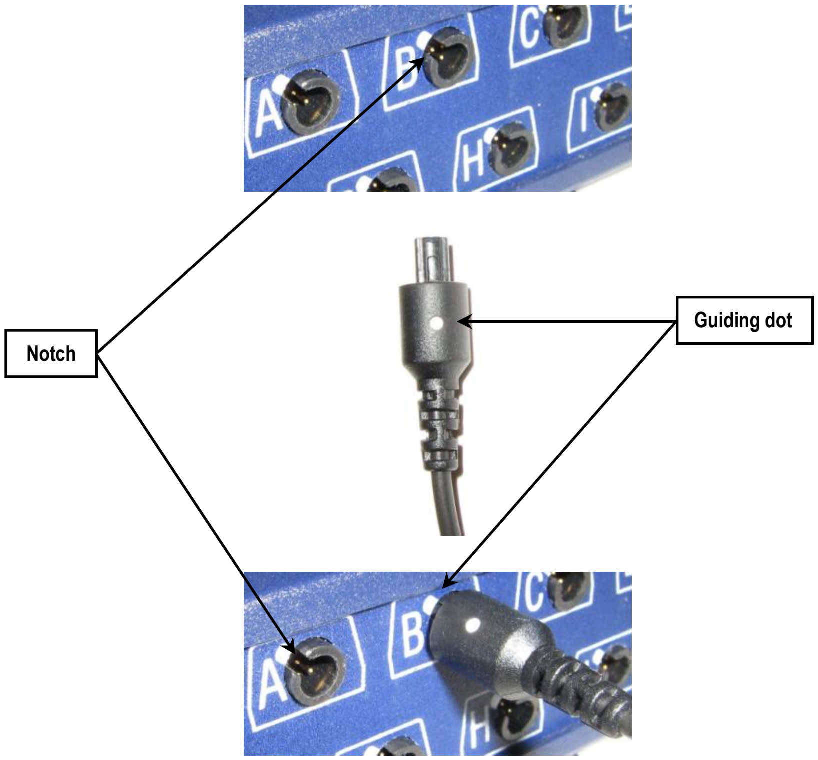
- The sensors should be placed on the frontalis muscles, in the orientation shown here.



- Instruct the examinee to relax and to follow the instructions for each task as they are presented.

# Connecting the Sensors to the Encoder

When connecting a MyoScan-Pro 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.
When used with Thought Technology's **Physiology Suite**, the MyoScan-Pro must be connected either to **channel C or D**.
When used with Thought Technology's **EEG Suite**, the MyoScan-Pro must be connected to **channel D** for ProComp2, ProComp Infiniti and FlexComp Infiniti, or to **channel E** for ProComp5 Infiniti.

# Starting a Session

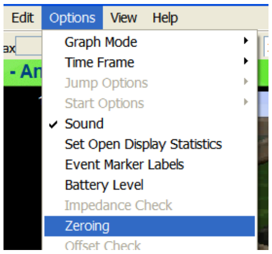
## *Before You Start*

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:

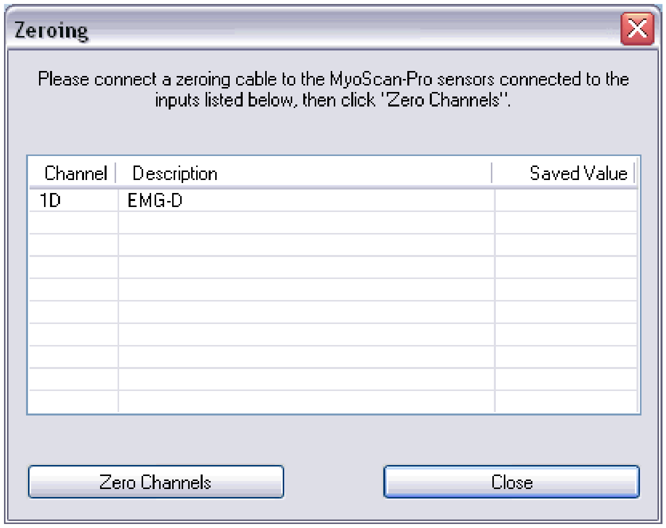
- Edit a display screen with the Screen Editor: *Screens* menu
- Verify the battery level: *Options* menu
- Zero your MyoScan-Pro sensor(s): *Options* menu
- Predefine the statistics for an open display session: *Options* menu

## *Zeroing MyoScan-Pro Sensor*

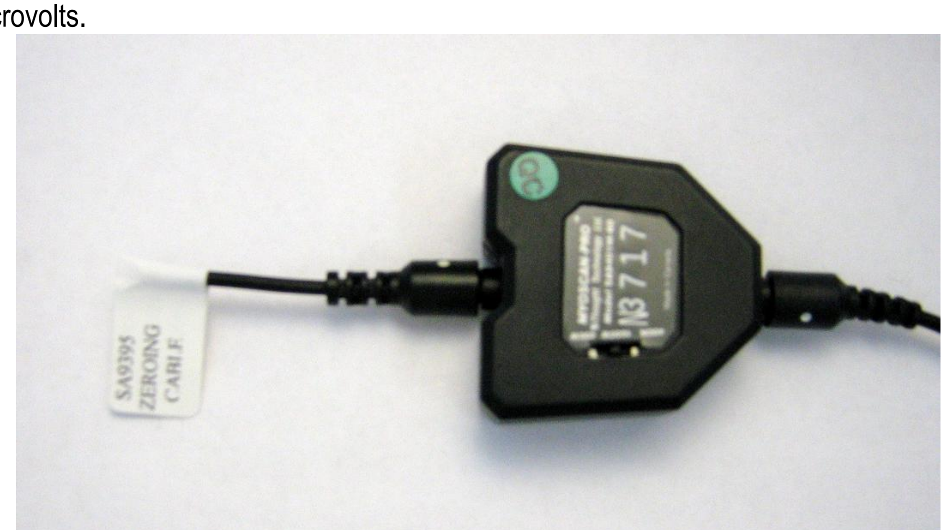
When using MyoScan-Pro sensors, it is a good idea to zero their physical channels every few weeks, in order to make sure that you get the most reliable EMG measurements possible.



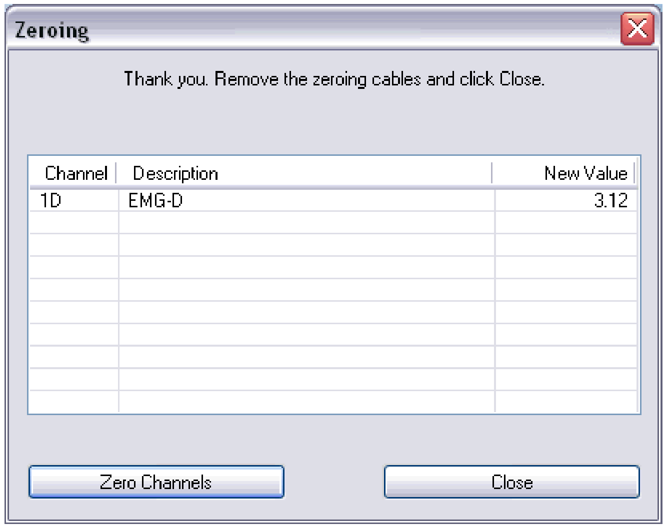

When you click on the *Zeroing* item from the *Options* menu, the program opens this dialog box and asks you to connect a zeroing cable onto each MyoScan sensor before you click on the *Zero Channels* button:




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*:

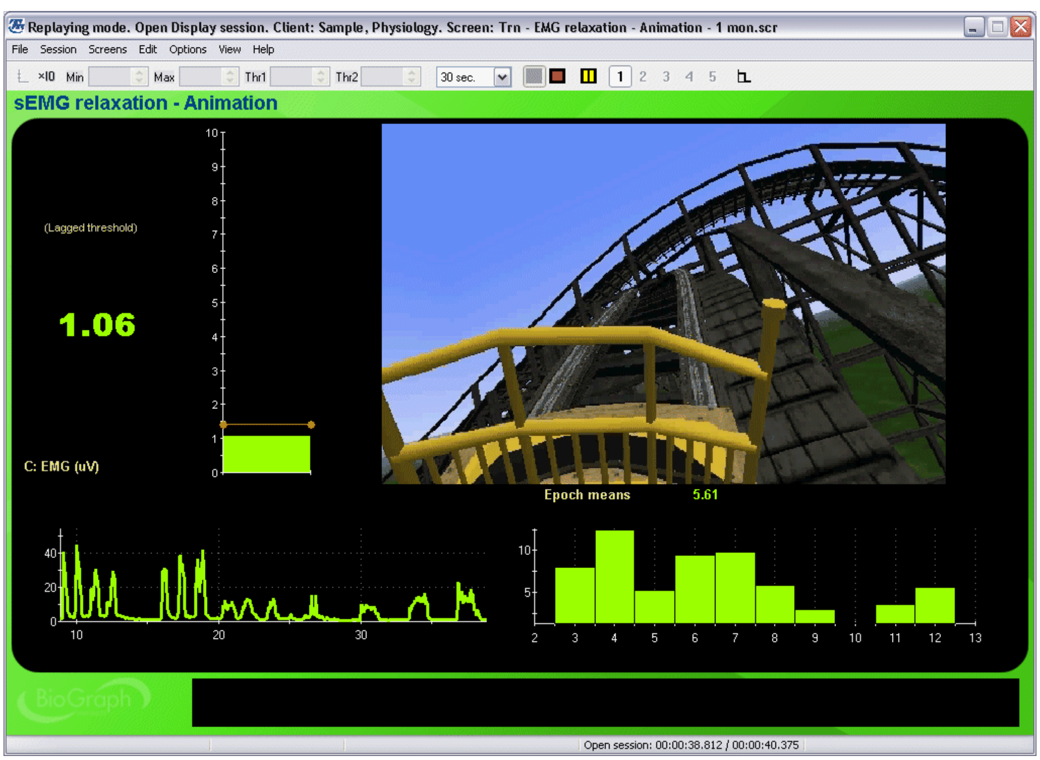



The zeroing information is saved as part of the channel set data, so the sensors do not have to be zeroed for every screen of a given channel set, **as long as you always connect the same sensor to the same encoder input**. If you have several MyoScan-Pro sensors, it might be best to label each one with 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 Relaxation Screen from Thought Technology's Physiology Suite*

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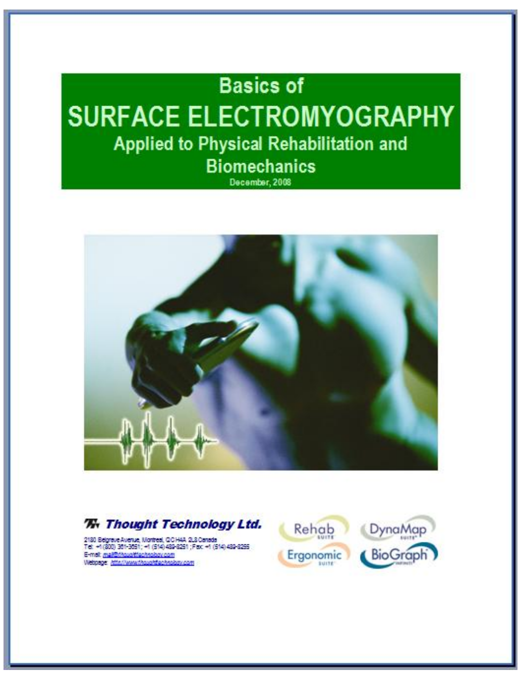


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