Electromyography (EMG) in Applied Biomechanics

Educational & Clinical Reference Document

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Scope and Intended Use

This document is intended as an educational and clinical reference for understanding the acquisition, interpretation, and limitations of electromyography (EMG) in applied biomechanics.

EMG data should be interpreted alongside kinematic, kinetic, and neuromuscular analyses. This reference does not replace medical diagnosis, institutional protocols, or clinical decision-making frameworks.

Electromyography measures the electrical activity of contracting skeletal muscle

Technical Definition

Electromyography (EMG) is the recording and analysis of the electrical signals generated by motor neurons during voluntary or involuntary muscle activation. It provides an indirect but quantifiable representation of central motor command to skeletal muscle.

Key Principle

EMG does **not** measure muscle force directly. It measures the **neural drive** sent to the muscle—the intensity and pattern of motor neuron firing.

> *"EMG amplitude reflects the number of active motor units and their firing rates, not the mechanical output of the muscle."*

EMG has evolved from clinical diagnostics to a cornerstone of movement science

Historical Timeline

1666

Francesco Redi: Muscle contraction produces electricity

1849

Du Bois-Reymond: First recorded human EMG signal

1960s

Surface EMG becomes clinically viable

1980s-Present

Digital processing enables real-time analysis

Contemporary Relevance

~15,000+

EMG-related studies annually
(across biomedical & applied fields)

Figures are approximate and represent trends across biomedical research.

Neuro-Mechanical Bridge

Connects motor commands (neuroscience) with movement execution (mechanics).

Invisible Coordination

Reveals activation timing and sequencing invisible to video analysis.

Objective Strategy

Provides quantitative data on neuromuscular strategies during complex tasks.

Clinical Application

Essential for rehabilitation monitoring, prosthetics, and performance optimization.

The motor unit is the fundamental source of all EMG signals

Anatomical Structure

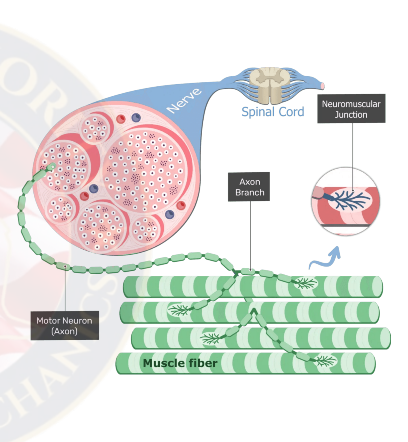
Consists of one **alpha motor neuron** and all the muscle fibers it innervates. Ratios vary from 1:10 (eye muscles) to 1:2000+ (gastrocnemius).

Signal Generation

Action potentials (70-100 mV, 1-2 ms duration) propagate at **50-120 m/s** down the axon to the neuromuscular junction, triggering synchronized fiber contraction.

EMG Detection

Electrodes detect the spatial summation of Motor Unit Action Potentials (MUAPs). Each MUAP contributes **20-2,000 µV** to the signal. The recorded signal represents spatial and temporal summation, not individual motor unit force.



Schematic of a motor unit: Spinal cord origin to muscle fiber innervation.

Neural drive increases through motor unit recruitment and firing rate modulation

1. Recruitment

Henneman's Size Principle: Motor units are recruited in order of increasing size.

Low Force	Type I (Slow-Twitch)
High Force	Type IIa & IIx (Fast-Twitch)

Primary mechanism at 0-50% MVC.

2. Rate Coding

Increasing the firing frequency of already active motor units to modulate force.

Threshold Rate	8-10 Hz
Maximal Rate	50-60 Hz

Dominant mechanism at >50% MVC.

EMG-Force Relationship Profile

Low Force (0-30% MVC)

Linear Increase

Moderate (30-70% MVC)

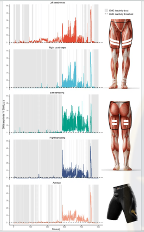
Curvilinear

High Force (>70% MVC)

Plateau Effect

EMG amplitude reflects neural drive intensity; muscle length and velocity also modulate it. The EMG–force relationship is task-, muscle-, contraction-type-, and velocity-dependent.

Resting muscle shows minimal electrical activity while active muscle generates complex signal patterns



Visual comparison of EMG signal density and amplitude.

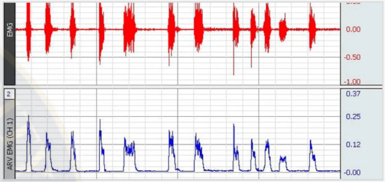
Representative physiological ranges (vary by muscle and recording conditions)

Parameter	Resting Muscle	Active Muscle
EMG Amplitude	< 5 µV RMS	50 - 5,000 µV RMS
Frequency	0-20 Hz (Noise)	20-250 Hz
Motor Unit Firing	Minimal / Zero	8-50 Hz
Metabolic Rate	1-2 mL O_2/100g/min	50-100+ mL O_2/100g/min

Quantitative Example: Biceps Brachii Progression

Rest	25% MVC	50% MVC	100% MVC
2-3 µV	**150-200 µV**	**400-600 µV**	**800-1,500 µV**

Modern EMG systems integrate electrodes, amplifiers, filters, and digital acquisition



Signal Flow

Muscle → Electrodes → Preamplifier → Filters → A/D Converter → Analysis

01

Electrodes

- Ag/AgCl Surface
- Impedance: >100 MΩ
- Noise: < 1 µV RMS

02

Amplifier

- Gain: 1,000-10,000x
- CMRR: >100 dB
- Rejects external noise

03

Filters

- High-pass: 10-20 Hz
- Low-pass: 450-500 Hz
- Notch: 50/60 Hz
- *Filter selection influences amplitude and frequency interpretation*

04

A/D Unit

- Rate: 1,000-2,000 Hz
- Resolution: 12-16 bit
- Nyquist compliant

Surface EMG provides non-invasive assessment while fine-wire EMG enables deep muscle measurement

Surface EMG (sEMG)

Application:	Non-invasive, adhesive electrodes on skin.
Targets:	Superficial, large muscles (e.g., Biceps, Quads).
Volume:	1-2 cm radius, depth up to 2 cm.
Limitation:	Cross-talk from adjacent muscles (10-30%).
Typical Use:	Sports science, ergonomics, biofeedback.

Fine-Wire EMG

Application:	Invasive insertion with hypodermic needle.
Targets:	Deep muscles (e.g., Multifidus, Tibialis Post).
Volume:	1-5 mm radius (highly localized).
Limitation:	Invasive, requires medical supervision.
Typical Use:	Clinical diagnostics, motor unit research.

Selection Criteria *Choice of EMG modality must align with anatomical depth, research question, and ethical constraints.*

Raw EMG signals require rectification and smoothing to extract meaningful amplitude information

1. Raw Signal

Stochastic, bipolar signal with mean value of zero.

Range: ±5,000 µV | Freq: 20-250 Hz

2. Rectification

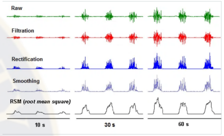
Full-wave rectification converts all negative values to positive.

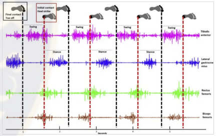
Operation: |EMG(t)|

3. Smoothing (RMS)

Root Mean Square calculation extracts the signal envelope/power.

Window: 50-200 ms





Quantitative Example

Processing choices must be standardized across trials for valid comparison.

±800 µV Raw Peak → **400 µV** Rectified Mean → **320 µV** RMS (100ms)

EMG timing reveals coordination while amplitude indicates neural drive intensity

Temporal Analysis (Timing)

Onset / Offset Detection

Threshold: >3x baseline SD. Defines muscle "on/off" state.

Latency Measurement

Typical range: **30-50 ms** from stimulus to activation.

Application

Reveals coordination strategies, anticipatory control, and sequencing.

Amplitude Analysis (Intensity)

Peak & Mean Amplitude

Infers neural drive level and muscle loading.

Median Frequency Shift

Fatigue indicator: Shifts from **80-100 Hz** down to **40-60 Hz** .

Application

Quantifies effort, load response, and metabolic fatigue state.

The Cross-Talk Challenge

of the signal. Mitigation requires precise electrode placement parallel to fiber direction.

Adjacent muscles can contribute **10-30%**

Critical Insight

Timing metrics are generally more reproducible than amplitude metrics across sessions.

Timing data is generally more robust and reproducible across sessions than absolute amplitude data.

EMG quantifies neural drive and coordination patterns, not direct muscle force

What EMG CAN Measure

- ✓ Neural drive intensity **r = 0.70-0.90**
- ✓ Activation timing **±10-20 ms**
- ✓ Bilateral symmetry / asymmetry
- ✓ Fatigue-induced frequency shift
- ✓ Neuromuscular adaptation to training

What EMG CANNOT Measure

- ✕ Direct muscle force output
- ✕ Muscle fiber type composition
- ✕ Absolute muscle strength
- ✕ Injury diagnosis (standalone)
- ✕ Injury risk without mechanical context
- ✕ Exercise "quality" or "effectiveness"

Critical Misconception

"Higher EMG = Better Exercise" is false. High EMG may indicate instability, inefficiency, or poor mechanical advantage.

Evidence

EMG-force correlation varies significantly (r=0.31 to 0.96).

(Vigotsky et al., 2018)

Integrated EMG-kinematic-kinetic analysis reveals complete neuromechanical movement strategies

1. Kinematics

Motion Capture (200-400 Hz)

Tracks joint angles, velocities, and acceleration. Answers: "Which muscles activate at specific joint angles?"

2. Kinetics

Force Plates (1-2 kHz)

Measures ground reaction forces and center of pressure. Links neural activation to force production outcomes.

3. Integration

Inverse Dynamics

Combines all data streams to calculate joint moments and power. Determines how neural strategies affect joint loading.

Quantitative Example: Vertical Jump Analysis

Data streams must be temporally synchronized.

Kinematics	EMG (Quad)	Kinetics	Outcome
45°	**850 µV**	**2,400 N**	**42 cm**
Knee Flexion Depth	85% MVC at 60°	Peak Ground Force	Jump Height

Squat and deadlift EMG analysis reveals phase-specific contributions

Values represent typical ranges reported in trained populations; individual variation is expected.

Squat Biomechanics

Descent Phase	(Eccentric)
Vastus Lateralis	**45-75% MVC**
Gluteus Maximus	**30-50% MVC**
Erector Spinae	**25-40% MVC**

Ascent Phase	(Concentric)
Vastus Lateralis	**70-95% MVC**
Gluteus Maximus	**60-85% MVC**
Biceps Femoris	**40-55% MVC**

Deadlift Sequencing

Initial Pull	(0-30% ROM)
Gluteus Maximus	**50-70% MVC**
Biceps Femoris	**40-60% MVC**
Erector Spinae	**45-65% MVC**

Lockout	(30-100% ROM)
Gluteus Maximus	**75-95% MVC**
Erector Spinae	**60-80% MVC**
Vastus Lateralis	**20-30% MVC**

Asymmetry Detection Thresholds

Normal Range	Clinical Concern	Injury Risk (2.5x)
< 10%	> 15%	> 20%

Exercise selection requires context-dependent EMG interpretation beyond simple amplitude ranking

Gluteus Maximus Peak EMG

1. Single-Leg Squat (Unstable)	95% MVC
2. Barbell Hip Thrust	92% MVC
3. Bulgarian Split Squat	88% MVC
4. Conventional Deadlift	85% MVC
5. Barbell Back Squat	78% MVC

Critical Interpretation

High EMG in unstable tasks often reflects stabilization demand rather than productive mechanical loading.

Unstable exercises show high EMG due to **stabilization demands**

even at moderate loads due to high rate coding requirements.

, not necessarily force production. For hypertrophy, mechanical tension (load) often outweighs pure neural drive. Explosive concentric actions can elicit **85-95% MVC**

Exercise selection must prioritize training goal, not EMG amplitude alone.

Load-EMG Relationship

30% 1RM Load	35-45% MVC
50% 1RM Load	55-65% MVC
70% 1RM Load	75-85% MVC
90% 1RM Load	90-100% MVC

Evidence-Based Recommendation: Select exercises based on training goal (Strength, Hypertrophy, Stability) with EMG as just one decision factor.

Clinical EMG applications quantify post-injury inhibition and guide neuromuscular rehabilitation

Arthrogenic Muscle Inhibition (AMI)

Reflexive neural inhibition protecting injured joints. Persists beyond tissue healing, preventing full recovery unless specifically targeted. Recovery of neural drive may lag behind structural healing.

Healthy MVC	100% Baseline
Injured MVC	35-45%
Activation Deficit	45-60%

Rehabilitation Progression (Post-ACL Reconstruction)

Week 2 Post-Op

Quadriceps EMG

120 µV

Asymmetry Index

65% Deficit

High inhibition, compensatory hamstring firing.

Week 6 Post-Op

Quadriceps EMG

340 µV

Asymmetry Index

35% Deficit

Neural drive recovering, reduced compensation.

Week 12 Post-Op

Quadriceps EMG

580 µV

Asymmetry Index

12% Deficit

Approaching clinical normalization threshold.

Return-to-Play Criteria

Symmetry: >90%

Timing Diff: <50 ms

Co-contraction Ratio: 0.6-0.8

Proper normalization is essential for valid EMG interpretation

Normalization is non-negotiable for interpretation.

Invalid Inter-Subject Comparison

Incorrect Approach

"Athlete A (450 µV) is working harder than Athlete B (320 µV)."

Why: Ignores skin impedance and fat thickness variations.

Correct Approach

Normalize to Maximal Voluntary Isometric Contraction (MVIC).

A: 450 / 650 = **69% MVC**

B: 320 / 400 = **80% MVC**

Result: B > A

Comparing Muscles Without Context

Incorrect Approach

"Quad (800 µV) is more active than Bicep (400 µV)."

Why: Different motor unit sizes and electrode distances.

Correct Approach

Normalize each muscle to its own baseline.

Quad: 800/1200 = **67%**

Bicep: 400/500 = **80%**

Result: Bicep > Quad

Ranking Solely by Peak EMG

Incorrect Approach

"Exercise X (95%) is superior to Exercise Y (75%)."

Why: Ignores load, time under tension, and stability.

Correct Approach

Consider multiple factors beyond peak amplitude.

Mean EMG: Y > X

Load: Y (150kg) > X (40kg)

Goal: Strength favors Y

EMG provides decision support within comprehensive analysis, not standalone verdicts

1. Mechanics

Kinematics

Joint angles, velocities, coordination. Defines *how* the body moves.

2. Load

Kinetics

Forces, moments, power. Defines the *stress* on tissues.

3. Strategy

Neuromuscular

Activation timing, drive intensity. Defines the *intent*.

Clinical Decision Support: Knee Pain Analysis

EMG Data	Delayed Quad Activation (80ms)
Kinematics	Excessive Valgus (15°)
Kinetics	High Loading Rate (150 BW/s)

Integrated Conclusion

Neuromuscular timing deficit contributes to poor mechanics, resulting in excessive joint loading.

Professional Judgment: Data informs decisions; it does not replace clinical reasoning. *Data informs clinical reasoning but does not replace expertise.*

Effective EMG application requires rigorous methodology and contextual integration

Core Principles

1 **Neural Proxy, Not Force Gauge**

EMG measures the electrical drive to the muscle, which does not equate to linear force output.

2 **Context is King**

Raw amplitude is meaningless without normalization (MVIC) and consideration of muscle length/velocity.

3 **Integration Unlocks Insight**

Combining EMG with kinematics and kinetics reveals the "why" behind the movement.

4 **Context-Dependent Interpretation**

Interpretation without context increases error risk.

Future Directions

High-Density EMG (HD-EMG)

Mapping spatial activation distribution across a muscle belly to detect regional targeting.

Wearable Integration

Moving from the lab to the field with wireless, textile-integrated sensors for ecological validity.

Real-Time Biofeedback

Using live EMG data to accelerate motor learning and correct neuromuscular inhibition patterns.

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Questions & Discussion

"Bridging the gap between biomechanical theory and clinical application through rigorous data analysis."

Suggested Discussion Domains

Signal Processing	**Normalization Protocols**	**Clinical Integration**	**Future Research**

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This document may be cited for educational use.

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