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UNLOCKING MUSCLE POTENTIAL

A Comprehensive Guide to
Kinvent's Portable Surface EMG

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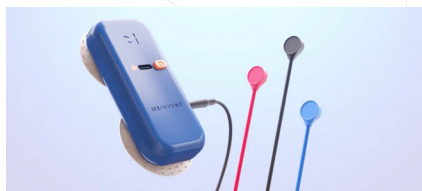
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INTRODUCTION

Welcome to this essential guide on surface electromyography (sEMG), a cutting-edge experimental technique.

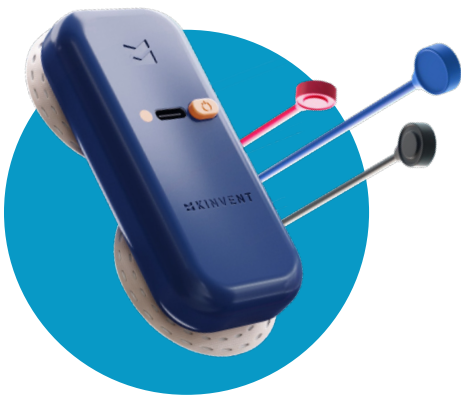
While not intended to replace the in-depth coverage found in comprehensive EMG literature, this guide simplifies your first steps in using surface EMG (sEMG) as a tool for research and evaluation. In these pages, you'll find a succinct overview and summary of the vital knowledge needed to establish a meaningful sEMG assessment. Our focus is on the practical elements and solutions, offering you a hands-on approach to this sophisticated technology. For those who wish to delve deeper, we recommend consulting specialized scientific publications and textbooks. These resources will broaden your understanding of the diverse perspectives, opinions, and strategies crucial for effective sEMG application.



04.2024 — **ESSENTIAL
GUIDE / SURFACE
ELECTROMYOGRAPHY (sEMG)**

—
A CUTTING-EDGE
EXPERIMENTAL TECHNIQUE.

WHAT IS EMG?



Surface electromyography (sEMG) stands as a specialized technique centered on the generation, capture, and interpretation of myoelectric signals. These signals emerge from the physiological shifts occurring in the muscle fiber membranes. Unlike the conventional sEMG procedures in Neurology, which evaluate artificially-induced muscle responses in static scenarios, kinesiological sEMG delves into the realm of voluntary muscle activity. It's particularly insightful during postural tasks, dynamic movements, work-related activities, and within therapeutic or training frameworks.

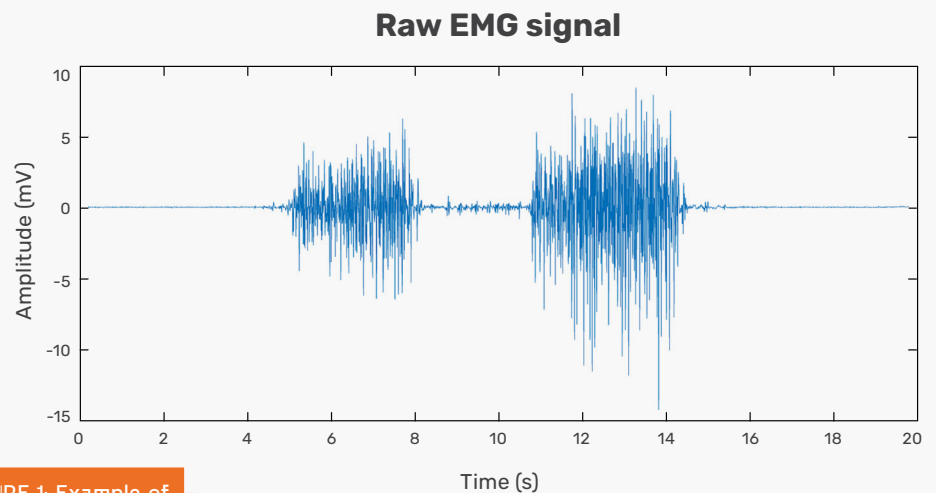


FIGURE 1: Example of a surface EMG signal

ADVANTAGES AND POTENTIALS OF SEMG

sEMG is distinguished as a sophisticated method in neurophysiological muscle analysis. Its non-invasive nature marks it as a safe, straightforward approach to measure muscle activity. The uniqueness of sEMG lies in its capability to offer an all-encompassing view of muscle function, a feat not achievable by

traditional methods such as visual observation or palpation. The graphical display of muscle activity sEMG provides enables a deeper exploration into the dynamics of muscle energy, during both rest and movement. The advanced technology of sEMG, particularly when combined with other sensors often used in biomechanics

such as inertial measurement units (IMU) of force plates, illuminates specific muscle functionalities and their coordination. This reveals critical insights into the nervous system's management of muscle functions, pivotal for accurate medical diagnosis and therapy.

sEMG OPENS THE DOOR TO ANSWERING KEY QUESTIONS

- Does the resting tone align with palpation findings?
- Are the muscles activating too early or too late in the recruitment sequence?
- Does a particular exercise target the intended muscle, or is there a compensatory pattern?
- Does the muscle relax post-movement, or does it remain irritable?

In the realm of evidence-based medicine, objective data reigns supreme. sEMG excels in this aspect, allowing practitioners to share their insights with peers, researchers, and insurance entities. Its established significance in Western medicine is clear. Additionally, the capacity to communicate sEMG results to patients paves the way for enhanced neuromuscular education. By visually witnessing their muscle activation patterns, patients gain the ability to fine-tune their control, aligning more closely with therapeutic guidance.

APPLICATIONS OF sEMG

sEMG has transcended its fundamental role in physiological and biomechanical research to become a cornerstone in various domains. As a crucial evaluation tool in applied research, it empowers scientists to uncover vital data and insights into muscle functionalities and interactions. In physiotherapy and rehabilitation, sEMG has proven itself indispensable, aiding healthcare professionals in monitoring muscle activity, gauging patient progress, and crafting personalized therapeutic strategies. This technology plays a pivotal role in formulating more efficient treatment plans, significantly contributing to improved recovery outcomes.

In the realm of sports training, sEMG serves as a critical asset, enabling trainers and athletes to decode muscle behavior during diverse physical activities. By scrutinizing muscle responses, trainers can craft highly tailored training programs, enhancing athletic performance while mitigating injury risks.

Beyond the spheres of healthcare and athletics, sEMG is instrumental in evaluating human interactions with industrial products and workplace conditions. Its application is vital in ergonomic studies and industrial design, driving the creation of products and environments that align with human physiological capabilities. This not only boosts productivity but also curtails the likelihood of work-related injuries.

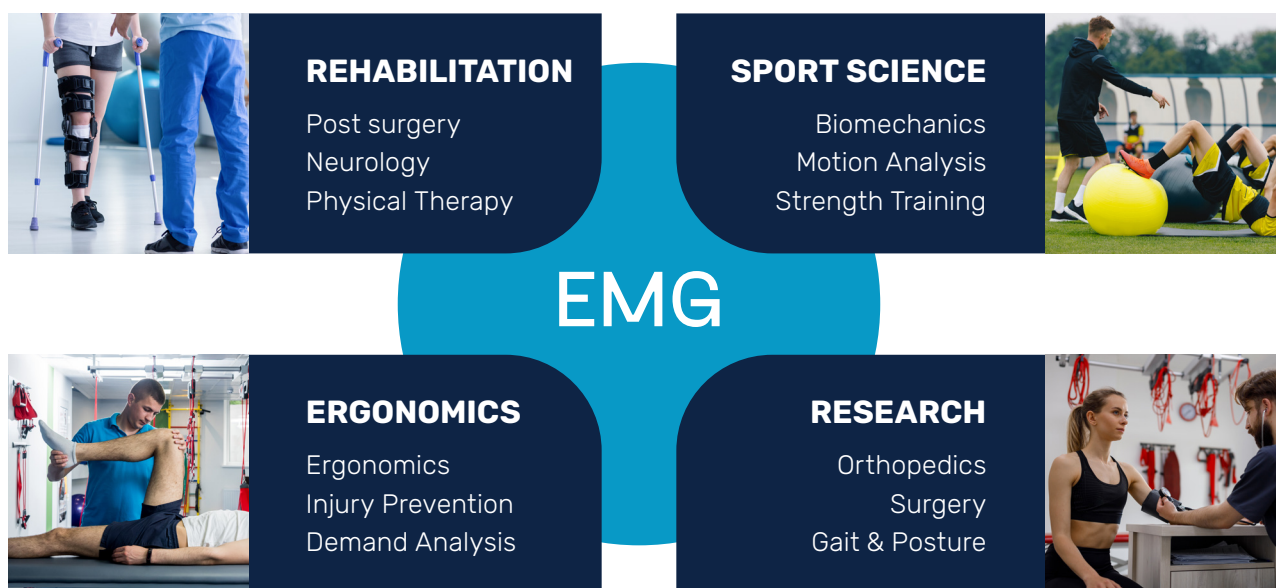


FIGURE 2: Typical applications of EMG

KEY BENEFITS OF USING EMG

- EMG sheds light on the intricacies of muscle activity.
- It streamlines the assessment of muscle performance.
- It informs decision-making processes, both pre- and post-surgery.
- EMG serves as a benchmark for tracking treatment progress and training regimes.
- It empowers patients to engage and exercise their muscles effectively.
- It is pivotal in analyzing and refining sports activities.
- EMG plays a crucial role in identifying muscle responses in ergonomic research.

PHYSIOLOGY OF THE SIGNAL: MOTOR UNIT

The concept of a 'Motor Unit' represents the smallest functional entity in the neural regulation of muscle contraction, as depicted in Figure 3. Defined as the combination of a motor neuron's cell body and dendrites, its axonal branches, and the muscle fibers it innervates, a Motor Unit epitomizes the intricate synergy within the neuromuscular system. The term 'unit' emphasizes a pivotal aspect of motor unit functionality: the synchronization of all muscle fibers within a particular motor unit, responding 'as one' during the innervation process. This synchrony ensures that when a signal is dispatched to a motor unit, every muscle fiber governed by that unit reacts simultaneously. Such harmonized action of muscle fibers is vital for fluid and coordinated movements, streamlining the neuromuscular control of motion. The nervous system, therefore, perceives each motor unit as a singular entity, despite it comprising numerous individual muscle fibers. This perception simplifies the intricate orchestration of muscle contractions and movements. In essence, the motor unit is the foundational element of our understanding of the neural control of muscular contraction, with its defining features and operational unity accentuating its paramount role in the neuromuscular system.

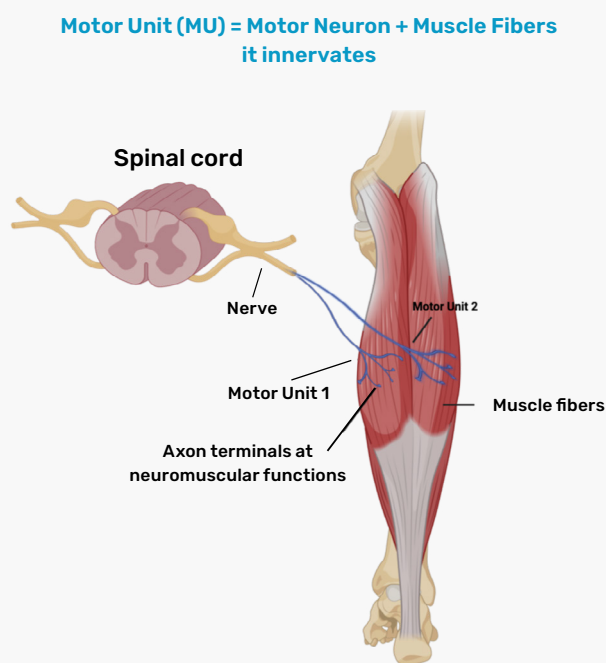


FIGURE 3

Axon of motor neurons extend from the spinal cord to the muscle. There each axon divides into a number of axon terminals that form neuromuscular junctions with muscle fibers scattered throughout the muscle

EXCITABILITY OF MUSCLE FIBERS

The excitability of muscle fibers, governed by neural mechanisms, is crucial for understanding muscle physiology. This concept is exemplified by the semi-permeable membrane model, highlighting the electrical characteristics of the sarcolemma, the delicate sheath

enveloping skeletal muscle fibers. The essence of this model is the ionic disparity between the inside and outside of a muscle cell, establishing a resting potential across the muscle fiber membrane. In a non-contracted state, this potential typically ranges from -80 to -90

millivolts (mV). This potential difference, sustained by an ion pump-based physiological process, results in the cell's interior being negatively charged relative to its exterior.

The activation journey commences with the stimulation of an alpha-motor anterior horn cell, triggered by the central nervous system or reflexively. This leads to the propagation of excitation along the motor nerve, culminating in neurotransmitter release at motor endplates and the creation of an endplate potential in the innervated muscle fiber. Consequently, the muscle fiber membrane's diffusion

properties are temporarily altered, allowing an influx of sodium ions (Na^+). This influx prompts a rapid membrane potential change, known as Depolarization. However, this state is swiftly restored by the active ion pump, which facilitates a reverse ion exchange, a process termed Repolarization. These intricate and coordinated processes enable precise muscle contraction and relaxation control, essential for movement and functionality, showcasing the intricacies of muscle physiology and the profound impact of neural control.

GENERATION OF SIGNAL

When the sodium ion (Na^+) influx surpasses a certain threshold, it ignites an Action Potential, swiftly transitioning the membrane potential from -80mV to $+30\text{mV}$. This abrupt, monopolar electrical surge is swiftly succeeded by a repolarization phase and an After Hyperpolarization period. The action potential, emanating from motor endplates, disseminates bidirectionally across and within the muscle fiber through a tubular system. This excitation prompts the release of calcium ions within the cell. Subsequent electrochemical processes, referred to as Electro-Mechanical Coupling, induce muscle cell components to contract. While the link between excitation and contraction is robust, it's worth noting that some minor excitations may not lead to contraction. Nonetheless, in healthy muscles, contractions are generally coupled with these mechanisms. The EMG signal originates from the action potentials at the muscle fiber membrane, driven by the aforementioned depolarization and repolarization processes. The extent of the Depolarization zone is estimated to be approximately $1\text{-}3\text{mm}^2$.

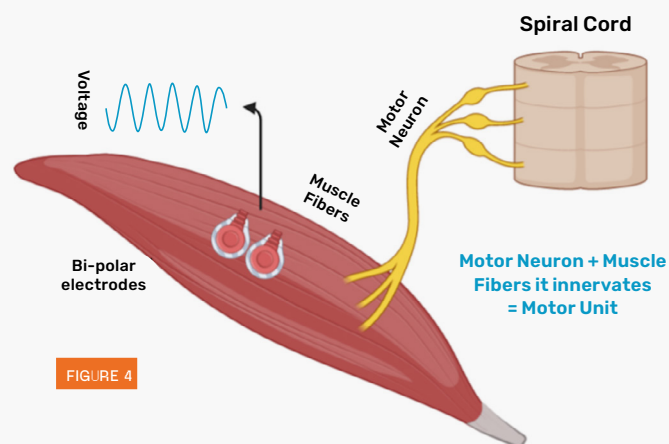


FIGURE 4



LIMITATIONS OF EMG

Monitoring Limits: While sEMG boasts advanced features, its capacity to monitor multiple muscle sites simultaneously is limited. Given the complex nature of the neuromuscular system, this constraint can be limiting. For a broader perspective, it's recommended to use a four-channel sEMG instrument, offering insights into the dynamics of opposing muscle groups.

Muscle Substitution Challenges: A critical challenge in sEMG is differentiating true muscle activity from

substitution patterns, where diverse muscle groups may mimic identical movements, leading to potential interpretation complexities.

Crosstalk Issues: A significant technical limitation is the 'crosstalk' phenomenon, where the energy of one muscle group interferes with another. This interference can hinder precise measurements and impact the specificity of sEMG recordings.

Standardization Difficulties: The effectiveness of sEMG can suffer from inconsistencies, particularly concerning electrode placement in different clinics or studies. Such variations can result in divergent interpretations, affecting the generalizability of the results.

Interpretation Nuances: It's crucial to recognize that sEMG doesn't directly measure muscle strength or force but focuses on electrical activity. Without appropriate normalization techniques, comparing sEMG amplitudes across different muscles can yield misleading outcomes.

Despite these challenges, sEMG remains an invaluable technique in muscle function analysis, enhancing traditional methods with objective, comprehensive data. However, realizing its full potential requires acknowledging and addressing its limitations, including standardization needs and the risk of misinterpretation. Balancing its strengths and limitations is key to effectively leveraging sEMG in clinical and research environments.



SIGNAL DETECTION IN ELECTROMYOGRAPHY (EMG)

Electromyography (EMG) stands as a pivotal tool in muscle function analysis, capturing and analyzing the electrical signals produced by muscles during contractions. These signals are essentially the collective action potentials from numerous muscle fibers, offering a window into the muscle's operational dynamics. The genesis of an action potential involves a swift shift in the muscle fiber's membrane potential, known as depolarization, initiated by a nerve impulse. This phase sees a surge of sodium ions into the cell, catapulting the membrane potential from around -80 millivolts (mV) to up to $+30$ mV. This is swiftly followed by repolarization, resetting the membrane to its resting state.

As the cycle of depolarization and repolarization unfolds, it generates an electrical wave that travels along the muscle fiber. This movement creates a potential difference detectable between two points on the fiber. In EMG, this difference is captured via a bipolar electrode setup and differential amplification, turning the muscle's activity into a quantifiable signal.

Imagine an action potential moving towards a pair of electrodes. As it nears the first electrode, the potential difference between the electrodes grows, hitting a peak as the action potential aligns with the first electrode. As it advances past the first and moves towards the second electrode, the potential difference shifts, peaking again when the action potential aligns with the second electrode. This dynamic creates a bipolar signal from the initial monopolar action potential.

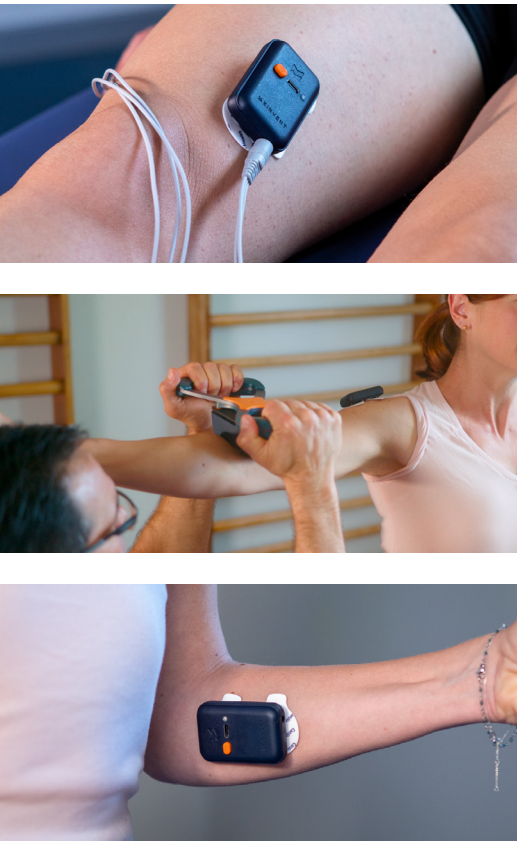
The collective activity of all muscle fibers within a motor unit, each fiber innervated by a single motor neuron, is represented in the signal detected by the electrodes. This activity forms a characteristic triphasic Motor Unit Action Potential (MUAP), its shape and size influenced by the fibers' geometric alignment relative to the electrode.

Detecting EMG signals requires precise electrode placement and sophisticated signal processing to navigate the signals' subtlety and potential external noise interference. Mastery of signal propagation and detection principles is essential for the effective use of EMG in assessing muscle functionality.

COMPONENTS OF THE EMG SIGNAL

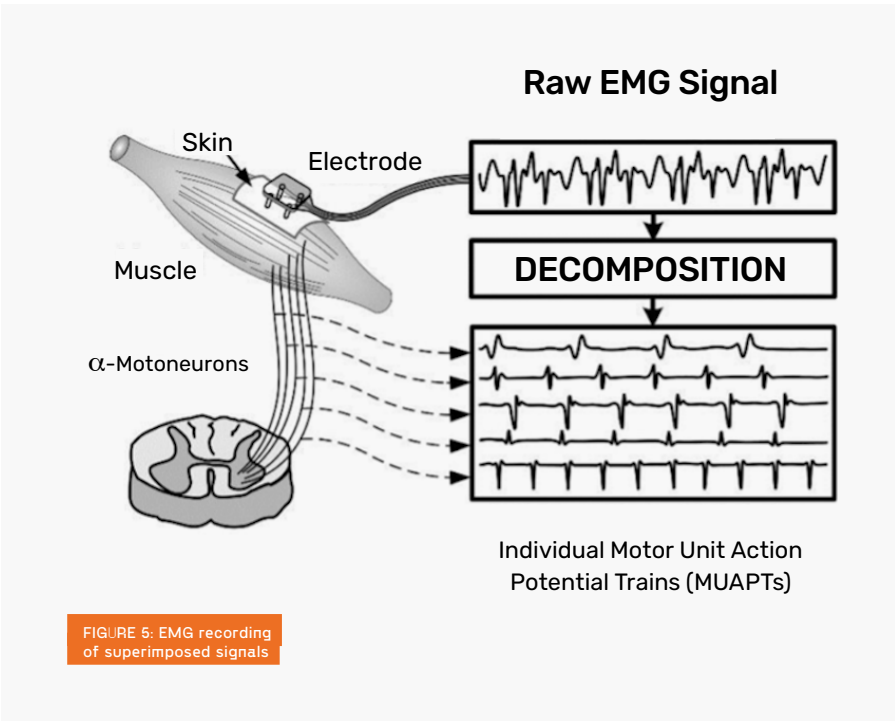
SUPERPOSITION OF MOTOR UNIT ACTION POTENTIALS

In the realm of kinesiological research, the electrical activity detected at the electrode site includes the overlaid Motor Unit Action Potentials (MUAPs) from all active motor units. This overlay generates a bipolar signal characterized by a symmetric distribution of positive and negative amplitudes, averaging to zero. This combined signal is known as an Interference Pattern, offering a snapshot of muscular electrical activity during contractions.



MOTOR UNIT RECRUITMENT AND FIRING FREQUENCY

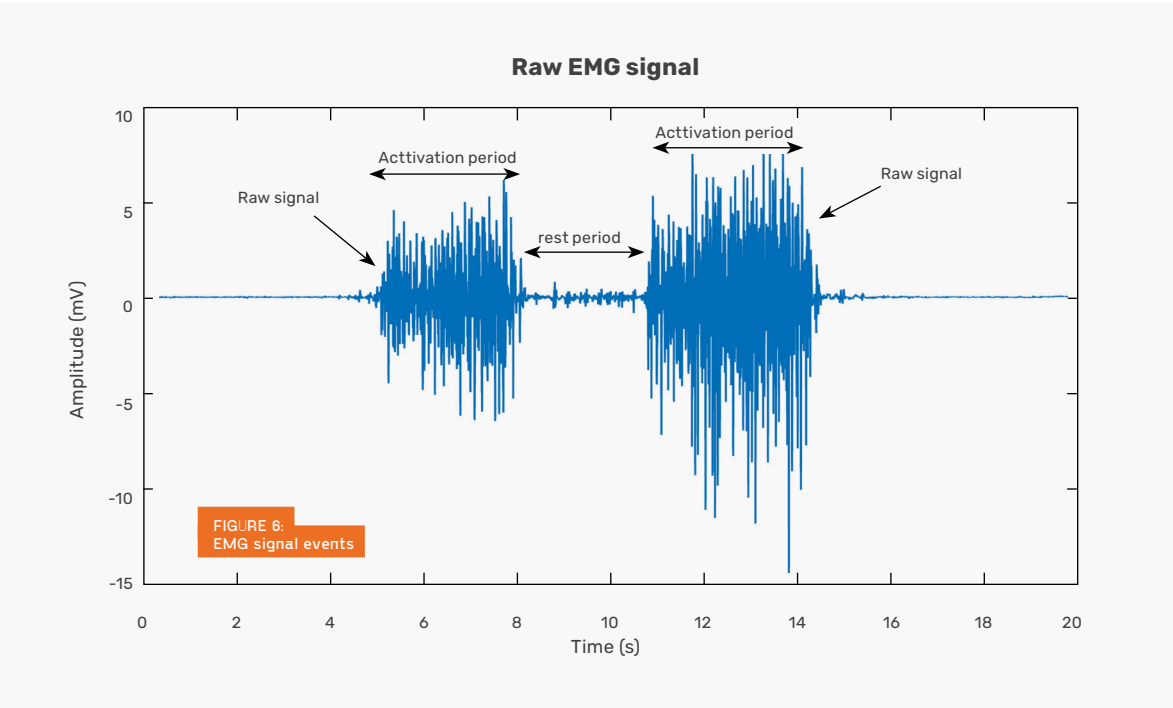
The intensity and density of the EMG signal are primarily influenced by two factors: the recruitment of MUAPs and their firing frequency. These mechanisms are crucial for adjusting the muscle's force during contractions. As additional motor units are recruited, the signal's magnitude increases, enhancing the muscle's force output. Similarly, the firing frequency, or the rate at which a motor unit is activated, plays a significant role in muscle force generation. However, it's important to note that surface EMG recordings might not precisely mirror the original characteristics of firing rate and amplitude due to the skin and connective tissues' low-pass filtering effect, which alters the original signal. Despite these modifications, the EMG signal broadly reflects the recruitment and firing patterns of the motor units within the muscle under examination, offering valuable insights into muscle behavior and performance.



DYNAMICS OF THE RAW EMG SIGNAL

The raw EMG signal, captured directly without filtering (beyond the amplifier's bandpass) or processing, is a dynamic and time-varying physiological signal that encapsulates the collective electrical activity of superimposed MUAPs. It provides detailed information on the complex interplay of muscle fibers and their motor units. For instance, a raw surface EMG (sEMG) recording

from static contractions of the biceps brachii muscle illustrates this principle. The nature of the raw EMG signal appears random or stochastic due to the asynchronous and varied activation of motor units. It exhibits non-stationary characteristics, with statistical properties like mean and variance changing over time, influenced by muscle's physiological state, force generation, and fatigue levels.



EMG BASELINE QUALITY IN MUSCLE RELAXATION

When a muscle is relaxed, the EMG should display a baseline that is essentially free of noise. The integrity of this baseline is influenced by several factors, including the performance of the EMG amplifier, environmental noise, and the conditions under which detection occurs. With an optimally performing amplifier and proper skin preparation, the average baseline noise should ideally remain below 1 to 2 microvolts, with 3 to 5 microvolts representing the upper threshold. Conducting a detailed assessment of the EMG baseline quality is crucial in every measurement to distinguish genuine muscle activity from signal noise or perceived hypertonicity.

In relaxed states, the raw surface EMG (sEMG) signal amplitude can fluctuate within a range of ± 5000 microvolts, particularly in athletes, with its frequency content spanning from 6 to 500 Hz, and the most significant power between 20 and 150 Hz. The inherent randomness of the raw EMG signal means that reproducing an identical recording burst is not feasible, due to the ever-changing combination of recruited motor units. When two or more motor units fire simultaneously and are proximal to the electrodes, superposed spikes occur. To reduce the non-reproducible elements of the signal, techniques such as applying a moving average smoothing algorithm or selecting an appropriate amplitude parameter, like the area under the rectified curve, are employed.

KEY FACTORS INFLUENCING EMG SIGNAL QUALITY AND INTERPRETATION

For accurate interpretation and application of EMG, understanding the factors affecting its signal is paramount. These factors fall into five main categories:

- **Tissue Characteristics:** The EMG signal is significantly influenced by the properties of the tissues it traverses. The conductivity of tissues like fat, muscle, and skin can alter the signal's amplitude and frequency content. Factors such as subcutaneous fat thickness, hydration status, muscle fiber type distribution, and blood flow also play roles in signal quality.
- **Physiological Crosstalk:** EMG readings can be distorted by crosstalk, the detection of activity from non-target muscles. This issue, prevalent among superficial muscles detectable with surface EMG, can be mitigated with precise electrode placement, though it remains a challenge in anatomically complex muscle groups.
- **Geometry Between Muscle Belly and Electrode Site:** The EMG signal is affected by the electrode's position relative to the underlying muscle. Changes in muscle length or position due to joint movements can influence the signal by altering the electrode's distance to active muscle fibers, especially during dynamic tasks.
- **External Noise:** Noise from external electromagnetic sources, like power lines or electronic devices, can infiltrate the EMG signal. Reducing this noise involves using shielded cables, grounding the EMG system and subject, and selecting a low-interference testing environment.
- **Electrodes and Amplifiers:** The technical specifications of the recording system, including electrode type, placement, inter-electrode distance, and amplifier performance (CMRR, input impedance, noise characteristics), directly impact signal quality.

Addressing these factors through meticulous setup and execution ensures the EMG data's accuracy and reliability, making it a valuable tool in neuromuscular assessment and research.

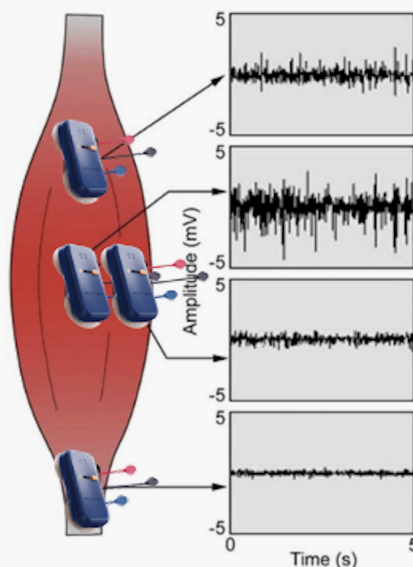
STRATEGIES FOR EFFECTIVE ELECTRODE PLACEMENT IN sEMG

Electrode placement is pivotal for the precise recording of SEMG activity, as electrodes are the primary sensors for capturing this activity. Although there is sparse literature on this topic, Fridlund and Cacioppo have identified six essential principles to improve the quality of SEMG recordings:

1. **Proximity to Targeted Muscle:** Choose a site close to the targeted muscle mass to reduce the tissue layer between the electrodes and muscle fibers. This proximity minimizes signal interference and enhances the recording's accuracy.
2. **Alignment with Muscle Fibers:** Position the electrodes parallel to the muscle fibers, as shown in Figure 7, to maximize sensitivity and specificity. Electrodes placed perpendicular to the fibers may compromise selectivity due to reduced alignment with the electrical activity path.
3. **Avoidance of the Motor End Plate Region:** Placement in the motor end plate region can result in lower recorded amplitudes because of differential amplification. Ideally, position electrodes along the midline of the muscle belly, equidistant between an innervation zone and the myotendon junction, ensuring alignment with the muscle fibers for optimal recording.
4. **Use of Anatomical Landmarks:** Opt for locations with clear anatomical landmarks to ensure consistent and reproducible electrode placement in subsequent sessions. This approach aids in maintaining the precision and reliability of SEMG recordings over time.
5. **Consideration of Practicality:** Choose sites that do not obstruct vision or movement and steer clear of problematic areas such as skin creases, bony prominences, and other physical obstructions that could compromise electrode placement or signal quality.
6. **Minimization of Interference:** Select the appropriate electrode size and space between electrodes carefully to limit interference from adjacent muscles. This consideration is crucial for isolating the desired muscle activity and avoiding crosstalk from nearby muscles.

By adhering to these six principles, researchers and clinicians can significantly enhance the quality of SEMG recordings, ensuring that the data collected is both accurate and reliable. Proper electrode placement is not only a matter of technical proficiency but also of understanding the anatomy and physiology of muscle activity, which are essential for the effective use of SEMG in muscle function analysis.

FIGURE 7. **Sensor Location**



Innervation Zone: Worst placement – The signal travels multi-directionally causing the frequency spectrum to skew higher

Correct Placement: Midline of the muscle belly between an innervation zone and myotendon junction in orientation of muscle fiber

Midline Offset: Signal degrades from crosstalk (activity of nearby muscles)

Myotendon Junction: Signal decreases due to very few and thinner muscle fibers

SIGNAL QUALITY PROCEDURES IN EMG STUDIES

Ensuring the validity and quality of EMG signals is a fundamental step in all EMG research, independent of skin preparation methods or electrode application techniques. To achieve this, several key procedures should be undertaken.



CHECKING SIGNAL VALIDITY

This critical step verifies that the correct muscle is being monitored and that genuine signals are being recorded. Signal sensitivity at the electrode site can be assessed by gently manipulating the cable, moving the limb, or applying slight pressure to the area. This helps confirm that the electrodes are adequately capturing the muscle's electrical activity.

IDENTIFYING ISSUES WITH SUBCUTANEOUS FAT

Thick subcutaneous fat layers can dampen EMG signals, rendering them weak or undetectable. It's vital to assess the thickness of subcutaneous fat at the electrode site to ensure signal strength will not be compromised.

CONDUCTING EXPLICIT STATIC TEST CONTRACTIONS

Performing static contractions can validate the capability of the EMG setup to capture meaningful data and confirm the subject's ability to activate the targeted muscle. During these tests, an increase in EMG signal amplitude in response to muscle contraction indicates a valid and functional recording setup.

DETAILED PROCEDURES EXPLAINED:

Electrode Site Sensitivity: Assessing this involves checking for signal responsiveness to movement, pressure, or limb manipulation. A non-responsive electrode site may indicate poor signal capture, necessitating adjustments.

Thick Subcutaneous Fat Tissue: Given that thick fat layers can weaken EMG signals, evaluating the tissue's thickness is crucial for predicting signal quality. Excessive thickness may require alternative electrode placement or adjustments to recording parameters.

Static Test Contractions: These are performed to ensure the recording setup can detect valid data. The ability of the subject to visibly contract the muscle and produce a corresponding increase in EMG signal amplitude serves as a confirmation of signal validity.

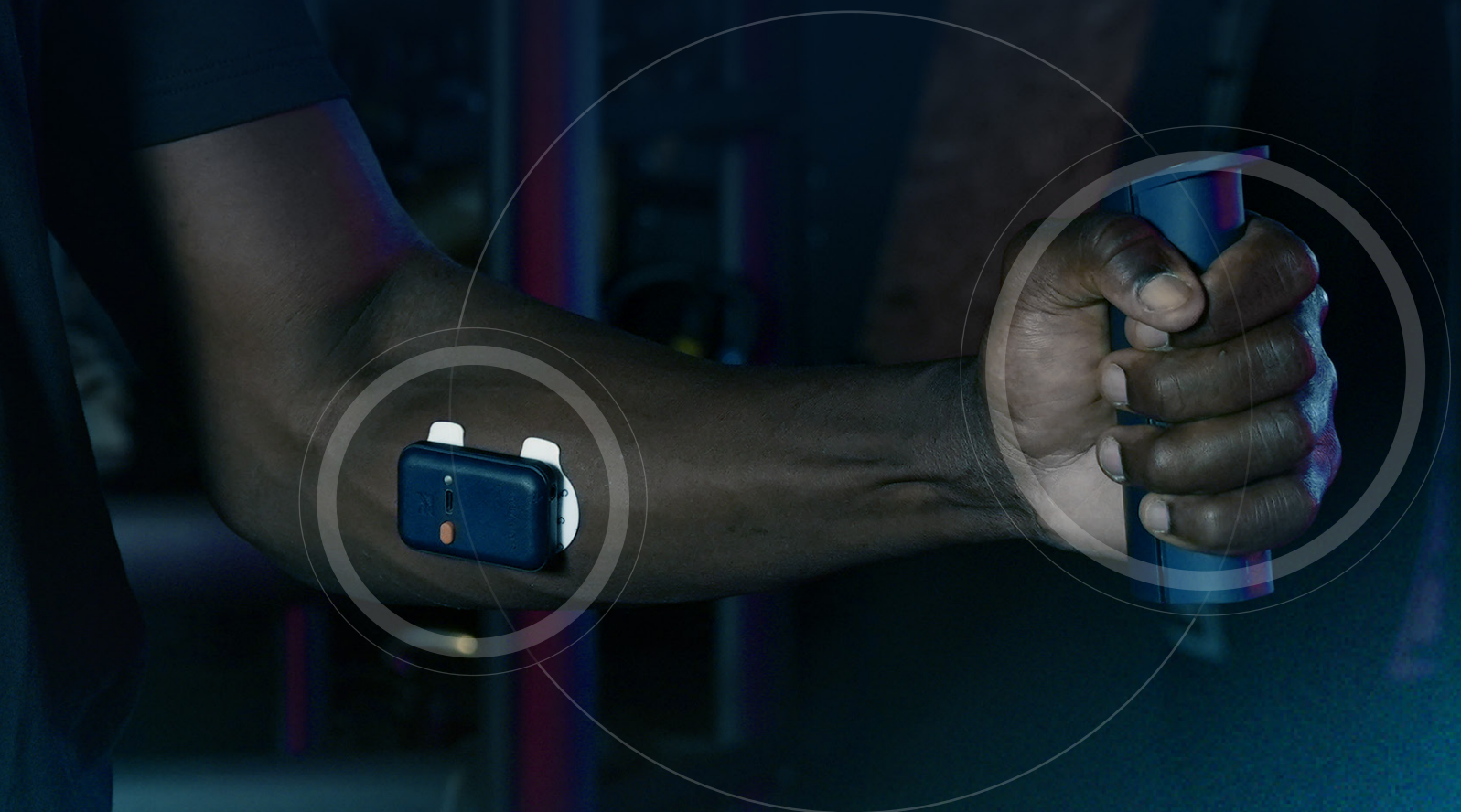
By meticulously following these steps, researchers can significantly enhance the reliability and accuracy of EMG data collection, ensuring that the signals recorded are both valid and of high quality.



QUALITY ASSESSMENT OF RAW EMG BASELINE

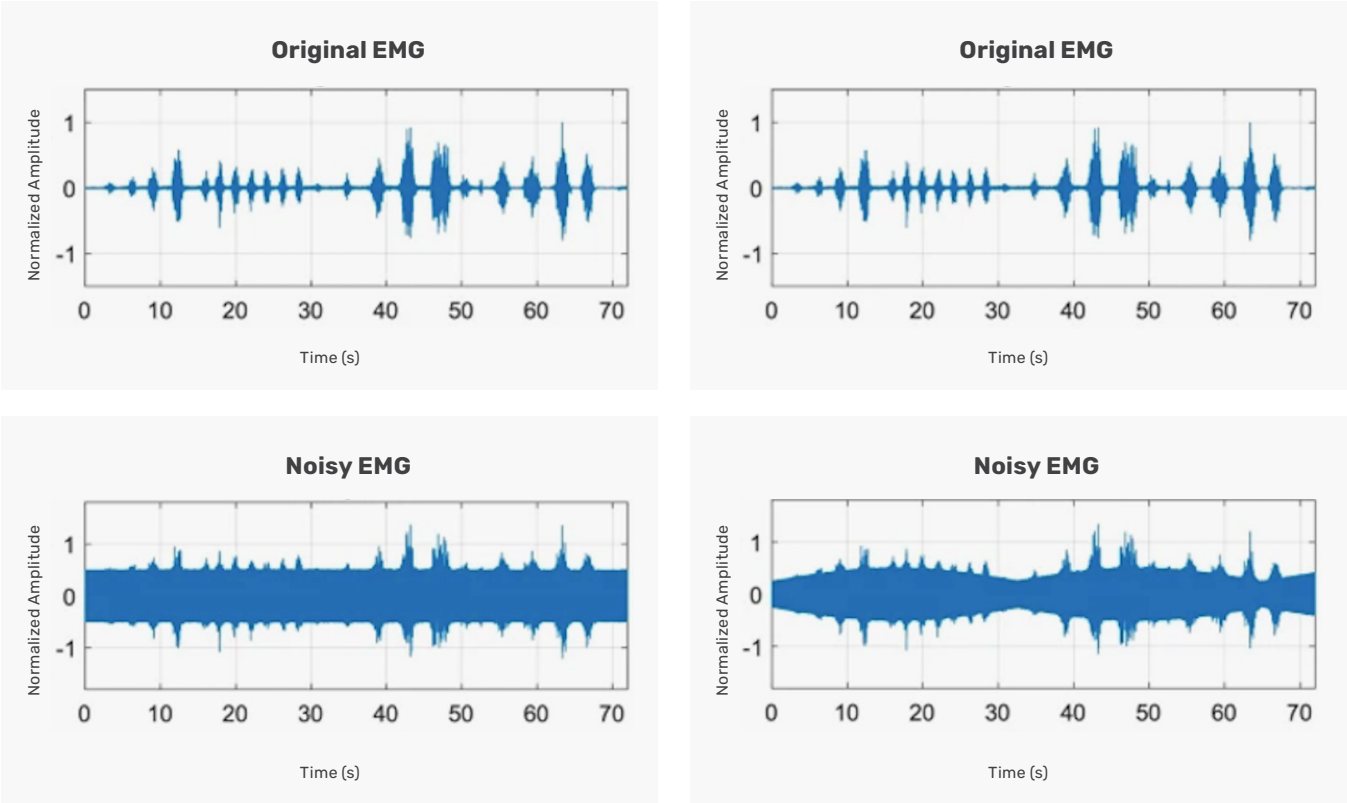
Visually reviewing the raw EMG baseline is an indispensable step that cannot be replaced by automated methods such as impedance checks. Given that the amplifier is tasked with detecting signals in the delicate microvolt range, these signals are highly susceptible to distortion from external noise or artifacts if not properly managed.

Upon connecting the electrodes to the amplifier, initiate the PC-signal monitor and closely examine the raw EMG trace for each channel. It's essential that the test subject is in a state of complete relaxation, which can be facilitated by having them lie on a therapy bench or similar equipment to ensure genuine relaxation.

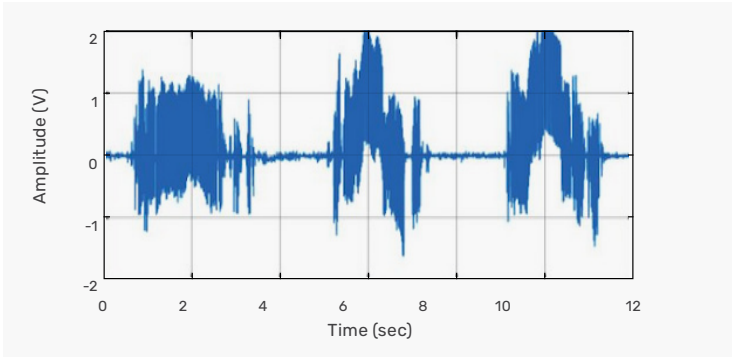


Your examination of the EMG baseline should focus on three primary aspects:

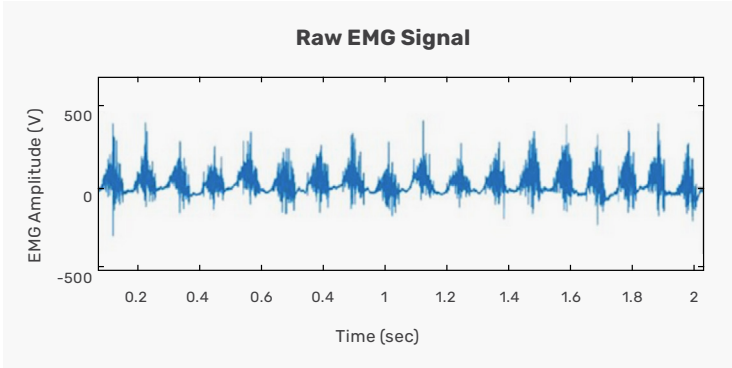
- 1. Baseline Noise:** A completely noise-free recording is unachievable; expect to observe minor spikes or fluctuations, but these should not surpass 10–15 microvolts. The optimal average noise level, calculated from the mean amplitude of the raw, rectified EMG over a 5-second period, should ideally fall between 1 (excellent) and 3.5 microvolts. Additionally, a frequency distribution test can serve as a secondary, objective method to assess baseline quality.



- 2. Baseline Offset:** Although most amplifiers feature automatic offset correction, the EMG baseline may still deviate from the true zero line. This deviation can be checked by verifying whether the mean value of the raw EMG equals zero. Failure to identify and adjust for this shift can result in inaccurate amplitude-based analyses for that record.



- 3. Baseline Shifts:** The baseline should consistently return to the zero line both before and after contractions. Any deviation suggests the presence of EMG artifacts or baseline shifts, which need to be addressed.



IDENTIFYING AND CORRECTING EMG ARTIFACTS

The EMG signal's sensitivity means it's prone to interference from external noise or artifacts. Nevertheless, most disruptions can be mitigated through rigorous skin preparation and precise electrode placement. The following are examples of common disturbances:

- **Baseline Offset:** A continuous baseline shift may occur if there are changes to the application site post-auto-calibration, or if the subject wasn't fully relaxed at the measurement's outset. An "Offset Correction" function can rectify this before data recording commences.
- **Baseline Shifts:** A typical EMG burst should revert to zero within milliseconds, maintaining a steady resting line at zero. Shifts lasting over 5 ms indicate an artifact, possibly due to excessive cable movement or changes in the distance between the muscle belly and the electrode, often from poor cable

attachment or local pressure. Jump tests might also reveal baseline shifts from significant muscle belly displacement due to impact forces. Proper electrode/cable attachment and skin preparation can resolve these issues.

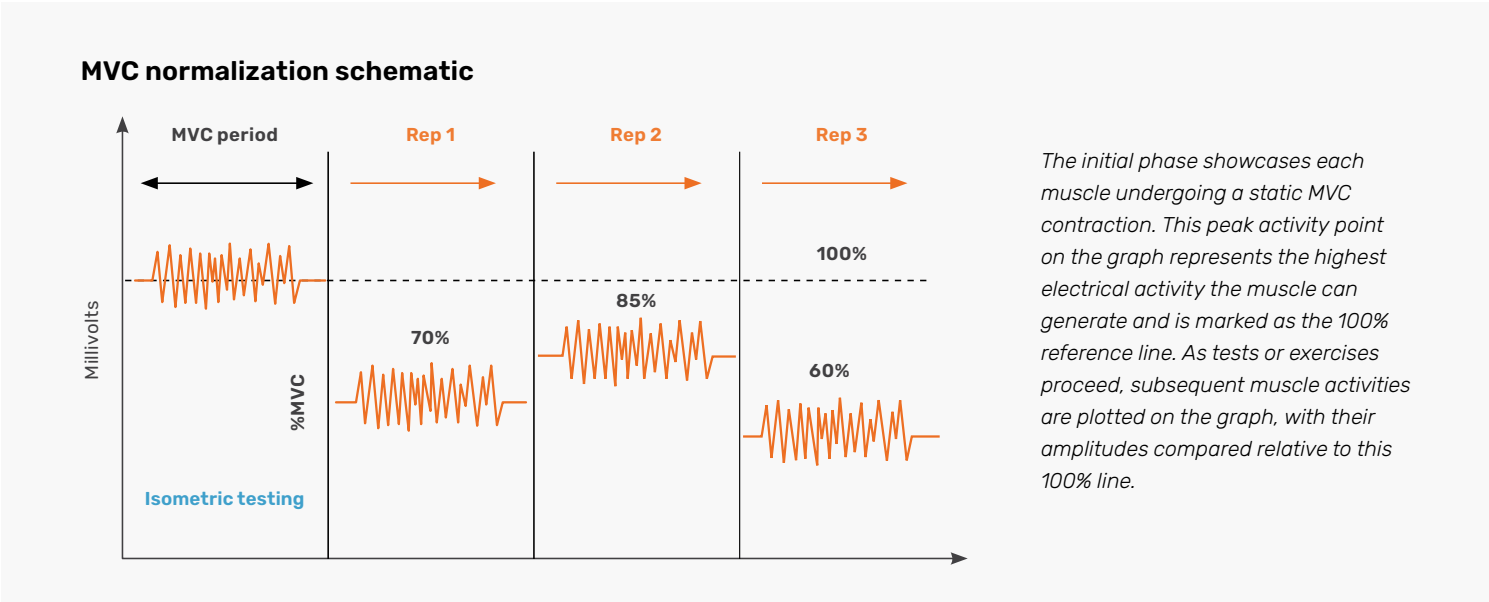
- **ECG Artifacts:** When measuring close to the heart, particularly muscles on the left shoulder and trunk, ECG bursts may intrude on the EMG recording. This biological artifact, though often unavoidable, can be minimized with thorough skin preparation and repositioning of the ground electrode. Advanced signal processing routines are capable of "cleaning" these bursts without altering the regular EMG signal characteristics.

By diligently applying these strategies, the accuracy and reliability of EMG data can be significantly enhanced, ensuring meaningful insights into muscle function.

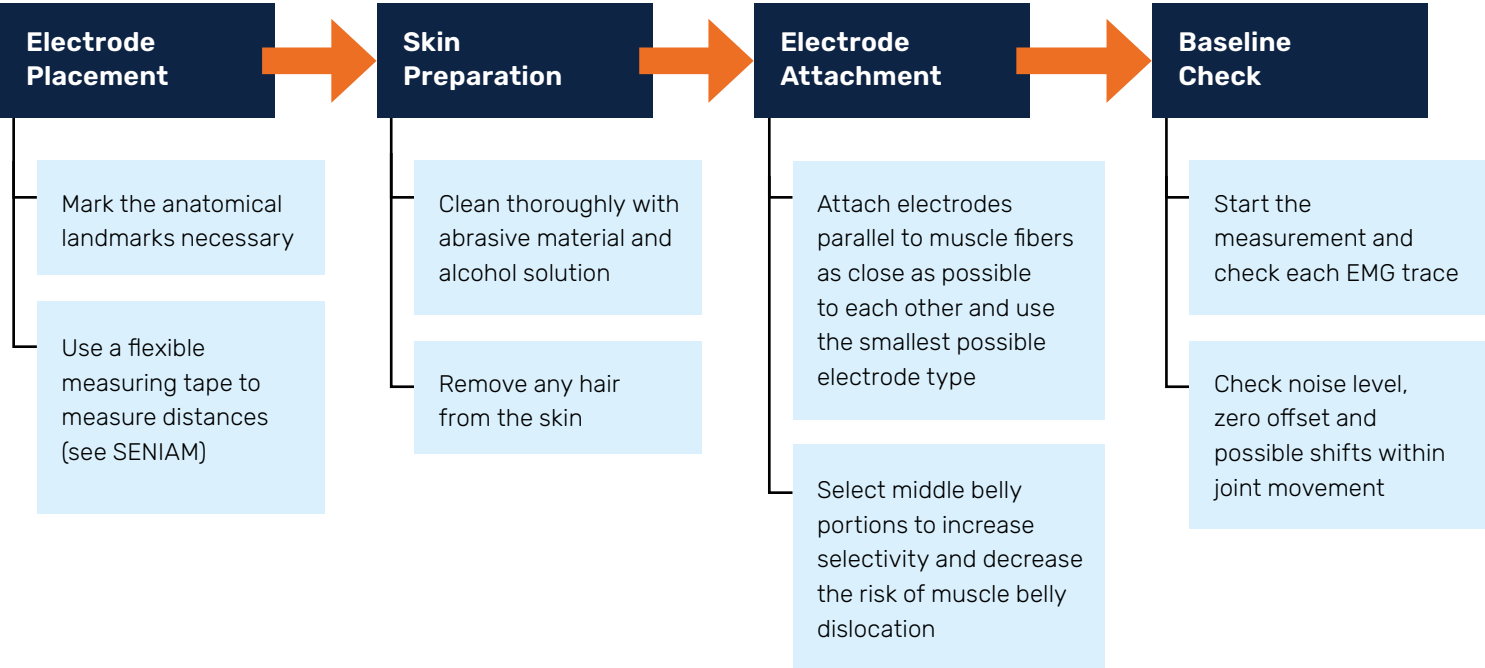
NORMALIZATION OF EMG AMPLITUDE

Due to various factors like electrode placement, skin impedance, muscle size, and inherent variability between individuals, EMG signals naturally differ in amplitude. In biomechanics and neuromuscular research, comparing muscle activity across individuals or different sessions for the same person is crucial. To enable these comparisons, EMG signals are often normalized against a reference value. The Maximum Voluntary Contraction (MVC) method

is a commonly used reference for normalization. MVC represents the peak force or torque a muscle or muscle group can exert during voluntary contraction. Expressing EMG amplitude as a percentage of the MVC-derived EMG amplitude allows for a standardized comparison scale across different conditions and populations, minimizing the impact of external factors and enabling a more objective evaluation of muscle activation levels.

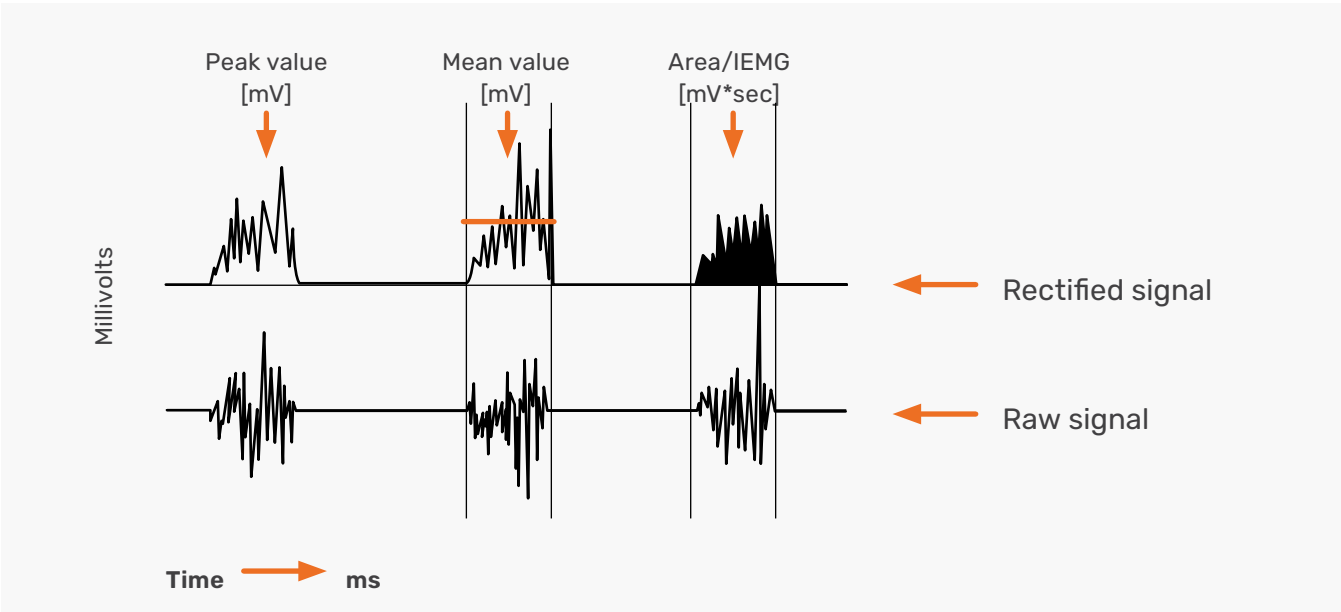


PREPARING AN ASSESSMENT WITH AN EMG DEVICE



EMG PARAMETERS – AMPLITUDE

Standard amplitude parameters such as mean, peak, minimum value, area, and slope are essential for analyzing EMG signals. Rectification is a critical prerequisite due to the signal’s bipolar nature. While the peak value of an EMG signal offers valuable insights, especially with averaged curves, it can be highly variable. A more stable measure is the average peak calculation, where the highest ten peak values within a period are averaged.



The mean amplitude, representing overall nerve activation for a specific muscle during a task, is less affected by the duration of analysis intervals and is ideal for comparative studies. The area under the curve, or integrated EMG (iEMG), is the mathematical integral of the EMG amplitude over a selected period, providing a cumulative measure of muscle activation.

TIMING

- **Time to Peak:** This measures the duration from the start of an analysis period or muscle tension onset to the maximum amplitude value, offering insights into muscle activation dynamics.
- **Onset/Offset Calculations:** These parameters indicate when a muscle starts and stops working, and its activity level during that period. They're crucial for understanding muscle behavior in response to stimuli and during rest.
- **Nerve Conduction Velocity:** This measures the speed of muscle response to stimulation, providing insights into the efficiency of nerve-muscle communication.

- **Muscle Activation Sequence:** Analyzing the order in which muscles activate during rest or movement helps in understanding muscle coordination and function.
- **Activity Diagrams:** Creating diagrams to visualize when a muscle is active or inactive during a movement can reveal patterns in muscle activity, valuable for analyzing gait or other motion studies.

By applying these strategies and parameters, researchers can gather comprehensive insights into muscle behavior, significantly enhancing the value of EMG data for neuromuscular research.

EMG TO FORCE RATIO: UNDERSTANDING THE RELATIONSHIP

EMG activation serves as the ignition for muscle force generation, implying a close relationship between EMG input and force output. While one might expect a direct correlation, the reality is more complex. The connection between EMG activation and force output has been thoroughly explored, with Basmajian and DeLuca's "Muscle Alive" providing an excellent overview. However, the relationship isn't always linear; it often resembles a curvy road where higher muscle forces demand increasingly greater EMG activation for further acceleration.

At the core of this relationship is the concept that EMG activation is essential for any force development, suggesting a deeply intertwined link between these two factors. Although there is a correlation, it can vary significantly. Typically, this relationship is curvilinear, meaning that at higher levels of force, a proportionally larger EMG input is necessary to increase the force output. In certain static force tests—where EMG and force are normalized to their maximum values—some smaller muscles exhibit a nearly linear EMG-force relationship.

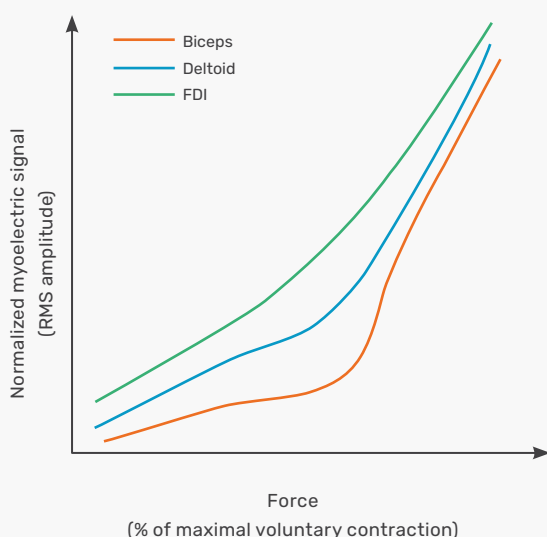


FIGURE 12: Effects of muscle on sEMG signal-force relationship. FDI = first dorsal interosseous muscle. N = average number of isometric contractions for each muscle group.

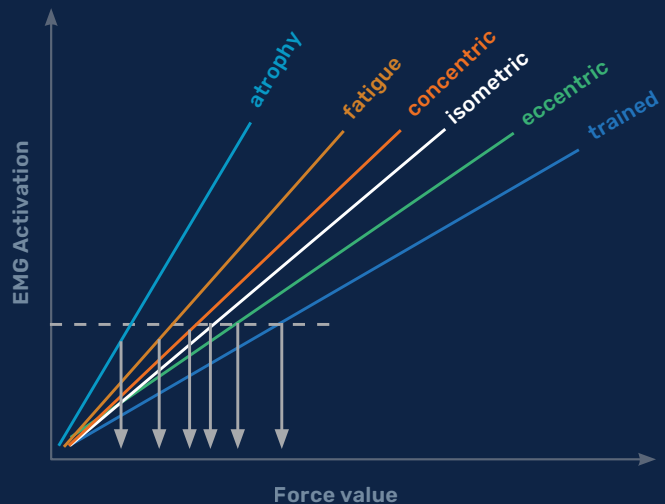
Source: Modified from J. H. Lawrence and C. DeLuca, Myoelectric signal versus force relationship in different human muscles. Figure 1. *Journal of Applied Physiology*. © 1983, The American Physiological Society.

TWO KEY OBSERVATIONS EMERGE FROM THE STUDIES

- **Individual Variability:** There's a notable degree of individual variability in the EMG to force relationship, with force contraction dispersion around 25% of the mean value among subjects. This variability could reflect differences in muscle conditioning, where deconditioned individuals might show higher EMG activity for the same force output compared to those with well-conditioned muscles.

- **Muscle-Specific Force Curves:** The force curve relationship also differs according to the muscle being studied. For example, the smaller first dorsal interosseous muscle shows a quasi-linear force to EMG relationship during isometric contractions. In contrast, larger muscles like the biceps exhibit a curvilinear relationship.

These insights are pivotal when employing EMG in biomechanical models for torque calculations or in clinical treatment protocols. It suggests that an increase in EMG generally corresponds to a similar increase in torque and compressive force around a joint. The EMG-force ratio thus acts as an indicator of a muscle's neuromuscular (training) status. During static contractions with gradually increasing force (ramping), well-conditioned muscles display a rightward shift in this ratio, while atrophic or significantly untrained muscles show a leftward shift.



SURFACE EMG AND CLINICAL SYNDROMES: A CLINICAL PERSPECTIVE

Surface Electromyography (SEMG) can reveal aberrant patterns associated with various psychophysiological and musculoskeletal dysfunctions, offering valuable insights into the myogenic etiologies of pain. Here's a brief overview of clinical syndromes where SEMG assessments prove beneficial:

- **Simple Postural Dysfunction:** Issues arising from incorrect posture.
- **Emotional Dysfunction:** Stress or emotional disturbances affecting muscle activity.
- **Learned Guarding or Bracing:** Protective muscle responses developed over time.
- **Peripheral Weakness or Deconditioning:** Muscle weakness due to lack of use or conditioning.

- **Acute, Reflexive Spasm or Inhibition:** Immediate muscle response to pain or injury.
- **Learned Inhibition:** Avoidance of movement to prevent pain, leading to muscle underuse.
- **Direct Compensation for Joint Hypermobility or Hypomobility:** Adjustments made by muscles to accommodate overly flexible or stiff joints.
- **Chronic Faulty Motor Program:** Long-term adoption of incorrect movement patterns.

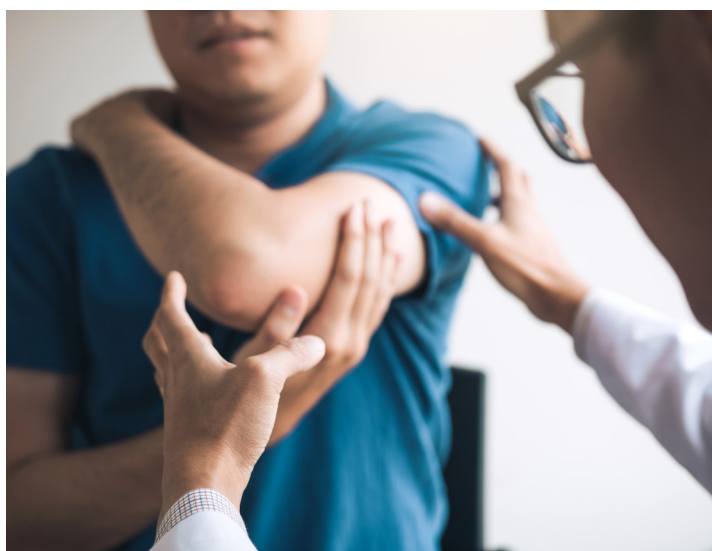
This framework for identifying and planning treatment for these syndromes was largely developed by Kasman. While this presentation is concise, Kasman, Cram, and Wolfe’s **“Clinical Applications in Surface Electromyography”** offers an in-depth exploration. It’s crucial to recognize that patients may exhibit characteristics of multiple syndromes simultaneously, necessitating a tailored approach to treatment.

Practitioners should consider several key questions when identifying relevant syndromes for a patient, incorporating insights from historical and clinical examinations, specific SEMG patterns, conditions under which aberrant patterns emerge, and scenarios where normal patterns are observed. This comprehensive assessment helps integrate the information to understand the patient’s condition fully.

Following this, simplified descriptions of the listed clinical syndromes are provided, including case examples to clarify the concepts.

POSTURE-RELATED MOTOR DYSFUNCTION

Improper posture, such as leaning the head forward and stretching arms while typing, can lead to abnormal motor activity, causing headaches and muscle tension in the neck and upper regions. Surface EMG assessments often reveal increased activity in the back muscles of the neck and upper trapezius. However, adopting a more appropriate posture leads to noticeable improvements in SEMG levels, highlighting the direct impact of posture on motor function.



EMOTION-RELATED MUSCLE DYSFUNCTION

Muscle activity can increase due to stress or as a reaction to traumatic experiences, such as PTSD. For example, an individual involved in a car accident may show no sustained improvement from physical treatments alone. Stress-profiling assessments, monitoring muscle sites like the wide trapezius and frontalis, reveal spikes in muscle activity when recalling the accident. Integrating PTSD treatment with physical therapy is recommended for optimal recovery, as emotional factors can significantly influence muscle function.

LEARNED GUARDING OR BRACING

This syndrome involves increased muscle activity as a protective response to pain, often resulting in behavioral abnormalities. For instance, a patient with a shoulder injury might frequently hold their neck and shoulder area, using cold packs for relief. Muscle scans show widespread activation in these regions, with the upper trapezius muscles exhibiting significantly higher activity than the lower trapezius. Interestingly, the uninjured side may show double the activity compared to the injured side, especially during minor movements. While sEMG feedback training improves muscle activation during therapy, maintaining these gains in daily life can be challenging. Relaxation therapies have shown positive outcomes in managing pain and reducing protective muscle responses.

PERIPHERAL WEAKNESS OR DECONDITIONING

This condition affects individuals who experience a decline in physical capability due to prolonged muscle inactivity, often resulting from extended immobilization after injury, surgery, or chronic poor motor habits with reduced physical activity. The repercussions include muscle mass reduction, impaired blood circulation to muscles, and diminished biochemical and physiological function. Symptoms are a steady decrease in maximal muscle force, diminished force maintenance across movements, and decreased fatigue resistance. For example, post-leg fracture immobilization can lead to quadriceps muscle atrophy, with subsequent recovery challenges in movement, strength, stamina, and overall mobility. sEMG evaluations can reveal discrepancies in muscle activity between affected and unaffected legs, indicating muscular weakness and deconditioning.

ACUTE, REFLEXIVE SPASM/INHIBITION

Muscle tension changes, either increased or decreased, can be reflex responses to pain or fluid buildup in a joint. For instance, an individual with a herniated disc might exhibit limited mobility and pain extending from the lower back to the hip and leg, with pronounced muscle activity in the lumbar paraspinal region corresponding to the pain side. sEMG might show increased activity in the erector spinae muscle during pain. Conversely, acute reflex-driven muscle inhibition, as seen in cases with trauma and swelling, leads to reduced sEMG amplitude during painful movements, indicating neurological suppression.



LEARNED INHIBITION/WEAKNESS

This syndrome involves subconscious motor activity suppression to avoid pain, akin to protective guarding but resulting in muscle suppression instead of spasm. For example, an individual repeatedly straining hip adductor muscles during sports learns to minimize muscle activation during high-intensity activities. sEMG readings may show normal adductor muscle activity on the unaffected side but significantly reduced activity on the affected side during demanding tasks, suggesting altered motor behavior to prevent pain.

DIRECT COMPENSATION FOR JOINT HYPERMOBILITY OR HYPOMOBILITY

Discrepancies in muscle activity can stem from chronic joint instability or stiffness, with the neuromuscular system compensating for loose joint structures or facilitating movement against joint resistance. This compensatory mechanism, while altering muscle activity, originates from biomechanical joint anomalies. For instance, a patient with limited mobility in the left temporomandibular joint (TMJ) may show increased activity in the right jaw muscle (masseter) due to the need to accommodate extended movement. The primary issue here is the joint's reduced mobility, not the muscle activity disparity. Addressing the joint dysfunction is crucial, as muscle activity often rebalances once joint mobility is restored.

CHRONIC MOTOR CONTROL DISRUPTION

This condition arises when the central nervous system adapts to pain, muscle weakness, joint instability, or other issues, disrupting the normal coordination among agonist, antagonist, and synergist muscles. For example, an individual with persistent neck and upper back pain might exhibit unbalanced sEMG activity, with heightened activity in the upper trapezius and reduced activity in the lower trapezius or serratus anterior. These discrepancies, often exacerbated by physical and emotional stress, indicate a flawed motor program leading to uneven strain on tissues. Treatment involves continuous assessment and adaptation, employing a protocol-driven approach that links assessment directly to treatment, focusing on the acquisition of neuromuscular skills.

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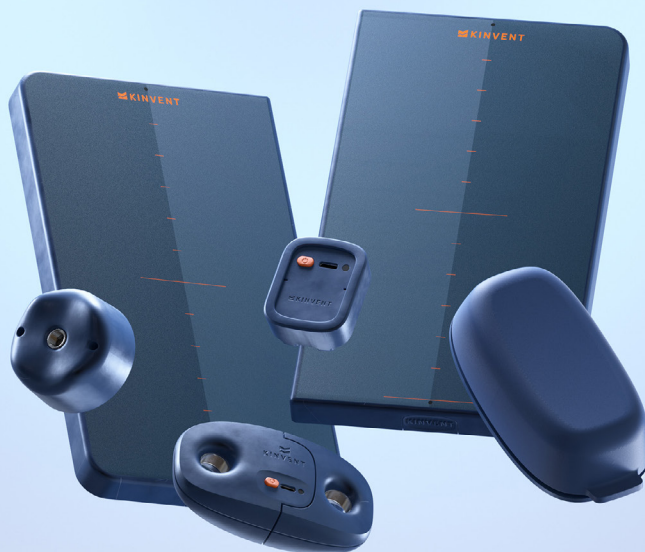
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