



*Section 2:
Technology and the Quality of the
sEMG Signal*



14: Signal Quality

- **The quality of the sEMG signal should be the first concern of any tests performed to collect sEMG signals.**
- **The quality of the EMG signal depends on:**
 - Sensor Location
 - Sensor characteristics
 - Noise contamination
 - Electrode-skin interface
 - Cross-talk from other muscles

Signal Quality:

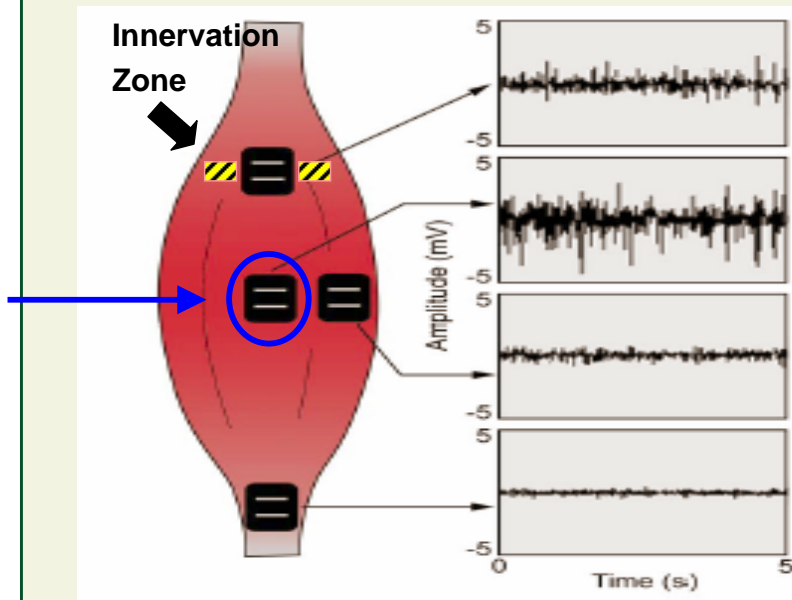
The quality or the fidelity of the detected sEMG signal determines the usefulness of the information extracted from the sEMG signal. Bad data yield contaminated results and compromised interpretation. The dominant factors are listed in the slide and are explained in the following slides.

The single best effort that can be performed by the user is to maximize the quality of the acquired signal. This is achieved by using superior equipment, by properly applying the sEMG sensor and reference electrode to the skin, and most importantly by placing the sEMG sensor in the middle of the belly of the muscle.

This last action by itself increases the signal to noise ratio and reduces the cross-talk from other muscles. Proper sensor location accomplishes more than any other procedure towards providing a high-quality sEMG signal.



15: Sensor Location: Signal Amplitude Variation



Proper sensor location

- Increases the signal
- Increases the signal to noise ratio
- Reduces cross-talk

De Luca C.J. The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13: 135-163, 1997.

Sensor Location and Signal Amplitude Variation:

The location of the sensor on the muscle renders dramatically different sEMG signal characteristics. Note that locating the sensor in the proximity of the tendon origin, the innervation zone, and the perimeters of the muscle yields lower amplitude signals. The fibers in the middle of the muscle have a greater diameter than those at the edges of the muscle or near the origin of the tendons. Because the amplitude of action potential from the muscle fibers is proportional to the diameter of the fiber, the amplitude of the EMG signal will be greater in the middle of the muscle. A sensor located on the innervation zone will detect the cancellation of the action potentials traveling in opposite direction, and will generally have a lower amplitude.

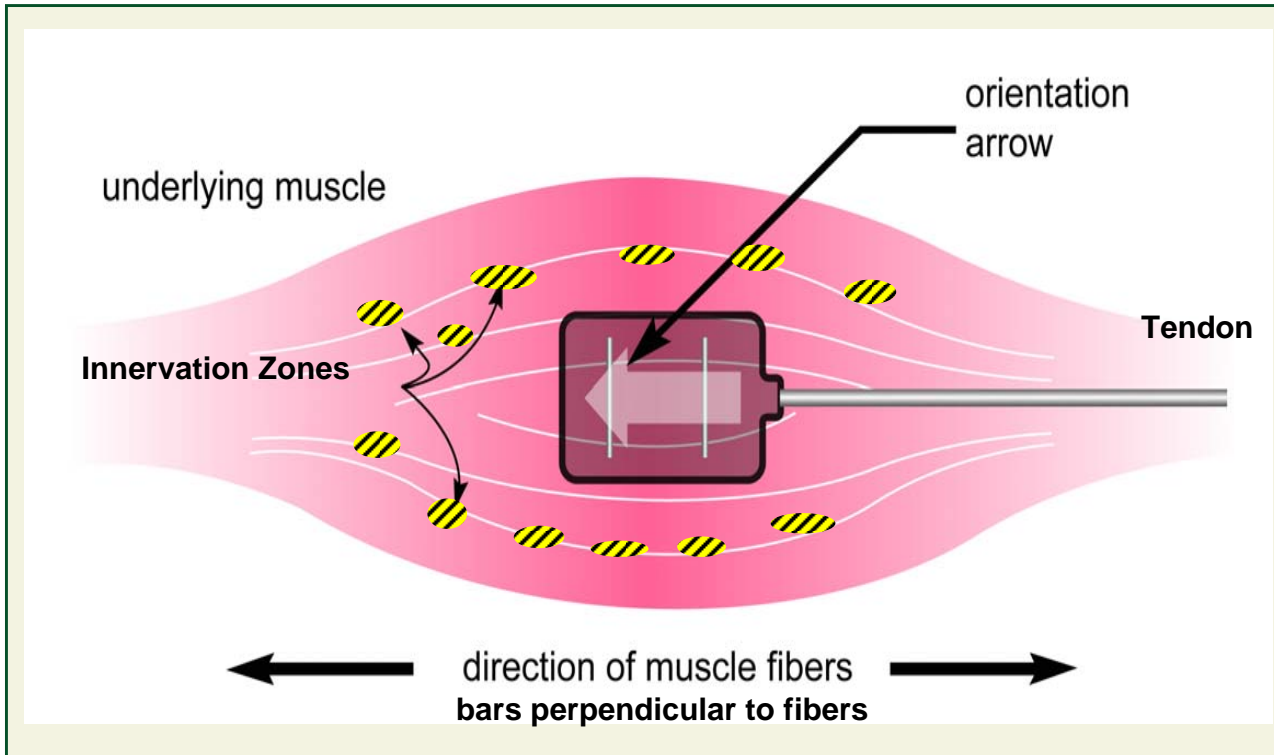
The preferred location is away from all these boundaries, towards the middle of the muscle surface.

The location of the sensor on the muscle is the single most important factor for obtaining the best signal to noise ratio with the least amount of cross-talk.

Means for locating the innervation zone, as well as known locations of the innervation zones on some muscles, are discussed later. The reported localizations of the innervation zones is in the periphery of the muscle.



16: Where to Locate the EMG Sensor for a High-Fidelity Signal?



Where to locate the EMG sensor for a high-fidelity signal?:

This cartoon indicates the preferred location for placing the sensor -- in the middle of the muscle surface and as far away as possible from the innervation zones and tendon origins. The small yellow striped areas indicate the innervation zones which in large muscles are located around the periphery, as discussed earlier. For better signal quality, the bars of the sensors should be aligned perpendicularly to the muscles fibers when possible. Admittedly, in multi-pennate muscles, this alignment is not possible.



17: Sensor Location: How do you Determine the Innervation Zone?

- **Direct Surface stimulation (motor point)**
- **Measurement of inverting action potentials on the surface with an array sensor**
 - [Masuda T. and Sadoyama T. Topographical map of innervation zones within single motor units measured with a grid surface electrode. *IEEE Trans. Biomed. Eng.*, 35:623-628, 1988.](#)
- **Location of highest value of the initial (t=0) Median frequency on the surface of the muscle**
 - [Roy, S.H., De Luca, C.J. and Schneider, J. Effects of electrode location on myoelectric conduction velocity and median frequency estimates. *Journal of Applied Physiology*, 61: 1510-1517, 1986](#)

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How do you determine the innervation zone?:

The location of the innervation zone is not identifiable by visual observations. There are at least three methods for locating it.

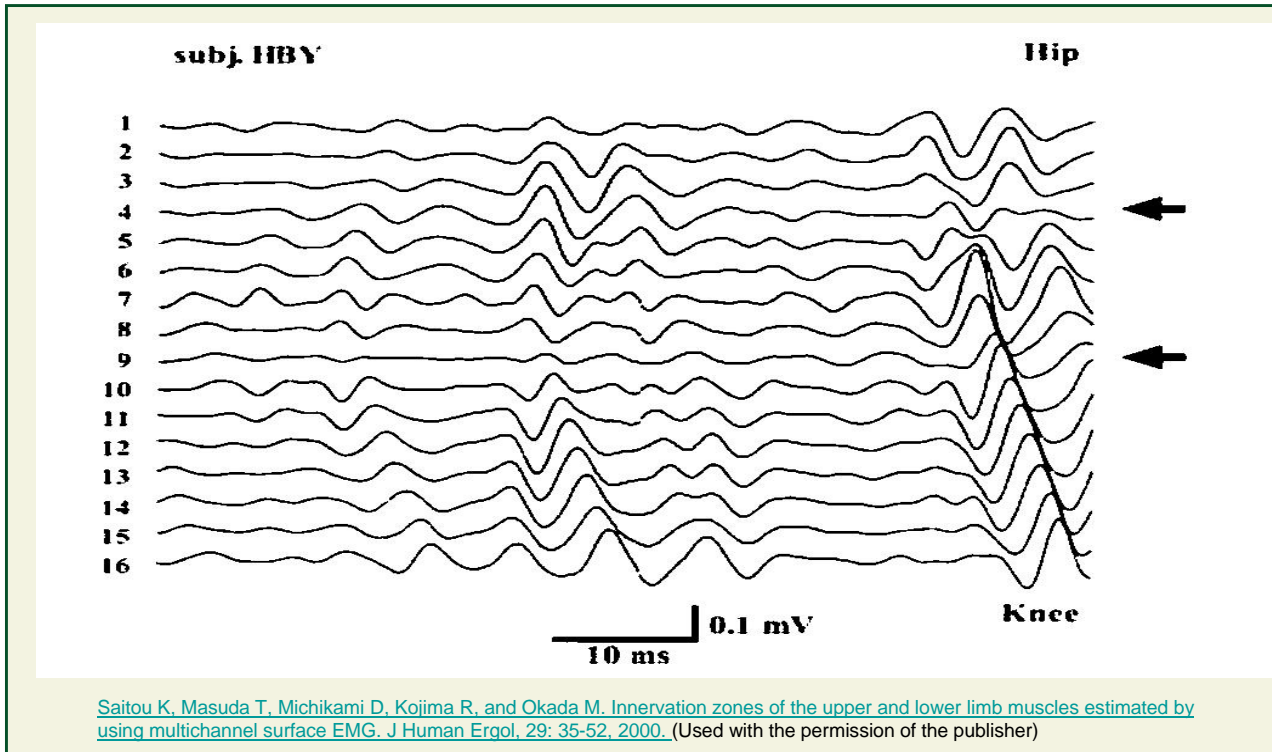
- The oldest method is to find the motor point on the surface of the muscle. This is achieved by locating the point(s) where the muscle begins to twitch with the lowest amount of current applied. It is not a very sensitive technique, as the innervation zone may be deep in the muscle, requiring relatively high levels of current to activate the innervation zone, sufficient to excite some stray motor nerve fibers that may be located near the surface that would cause muscle fiber twitching. (Note that less current is necessary to activate nerve fibers than muscle fibers.)
- The second method was introduced by Masuda and Sadoyama (see cited reference). It relies on using an array sensor consisting of a series of electrode bars to detect the action potential of a motor unit during a weak contraction. The location where the phases of the action potential invert or the amplitude approaches zero is the location of the innervation zone for that motor unit.
- The third method is to locate the position on the surface of the muscle where the median frequency at the beginning of a muscle contraction is the greatest. This location coincides with an innervation zone.

Method #2 is the most sensitive and accurate. Masuda and colleagues have provided the location of the innervation zones for various muscles commonly used in EMG studies. Examples are shown in the next 2 slides.

- The location of the innervation zone is not identifiable from visual observations.
- There are at least three ways to calculate it.



18: Sensor Location: Method for Finding Innervation Zones



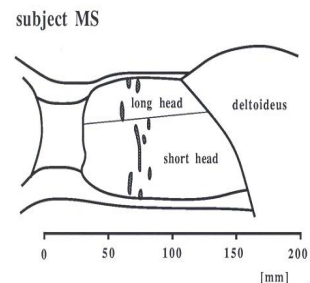
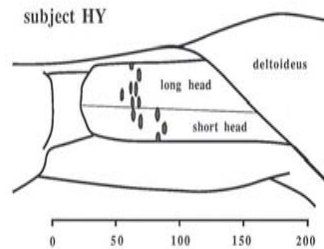
Method for Determining the Proximity of the Innervation Zone (from Masuda and Sadoyama):

1. A linear sensor array of 16 electrodes is placed on the skin above a muscle. A mild contraction is made, sufficient to generate motor unit action potentials that can be visibly identified. The figure shows the time course of three motor unit action potentials
2. The action potential travels in both directions from the neuromuscular junctions that constitute the innervation zone. Thus when differential recordings are made between adjacent electrodes, the pair on top of, or in the near proximity of, the neuromuscular junction will detect the lowest amplitude action potential. (If the neuromuscular junction is located precisely between two electrodes and the tissue between the muscle fiber and the electrodes is isotropic, then the amplitude will be zero.)
3. The two arrows in the figure indicate the location where the amplitude of two different action potentials is the smallest, indicating the proximity of the innervation zone.



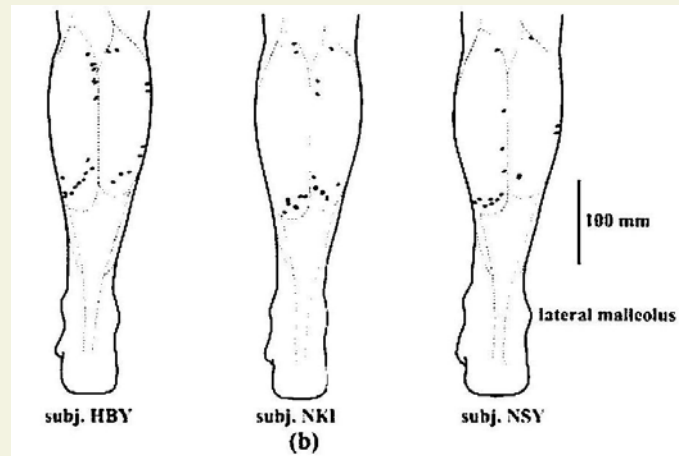
19: Sensor Location: Examples of Innervation Zone Locations

Human Biceps Brachii



Masuda T and Sadoyama T. Distribution of innervation zones in the human biceps brachii. *Journal of Electromyography and Kinesiology*. 1 :107-115, 1991. (Used with the permission of the publisher)

Soleus and Gastrocnemius



Note that:

1. The innervation zones are located either at the perimeter of the muscle or at one end of the muscle.
2. The middle of the muscle is generally devoid of innervation zones, leaving it a clear location for placing the sensor.
3. The location of the innervation zones is similar across subjects.

Examples of Innervation Zone Locations in Upper and Lower Limb Muscles:

1. The innervation zones are located either at the perimeter of the muscle or at one end of the muscle.
2. The middle of the muscle is generally devoid of innervation zones, leaving it a clear location for placing the sensor.
3. The location of the innervation zones is similar, but not identical among subjects.



20: Noise Contamination

- **Physiological Noise**
 - EKG, EOG, respiratory signals, etc.
 - Reduced by judicious location of the sensor and by rotation of the sensor
- **Ambient Noise**
 - power line radiation (50, 60 Hz)
 - Removed by differential detection
 - Cable motion artifact
 - Removed by high quality technology
- **Baseline Noise**
 - Electro-chemical noise (skin-electrode interface)
 - Reduced by effective skin preparation
 - Thermal noise (property of semiconductors)
 - Reduced but not eliminated by modern technology
- **Movement Artifact noise**
 - Movement of electrode with respect to the skin (induced by force transients or movement of the skin)
 - This is the most obstreperous noise
 - Reduced by effective skin preparation and filtering

Noise Sources:

There are several sources of noise with which we must be concerned: The physiological noise, the ambient noise, the baseline noise and the movement artifact noise.

The physiological noise originates from other tissues that generate electrical signals, such as EKG, EOG, respiratory muscles, and the like. It can be reduced by location the sEMG sensor further away from the source of the noise, by rotating the sensor so that the electrodes align on equipotential planes (that is: both electrodes are equidistant from the source), and by some filtering.

The ambient noise (power line noise and cable motion artifact) originates from the electromagnetic radiation that is pervasive in all environments. The *power line noise* (50 or 60 Hz) is generally not a concern because modern differential amplification technology (see next slide) and proper circuit design combined with judicious location of the reference electrode on the subject can virtually eliminate this ambient noise. The *cable motion artifact* originates when the cable(s) from the electrodes or sensor to the amplifier moves and cuts an electromagnetic field in the environment to generate a potential that is subsequently amplified by the recording system. Modern EMG technology now uses sensors that have the first-stage of amplification located on-board or within centimeters of the site of the electrodes. The output of the first-stage amplification has a low-impedance, rendering the cable ineffective in generating a cable motion artifact. Thus, present technology virtually eliminates the first two sources of noise, which in previous decades were a difficult-to-deal-with nuisance.

The baseline noise originates in the electronics of the amplification system and at the skin-electrode interface. It is can be observed when a sensor is attached to the skin and the muscle is completely relaxed. The ionic exchange between the metal in the electrode and the electrolytes in the salts of the skin (also known as the electrolyte-electrode interface) generates an *electro-chemical noise*. The magnitude of this noise is proportional to the square root of the resistance of the electrode surface [Huigen et al., 2002]. Thus, it can be reduced by increasing the electrode area and by cleaning the electrode surface, but it cannot be eliminated. The *thermal-noise* is generated by the first stage of the amplifiers and is due to a physical property of the semiconductors. It also cannot be eliminated. Both noises are referred to as $1/f$ noises, with the amplitude of the frequency spectrum greatest at 0 Hz and continuously decreasing with increasing frequencies [Huigen et al., 2002]. According to Fernandez and Pallas-Areny [2000] the electrochemical noise is generally greater than the thermal noise.

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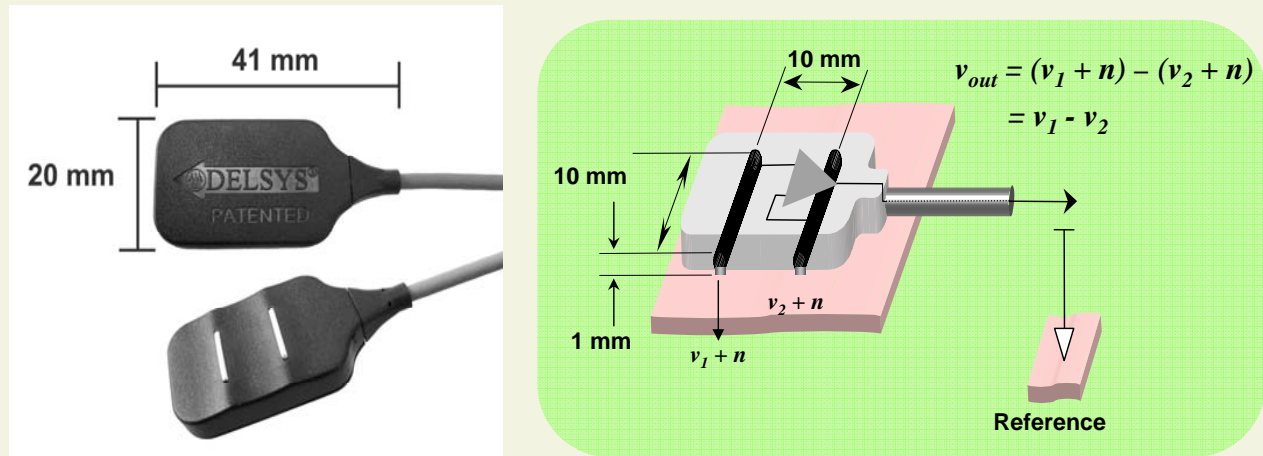
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The ambient noise and the baseline noise can be substantially reduced to the level that they are not significant contaminants by using well designed modern technology, by effective preparation of the skin below the sEMG sensor, and by using effective reference electrodes.

The movement artifact noise also originates at the electrode-skin interface. This noise is the most obstreperous and requires the most attention. There are two common sources. One occurs when a muscle contracts and relaxes causing the length and cross-section to change. This volumetric morphing stretches and relaxes the skin which alters the electro-chemical balance of the two skin-electrode interfaces causing a time-varying voltage across the two electrodes. The other, often much more significant, source occurs when a force impulse originating within the muscle, as in the case of a jerk movement, or from outside the limb, as in the case of a heel-strike while walking, is transmitted to the electrodes. This phenomenon is amplified considerably by the presence of hydrophilic gel that is at times placed between the electrode and the skin [Roy et al., 2007]. It is difficult to reduce and almost impossible to eliminate. A good electrode-skin preparation and appropriate filtering are helpful.



21: Single Differential Electrode Removes Power Line Noise



- Ambient (power line) noise (n) is almost similar on both electrodes (common mode source)
- System subtracts two signals -- ambient noise is removed, resultant EMG signal is amplified
- High input impedance, low output impedance

Single Differential Electrode with low output impedance Removes Ambient Noise:

As may be seen in the green panel, each sensor has two electrodes which detect two different potentials (v_1 and v_2 , which are represented in the figure as voltages) with respect to a reference located some distance from the sEMG sensor. These potentials are caused by the ionic currents that travel along the muscle fibers below the electrodes. Both potentials are contaminated by the noise sources described in the previous slide.

Ambient noise (n) that originated much further away (such as 50 or 60 Hz power line radiation and higher frequency radiation from electronics communication systems, such as radio stations, TV stations, etc.) from the sensors than the interelectrode distance will arrive at the electrodes nearly at the same time, or "in phase". These noises are also known as common - mode signals. Whereas, because the EMG signal travels at speeds of only 2.5 to 5 m/s the two sensors "see" different potentials due to muscle activity. Thus, by subtracting the two potentials, the ambient noise is removed and the difference ($v_1 - v_2$) is detected as an sEMG signal. This "difference" potential is the result of "differential" detection. The effectiveness of the circuitry to eliminate the common-mode signals is measured by the Common-mode rejection ration (CMRR).

Note that differential amplification will not remove noise contributions from other noise sources such as the EKG, which are local events like the sEMG signal.

FOR MORE INFORMATION ON SENSORS go to [Appendix A "sEMG Sensor Factors" located at the end of the practicum.](#)

For more information on the Delsys DE 2.1 sensor go to <http://www.delsys.com/Products/EMGSensors.html>

Definition - The electrode is the metallic detection surface that exchanges ions with the salts in the skin. The sensor is the complete unit that provides the sEMG signal.

The sensor used to detect the sEMG signal is the most important component of the recording system. The fidelity of the signal obtained from the sensor determines the quality of the signal that is provided by the recording system. The remainder of the system can only worsen the quality of the signal. Because the sEMG signal originating in the muscle is much smaller than the ambient electrical signals that originate from surrounding sources, it is strongly recommended (insisted) that the sensor detect "differential" signals.



22: Sensor Characteristics: Importance of Fixed Electrode Spacing

- **Fixed inter-electrode spacing is essential because:**
 - Amplitude of signal is **directly** proportional to spacing
 - Bandwidth of signal is **inversely** proportional to spacing
- **1 cm is a preferred compromise**

[Lindstrom L.R. Magnusson R and Petersen I. Muscular Fatigue and action potential conduction velocity changes studied with frequency analysis of EMG signals. Electromyography. 4: 341-356. 1970.](#)

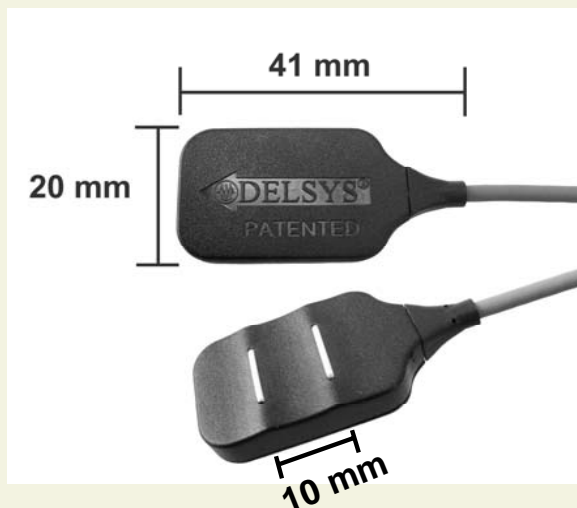
Importance of fixed electrode spacing:

By maintaining a fixed inter-electrode spacing, the bandwidth of the sEMG signal will remain constant. The band-width of the sensor determines how much of the signal energy and the noise energy constitutes the acquired signal. If the electrode spacing is varied as may occur with sensors that have separate electrodes that may be attached with variable spacing at each application, then the information content in the acquired sEMG signal will not be constant and comparison among muscles and subjects will be unreliable.

A small inter-electrode spacing is preferable as it will reduce the amount of crosstalk signal detected from adjacent active muscles. Remember that the differential recording amplifies the difference between the potentials at the two electrodes. The greater the spacing of electrodes the greater the difference of the propagating cross-talk signal. Additional advantages of the 1 cm spacing will become more apparent later in the presentation.



23: Sensor Characteristics



- Dry electrode (no electrolyte)
- Use as a probe
- Noise < 1.2 μ V RMS (0-500 Hz)

sEMG sensor characteristics:

The Delsys DE 2.1 parallel bar differential sEMG sensor is presented in the slide. For additional information go to <http://www.delsys.com/Products/EMGSensors.html>

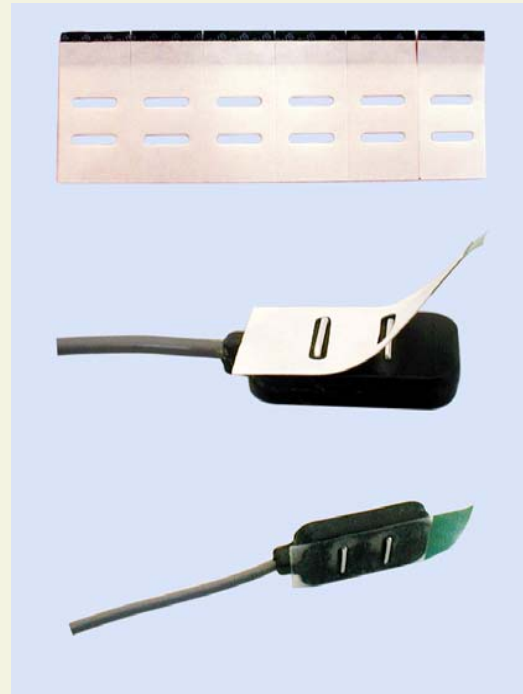
In addition to the electrical characteristics of the sensor, the design of the sensor should address other practical factors such as:

1. Effectiveness of the electrical contact between the electrode and the skin
2. Facility of attaching the sensor to the skin
3. Durability of the adhesion to the skin
4. Insensitivity of the electrical and mechanical performance to the presence of sweat.
5. Insensitivity to movement artifact
6. Ease of use on small muscles



24: Electrode-Skin Interface

- **Maintains proper electrical contact with the skin during**
 - **Movement**
 - **Sweating**
- **Tested on various skin types**
- **Worn by Boston Marathon runners**
- **Worn for over 24 hour periods**



Use of a good sensor-skin interface:

Next to placing the sensor in the middle of the belly of the muscle, an effective electrode-skin contact will provide great benefits in assuring a high quality signal.

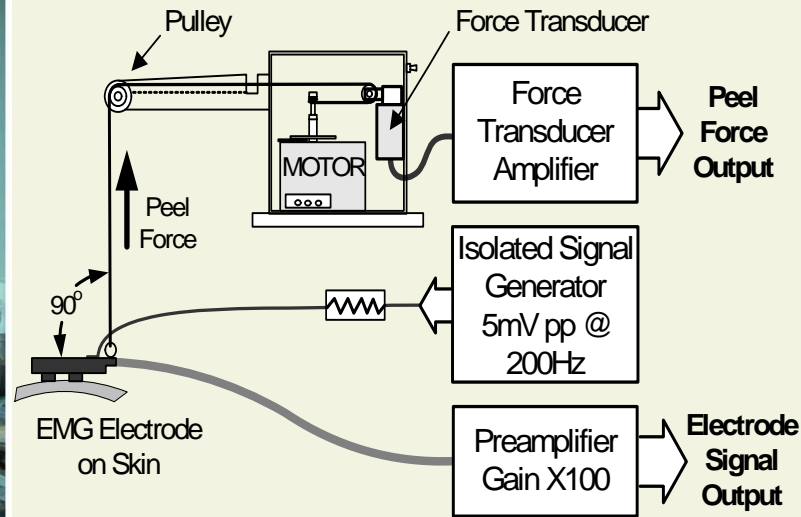
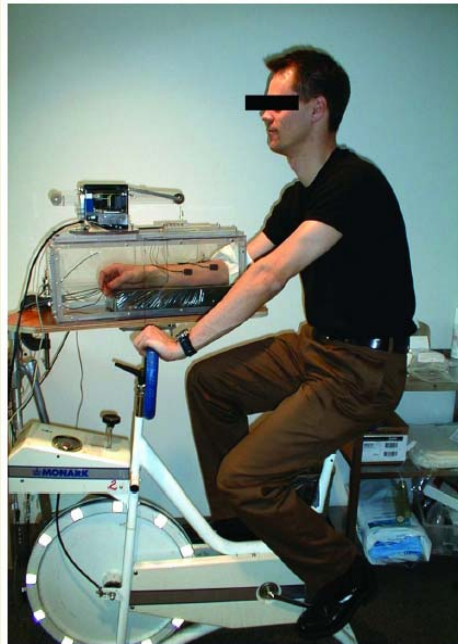
Method of application:

1. Shave excessive hairs, although in most cases the hair can simply be moved aside or sensor can be placed over hair.
2. Clean skin with alcohol to remove skin debris. Allow alcohol to evaporate. (When using Delsys sensors, abrasion of the skin is NOT required.)
3. In most cases (depending on skin type) no electrolyte is required.
4. Attach sensor-skin interface. Press hard to assure maximal adhesion to the skin.

The quality of the adhesive capability of the sensor and its response to mechanical perturbations have been tested as shown in the following slides.



25: Electrode-Skin Interface: Tests of Sensor Adhesion to Skin



[Roy SH, De Luca G, Cheng S, Johansson A, Gilmore LD, and De Luca CJ. Electro-mechanical stability of surface EMG sensors. Medical & Biological Engineering & Computing, 45: 447-457, 2007.](#)

Tests of sensor adhesion to skin:

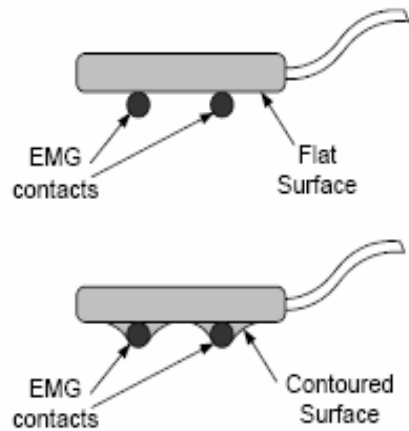
In the referenced study, we developed tests and procedures for designing the contact surface of sEMG sensors. Specifically we evaluated different sensor designs and different interfaces between the sensor and the skin to determine how they affected sensor performance under conditions of sweat accumulation on the skin (sweat test) and when mechanically disturbed by impact and sinusoidal forces.

In one series of tests we evaluated how well the sensor remains affixed to the skin when differently shaped sensors were peeled by a mechanical device (shown above). We were specifically interested in evaluating whether contouring the skin surface of electrode improves performance.

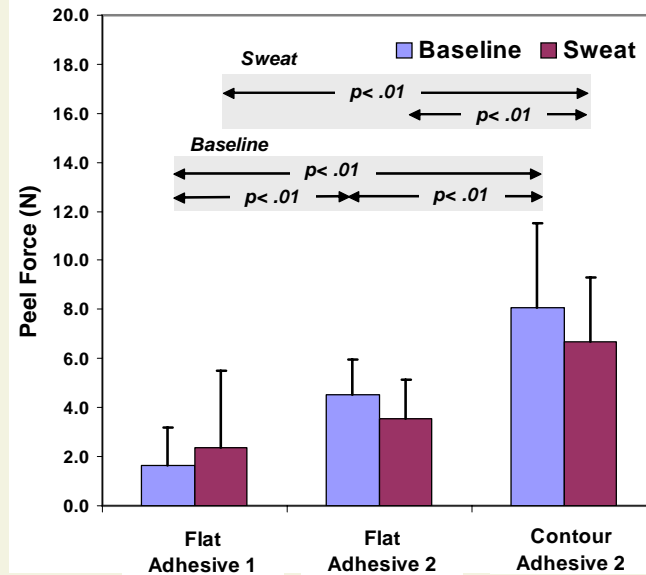
In another series of test we evaluated the effect that conductive gels and other preparations have on reducing artifact when the sensors are perturbed.



26: Electrode-Skin Interface: Contoured Electrodes



Patent # 6,480,731



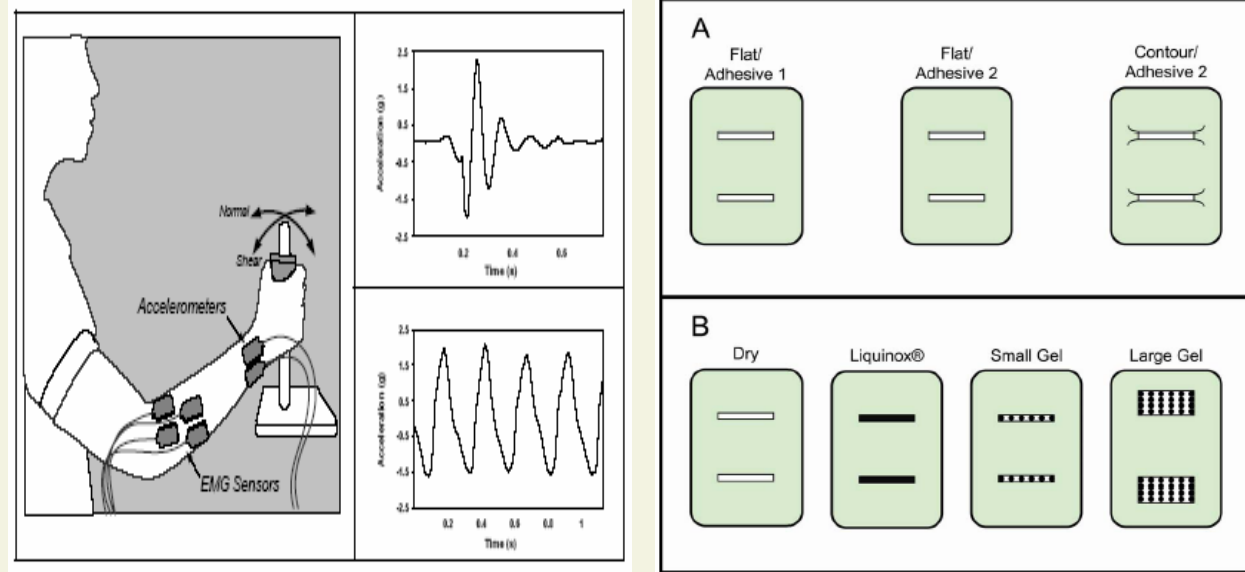
[Roy SH, De Luca G, Cheng S, Johansson A, Gilmore LD, and De Luca CJ. Electro-mechanical stability of surface EMG sensors. Medical & Biological Engineering & Computing, 45: 447-457, 2007.](#)

Contoured electrodes improve ability of adhesive to attach:

The contoured edges around the electrodes significantly increased the amount of force required to peel the sensor away from the skin, implying that it enables a better contact between the sensor and the skin.



27: Mechanical Perturbations and Electrode Surfaces



Roy SH, De Luca G, Cheng S, Johansson A, Gilmore LD, and De Luca CJ. Electro-mechanical stability of surface EMG sensors. *Medical & Biological Engineering & Computing*. 45: 447-457. 2007

Mechanical perturbations and electrode surfaces:

This was a test for establishing the influence of various electrolytes between the electrode and the skin on the generation of a movement artifact. (These are commonly used to improve the electrical conductivity between the electrode and the skin.) We also tested the performance of the sensor with no applied electrolyte.

Mechanical disturbances were applied as a sinusoidal force in the normal and shear direction, and also as an impact in the normal and shear direction.

The disturbance on the skin was monitored with accelerometers and the artifact was monitored by the sensors. See next slide for results.



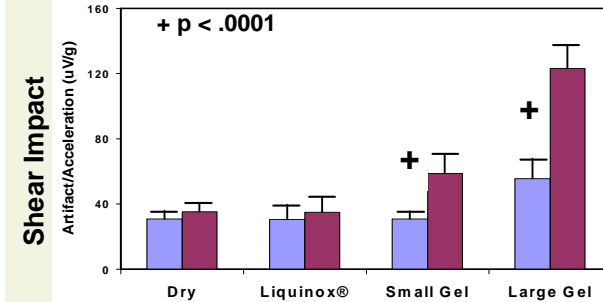
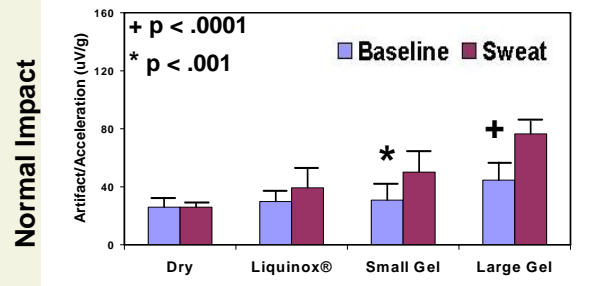
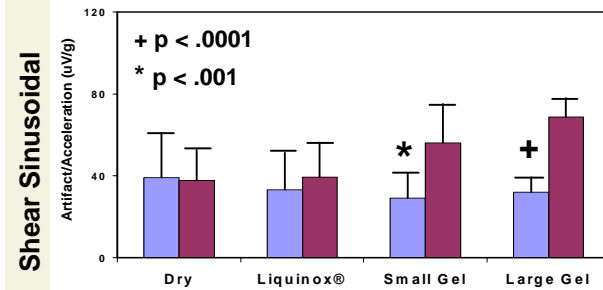
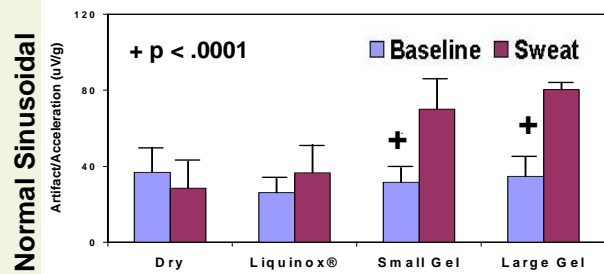
28: Electrode-Skin Interface: Movement Artifact

Movement artifact and the influence of electrolyte contact:

The results of the mechanical perturbations demonstrated that the gel electrolyte performed poorly and worsened in the presence of sweat. The dry electrode (no electrolyte) generally performed the best in the impact test, and the performance was statistically similar to that of the second best (Liquinox) in the shear sinusoidal test.

Note that the impact test represents the disturbance profile on the lower limb that occurs during walking.

FOR MORE INFORMATION ON SENSORS go to the end of the presentation to [Appendix A: sEMG Sensor Factors](#).



Roy SH, De Luca G, Cheng S, Johansson A, Gilmore LD, and De Luca CJ. Electro-mechanical stability of surface EMG sensors. *Medical & Biological Engineering & Computing*, 45: 447-457, 2007



29: Noise in the EMG Signal: Basic Concepts

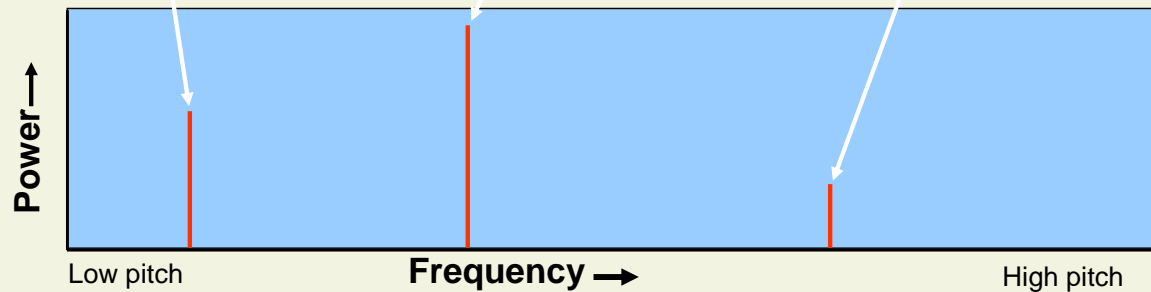
- **Concept of Frequency Spectrum**
- **Concept of Filtering**

Noise in the EMG signal:

In the next sequence of slides we will discuss other characteristics of noise components. But in order to do so we need to review the concept of the frequency spectrum of signals, and the concept of filtering. The prior concept shows the frequency range that are common to both the noise signals and the EMG signal. The latter removes unwanted frequency components from the detected signal.



30: Frequency Spectrum



Frequency spectrum:

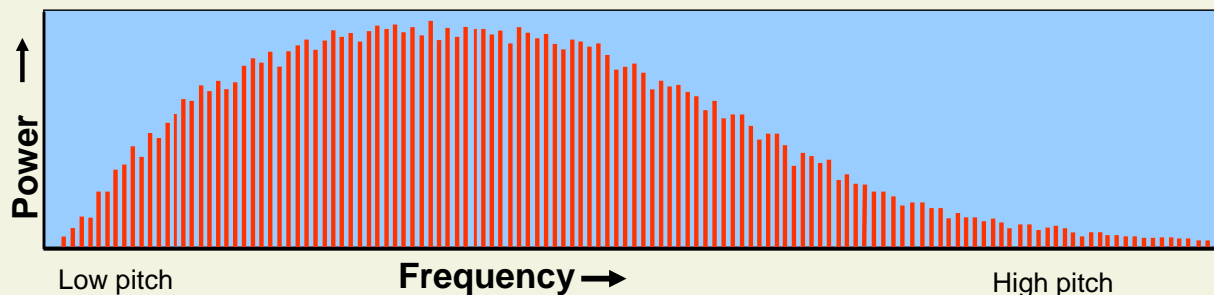
The concept of a frequency spectrum can be difficult to grasp for a novice. The frequency spectrum of the EMG signal can be understood by drawing a parallel to the sound emanating from an orchestra. Consider the arrangement of the instruments in an orchestra. (To simplify the comparison the arrangement of instruments in the above figure has been inverted with the base section on the left and the violin section on the right.)

When a single base plays a note it emits a relatively low frequency (pitch) sound. A single frequency contribution to the spectrum is made in the spectrum plot below at the corresponding frequency value. The height of the contribution (the bar) corresponds to the loudness (amplitude) of the note.

A similar operation is performed for a violin having higher pitch (frequency) and for an instrument located in the middle of the orchestra, having an intermediate frequency.



31: Frequency Spectrum



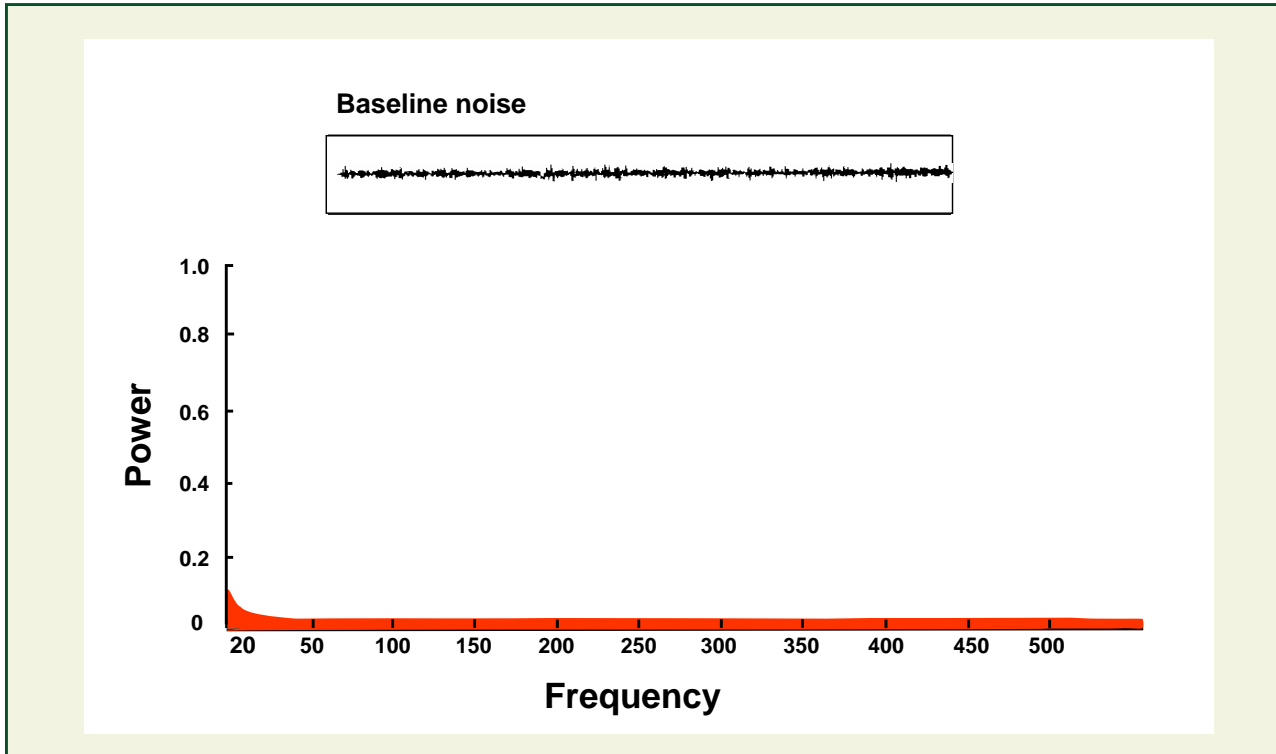
Frequency spectrum:

When all the instruments play, the individual frequency contributions fill the spectrum. And as the orchestra, in unison, modulates the amplitude of all the instruments the envelope of the spectrum modulates correspondingly.

The frequency spectrum of the sEMG signal is constructed in a similar fashion, with a range from 0 to approximately 450 Hz, with a peak in the neighborhood of 80 to 100 Hz.



**32: Noise Contributions to EMG Signal:
Baseline Noise**



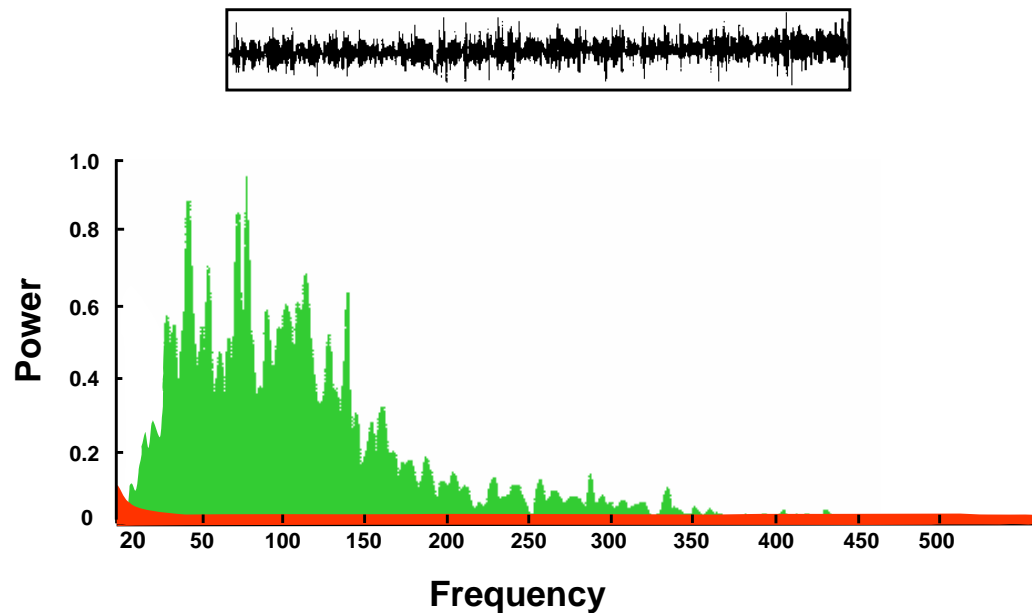
Noise contributions to the EMG signal:

The baseline noise of the recording system has a frequency spectrum that ranges from 0 Hz to a frequency range much greater than the sEMG signal (several thousand Hz). The amplitude is greater at the low frequency end and tapers to a near constant amplitude at higher frequencies, still within the bandwidth of the sEMG signal frequency spectrum.



33: Noise Contamination of the EMG Signal

Baseline noise + EMG signal



Noise contributions to the EMG signal:

The signal in the box consists of the sEMG signal and the baseline noise. Note that there is no visible indication of the presence of baseline noise. The corresponding spectra of the baseline noise (red) and the sEMG signal (green) can be seen in the plot.

The noise spectrum has the characteristics of $1/f$ noise, which has its highest amplitude at 0 Hz. It quickly decreases to a near constant level by 10 to 20 Hz. This is an example of the relative amplitudes measured during a weak contraction (say 10% MVC). During higher level contractions, the baseline noise signal remains constant and the sEMG signal amplitude increases. Hence, the baseline noise is obviously a greater concern for sEMG signals acquired during weak contractions.



34: Movement Artifact

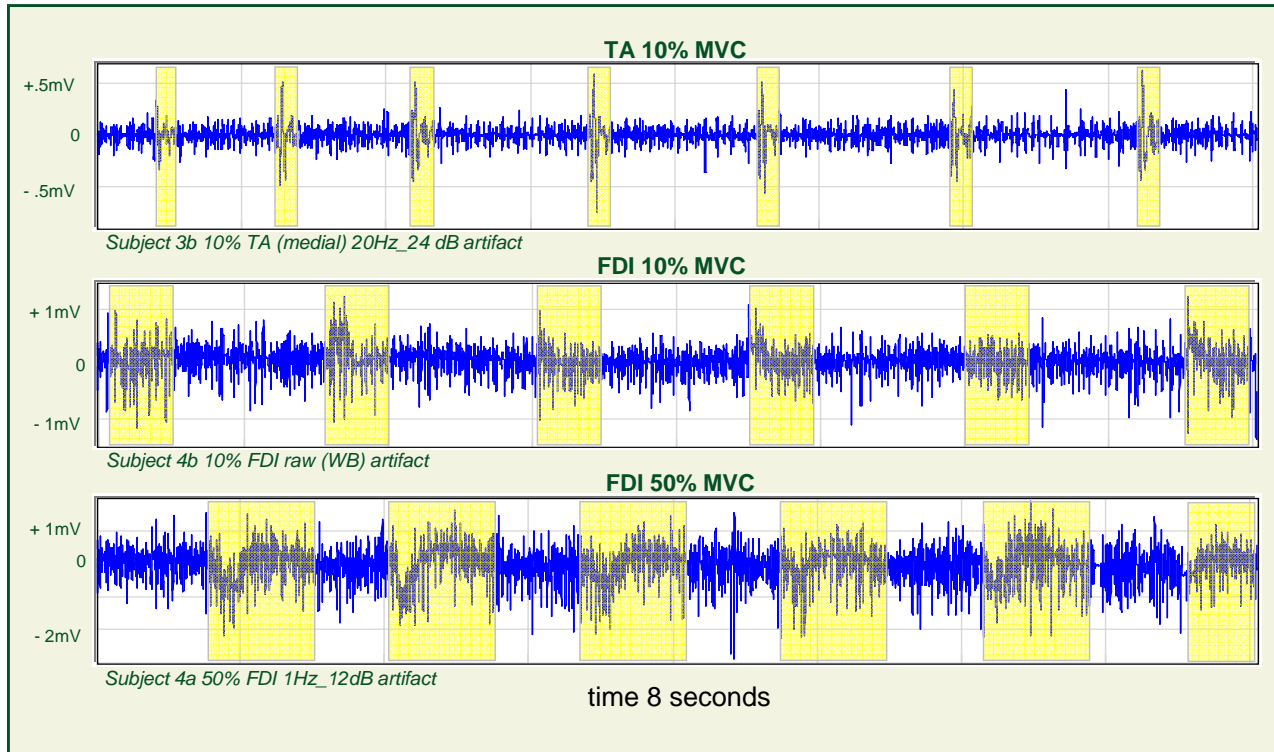
- **Induced by force transmission through the muscle and skin**
- **Caused by relative movement of sensor with respect to skin**
 - Poor electrical contact between electrode and skin
 - The electrolyte material between electrode and skin
- **More dominant in low level EMG signals**
- **Contaminates EMG signal**
 - Frequency components superimpose on those of EMG signal

Movement artifact:

Movement artifact is the most problematic noise in the sEMG signal. In contractions below 10% MVC, it can dominate the amplitude of the signal. It must be addressed when analyzing the sEMG signal. An example is shown in the following slide.



35: Example of Movement Artifact in EMG Signal

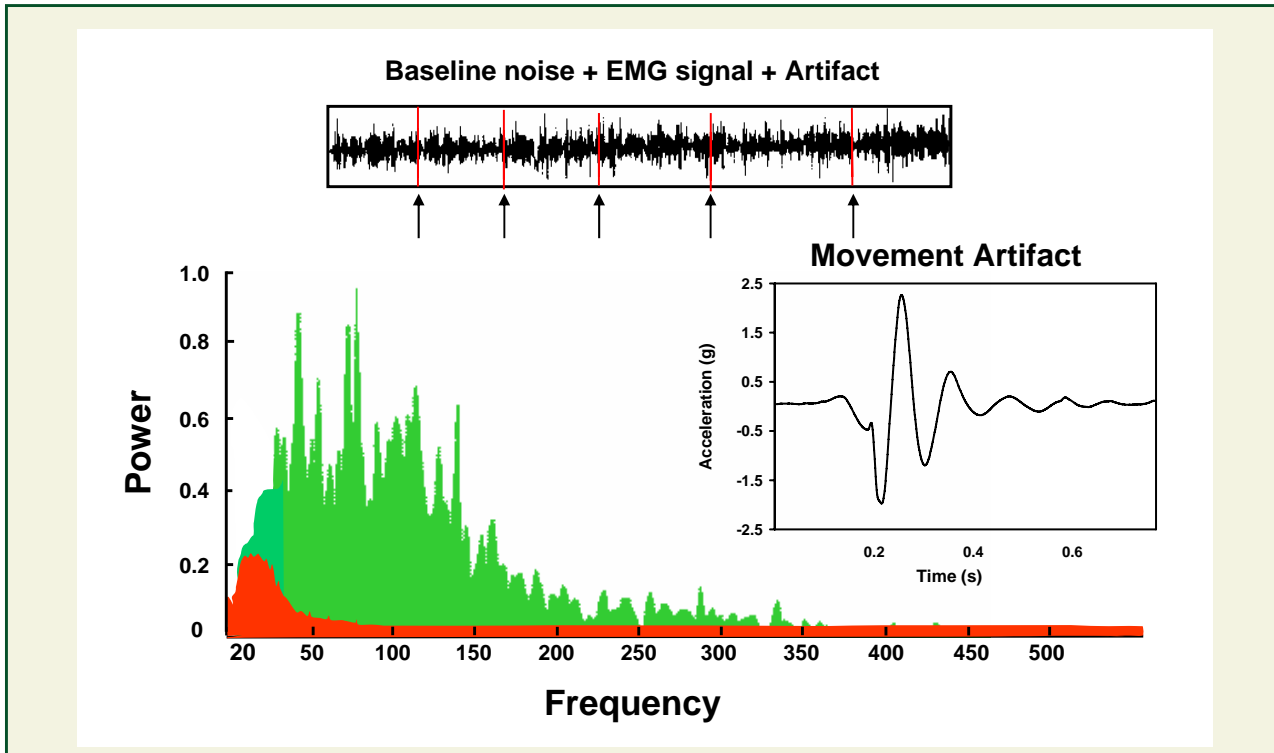


Example of movement artifact in EMG signal:

The movement artifacts are highlighted in yellow in these sample EMG signals. Notice that at low contraction levels, the movement artifact can significantly alter the amplitude of the signal and may cause confusion in the interpretation of the sEMG signal, as the artifact appears to be part of the sEMG signal. At higher contraction levels, the movement artifact may be harder to identify within the EMG signal.



36: Noise Contamination of EMG Signal: Movement Artifact



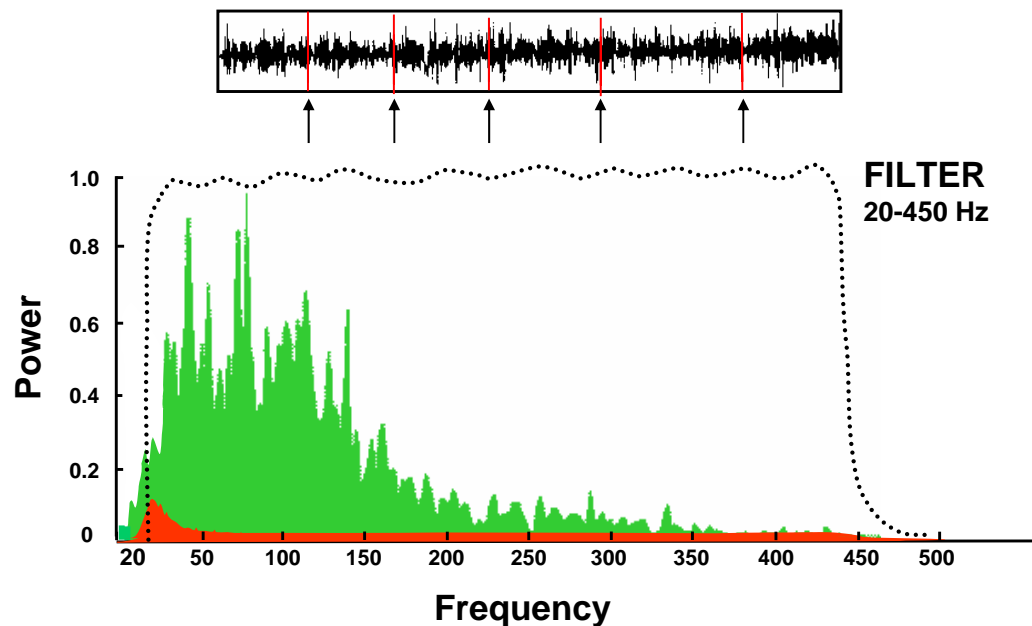
Noise contributions to the EMG signal:

The signal in the box at the top of the slide is an sEMG signal acquired during a contraction in which a movement artifact was induced. The location of the movement artifact is indicated by the vertical arrows. An expanded plot of the movement artifact is shown in the lower frame on the right. This motion artifact is comparable in amplitude and shape to that caused during a heel strike while walking. The frequency spectrum of this artifact together with that of the baseline noise is shown in red. Note that it has a considerably greater amplitude than that of the baseline noise (shown in a previous slide) and the bandwidth generally ranges from 0 Hz to 50 Hz, occasionally it may be higher.



37: Filtering the sEMG Signal

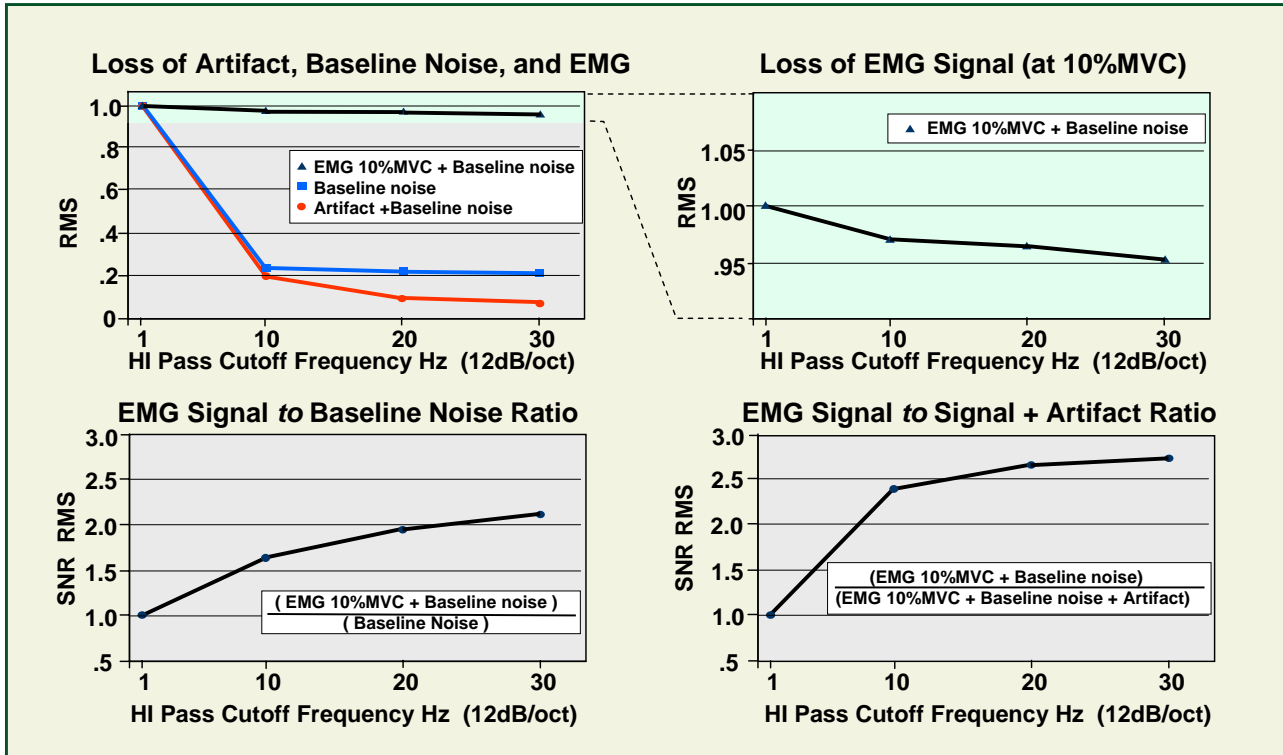
EMG signal with Baseline noise and Artifact reduced



Filtering the EMG signal:

The spectra of both noise sources are shown superimposed on that of the sEMG signal. Much, but not all of their contribution can be removed by judicious filtering. At the high end, a cut-off point at 450 Hz truncates the contribution from the baseline noise without removing any significant contribution from the sEMG signal. At the low-frequency end, a cut-off point at 20 Hz is recommended. This point is contested by other investigators, but the following slide will present evidence in support of this position.

DELSYS®38: Effect of Hi-Pass Filter Cutoff Frequency on EMG Signal Parameters
 I.P. of Carlo J. De Luca



Effect of Hi-Pass filter cutoff frequency on EMG signal parameters:

Top left panel -- Losses in the RMS value of the sEMG signal (black), the Baseline noise (blue), and the movement artifact (red) when the signal is filtered with a high-pass (low-frequency cut-off) at 1, 10, 20 and 30 Hz. Approximately 80% of the noise is removed at 10 Hz, with only 3% loss in the sEMG signal (top right panel). However, an additional 10% of the movement artifact is removed at 20 Hz, with no appreciable additional loss of sEMG signal. Filtering at 30 Hz does not appear to provide any real benefits in noise reduction, while it removes approximately an additional 1% of the sEMG signal.

The benefit of filtering at 20 Hz may be seen in the bottom two panes, where the signal to noise ratio increases only marginally at 30 Hz. It should be noted that for movement artifacts having a wider bandwidth, the cut-off frequency should be greater than 20 Hz.



39: Effect of Hi-Pass Filtering Compared to Sensor Location

<u>RMS Amplitude</u>	<u>High Pass -3dB</u>	<u>Slope dB/oct</u>	<u>Shift</u>
	10Hz → 20Hz	12dB → 24dB	2cm
Resting Noise (RMS)	↓ 10 - 20%	↓ <6%	
Resting Noise + Artifact (RMS)	↓ 10 - 50%	↓ <13%	
sEMG signal (10% -100% MVC)	↓ <2%	↓ <1%	19 - 38%
sEMG signal + Artifact (10% -50% MVC)	↓ <4%	↓ <3%	19 - 38%
<u>Median Frequency (Hz)</u>			
sEMG signal (10% -100%MVC)	↑ <3%	↑ <1%	10 - 20%
<u>Signal to Noise Ratio</u>			
Resting Noise + Artifact Signal (artifact reduction)	↑ 20 - 36%	↑ 4 -10%	
sEMG signal (10% -100% MVC)	↑ 11 - 28%	↑ <7%	
sEMG signal + Artifact (10% -50% MVC)	↑ 11 - 28%	↑ <7%	

Effect of hi-pass filtering compared to sensor location:

Note that a 1 cm shift in the location of the sensor introduces a dramatic variation in the amplitude of the sEMG signal, in the range of 10 to 40%. This is far greater than that resulting from filtering. Thus, in terms of amplitude consistency, electrode positioning (inter-subject comparison) and re-positioning (intra-subject comparison) is more important for obtaining a greater signal to noise ratio.

FOR MORE INFORMATION ON SENSORS go to [Appendix A: sEMG Sensor Factors.](#)



40: How to Reduce Movement Artifact

- **Remove excessive hairs. Moderate hair can remain**
- **Clean the skin with alcohol to improve electrical contact with electrode**
- **Use a good adhesive to maintain contact**
- **Do NOT use gel electrolyte**
- **High pass filter the sEMG signal at 20 Hz**



41: Recommendation: Detecting the sEMG Signal

- **Active Sensor of High quality signal**
 - Reduces cable artifact
 - Reduces noise contamination
- **Differential detection**
 - Reduces ambient electrical noise
- **Fixed Inter-electrode spacing (Preferably 1 cm)**
 - Maintains constant frequency bandwidth
 - Reduces cross-talk
- **Effective Electrode-Skin preparation for sEMG sensor and Reference electrode**
 - Reduces Noise contamination
 - Reduces ambient electrical noise
 - Reduces movement artifact
- **Locate sensor in the belly of the muscle**
 - Reduces cross-talk
 - Increases signal to noise ratio
 - Do not place sensor on the tendon or on the innervation zone