



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

Third Class

Subject (Biomechanics II)

Code (UOMU0103062)

Asst. Lec. Mariam Ghassan Al-marroof

1st term – Lecture 6&7



Muscle Actions Revealed Through Electromyography, Back to Basics, Phasic Behavior of Muscles.

Introduction

Electromyography (EMG) is a technique used to measure the **electrical activity generated by skeletal muscles**.

Muscle contraction results from **ionic currents within muscle fibers**, and EMG detects the **voltage differences associated with these ionic movements**.

Accurate interpretation of EMG signals requires understanding three fundamental scientific principles:

1. **Electrochemical behavior of electrodes**
2. **Electrical potentials generated at the electrode–electrolyte interface**
3. **Sources of signal distortion during measurement**

1. Electrode Function in Bioelectric Measurement

An electrode acts as a **transducer** that converts:

ionic current in biological tissue → electronic current in the recording system

This conversion occurs at the **interface between the electrode surface and the electrolyte**, which in biological measurements is typically **body fluids or conductive gel applied to the skin**.

Because of this interface, the electrode does not behave as a simple conductor; instead, it introduces **electrochemical effects that influence the measured signal**.



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2. Electrode Potential

The **electrode potential** is defined as the **voltage difference between the metal electrode and the surrounding electrolyte.**

This potential depends on:

- the chemical properties of the metal
- the composition of the electrolyte

Since the metal and the electrolyte together determine the potential, the system is referred to as a **half-cell.**

3. Half-Cell Concept

simple electrochemical half-cell consisting of:

- a metal electrode
- an electrolyte containing ions of that metal

When the electrode is immersed in the electrolyte, two simultaneous processes occur:

1. **Metal atoms lose electrons and enter the solution as positive ions**
2. **Metal ions in the solution gain electrons and deposit onto the electrode surface**

These opposing reactions produce a **separation of electrical charges at the interface** between the electrode and the electrolyte.

This charge separation generates a **stable electrical potential known as the half-cell potential.**



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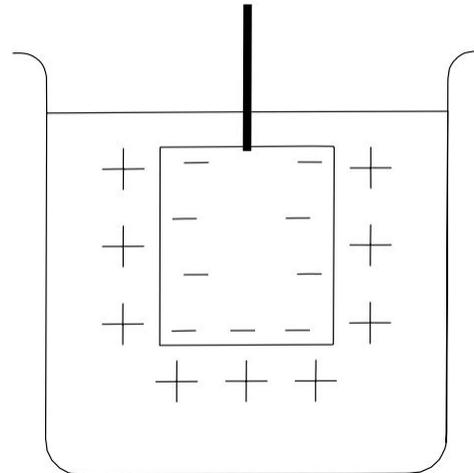


Figure 4.1 A simple half-cell

4. Formation of the Electrical Double Layer

At the electrode–electrolyte interface, the separation of charges forms what is called the **electrical double layer**.

This structure consists of:

- a layer of charges on the electrode surface
- an opposite layer of ions in the electrolyte

The two layers are separated by a very small distance, producing behavior similar to a **capacitor**.

The double layer plays a key role in determining:

- electrode impedance
- signal stability
- susceptibility to motion artifacts.



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5. Potential Difference Between Two Electrodes

Figure 4.2 demonstrates an electrochemical system with two different electrodes:

- **Zinc electrode (Zn)**
- **Copper electrode (Cu)**

Each electrode is placed in its corresponding electrolyte:

- ZnSO₄ solution
- CuSO₄ solution

Because zinc and copper have **different half-cell potentials**, a **galvanic potential difference** develops between the two electrodes.

This phenomenon forms the basis of an **electrochemical cell**.

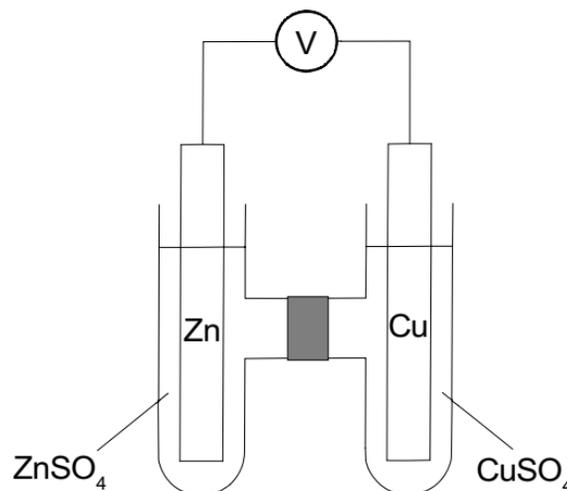


Figure 4.2 The potential (V) between two electrodes, one made of zinc/zinc sulphate and the other of copper/ copper sulphate.



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7. Motion Artifacts

A major source of measurement error in EMG recordings is **motion artifact**.

Motion artifacts occur when **movement of the electrode relative to the skin** alters the electrochemical conditions at the electrode interface.

This movement disturbs the electrical double layer, causing changes in electrode potential that appear as **false signals in the recording**.

Consequently, reliable EMG measurements require:

- stable electrode placement
- minimal skin movement
- proper conductive contact.

8. Half-Cell Potentials of Common Electrode Materials

Different metals exhibit different half-cell potentials.

Approximate values include:

Table 4.1 Typical Half-Cell Potentials for Different Metals That Could Be Used for EMG Electrodes

Electrode	Potential (V)
Zinc	-0.760
Tin	-0.140
Lead	-0.126
Hydrogen	0.000
Silver (Ag)	0.799
Platinum	1.200
Gold	1.420
Ag/AgCl	0.223



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Among these materials, **silver/silver-chloride electrodes** are widely used in biomedical measurements because they provide:

- stable electrochemical properties
- low noise
- reduced polarization effects.

Electrophysiology of the EMG Signal

Muscle electrical activity originates from **nerve impulses traveling along motor neurons**.

Important terms:

Motor Unit

A motor neuron and all muscle fibers it innervates.

A single motor neuron may innervate:

- as few as **3 muscle fibers**
- up to **2000 fibers**.

Motor Action Potential (MAP)

Electrical signal that propagates along a muscle fiber after nerve stimulation.

Motor Unit Action Potential (MUAP)

The **combined electrical activity of all muscle fibers within a motor unit**.

EMG Signal

The EMG signal recorded on the skin is the **algebraic summation of many MUAPs from active motor units**.



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Dipole and Action Potential

This figure 4.3 explains how electrical signals are detected.

A moving **dipole** inside the tissue produces a changing voltage between two recording electrodes (points A and B).

Signal sequence:

1. No potential difference when dipole is far away
2. Negative signal when dipole approaches electrode A
3. Positive signal when dipole passes A
4. Negative signal again when dipole moves away

This produces a **triphasic waveform**, similar to the electrical signals recorded in EMG.

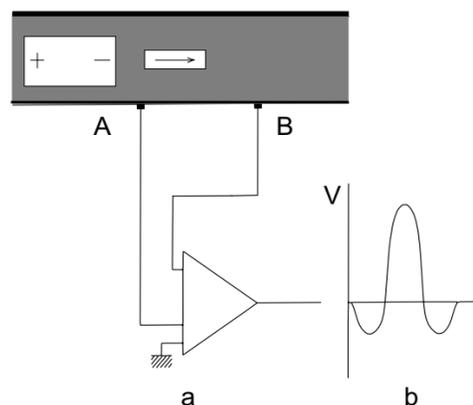


Figure 4.3 A dipole moving down a volume conductor (a) is analogous to the action potential that travels down a nerve axon. Refer to the text for an explanation of the way that the triphasic signal (b) is generated



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Sampling Frequency in EMG Recording

When EMG signals are recorded digitally, they must be **sampled at appropriate frequency**.

Nyquist (Shannon) Sampling Theorem

Sampling frequency must be **at least twice the highest signal frequency**.

Surface EMG frequency range:

1 Hz – 3000 Hz

Therefore theoretical sampling requirement:

≥ 6000 Hz

However, most EMG signal power occurs between:

50 – 150 Hz

Thus, **500 Hz sampling is generally sufficient for surface EMG recordings**.

Figure 4.4 – Aliasing Problem

This figure demonstrates **aliasing**, which occurs when sampling frequency is too low.

Example shown:

- actual signal frequency = 30 Hz
- sampling frequency = 60 Hz

In this situation, the recording may incorrectly appear as **no signal at all**.

Aliasing causes **misinterpretation of physiological data**.



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Surface vs Indwelling Electrodes

Two main types of EMG electrodes are used.

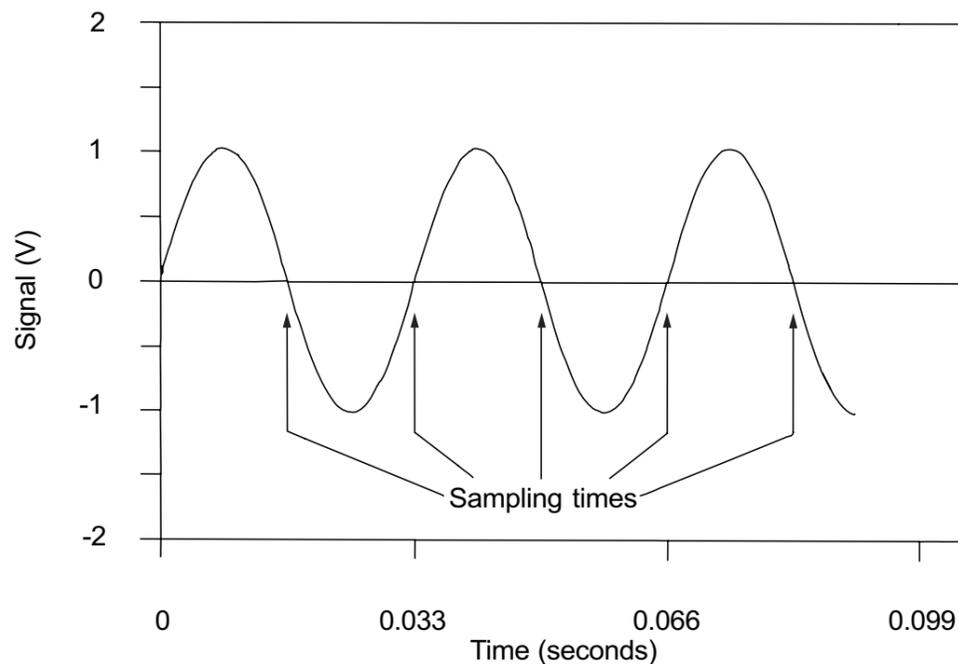


Figure 4.4 Although this signal has a frequency of 30 Hz and sampling is at 60 Hz, it is still possible to get no signal. This problem is known as aliasing.

Surface Electrodes

Characteristics:

- placed on skin surface
- non-invasive
- easy to apply
- suitable for gait analysis



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Limitation:

- cannot detect activity of deep muscles.

Indwelling Electrodes (Needle or Wire)

Characteristics:

- inserted into muscle tissue
- capable of measuring deep muscle activity

Used in clinical cases such as:

- spastic hemiplegia
- deep muscle pathology.

Feature	Surface Electrodes	Indwelling Electrodes
Invasiveness	Non-invasive	Invasive
Muscle depth	Superficial muscles	Deep muscles
Signal specificity	Lower	Higher
Cross-talk	Possible	Minimal
Ease of use	Easy	Requires expertise
Comfort	Comfortable	May cause pain

Frequency Content of EMG Signals

This figure compares **surface electrodes vs indwelling electrodes**.

Observation:

- indwelling electrodes detect **higher frequency components**
- surface electrodes detect **lower frequency signals**



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Reason:

Surface electrodes record **summed activity from multiple motor units** through surrounding tissue.

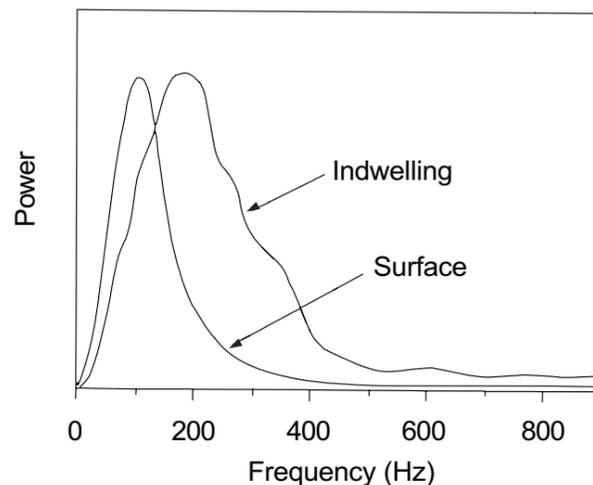


Figure 4.5 The power in an EMG signal plotted as a function of the frequency content. Notice that indwelling electrodes have a higher frequency content.

Examples of Surface Electrodes

This figure shows commercially available adhesive electrodes used for EMG recording.

Preparation steps before placing electrodes:

1. shave hair
2. lightly abrade skin
3. clean with alcohol

This reduces **skin impedance and noise**.



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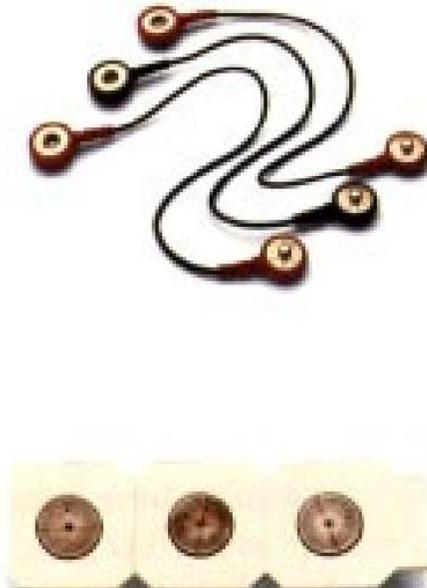


Figure 4.6 Some examples of commercially available surface electrodes used to capture EMG signals. These electrodes are used more often to capture ECG (electrocardiographic signals, but they also work well for EMG

Differential Amplifier

EMG signals are extremely small (microvolts), therefore amplification is necessary.

Differential Amplifier

The amplifier measures the difference between two electrode inputs:

V_1, V_2

Output signal:

V_o = amplified difference between the two signals.



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A ground electrode is required to stabilize the reference voltage and prevent amplifier saturation.

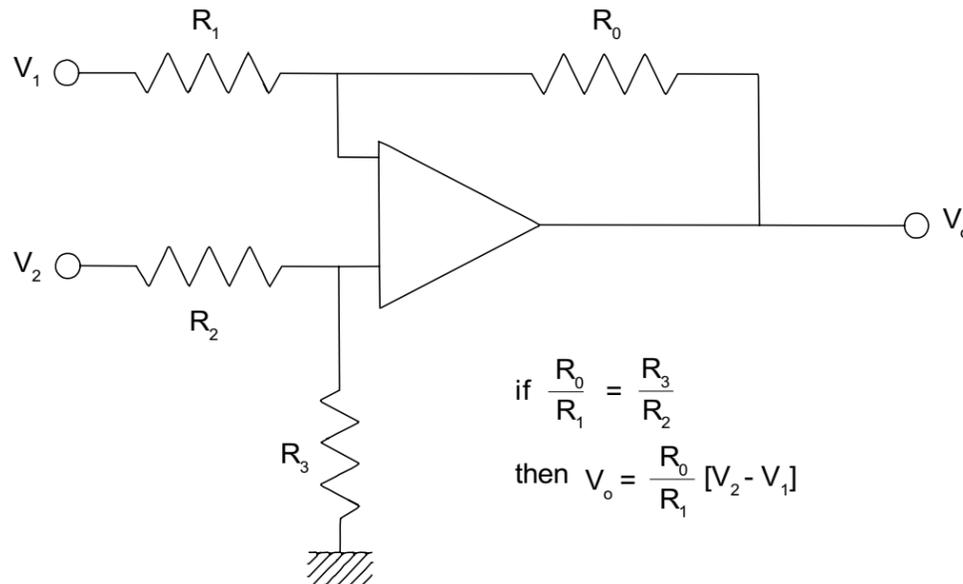


Figure 4.7 A simple differential amplifier. The signals V_1 and V_2 are the input from the electrodes placed on the muscle; the signal V_o is the output from the amplifier.

EMG Signal Processing Methods

Raw EMG signals are difficult to interpret, therefore several processing methods are applied.

EMG Processing Methods

Common techniques include:

1. Full-Wave Rectification

Convert negative signal values to positive.

2. Linear Envelope

Rectified signal passed through a low-pass filter.

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This method provides a **smooth representation of muscle activity**.

3. Integration

Area under the EMG curve represents total muscle activation.

4. Threshold Detection

Muscle is classified as **active or inactive** based on a predefined threshold.

Most gait studies use **linear envelope processing**.

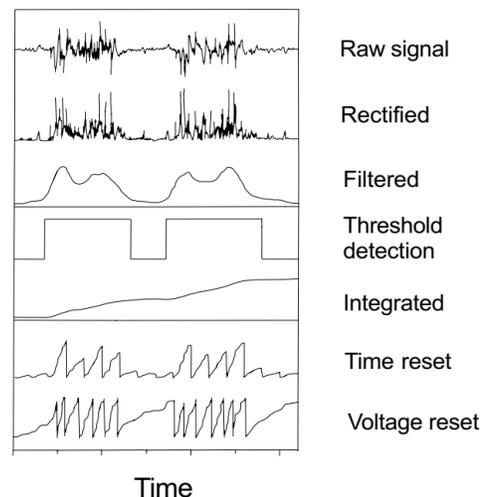


Figure 4.8 Some of the most common methods for processing the raw EMG signal. Notice that the threshold detector to determine if a muscle is on or off must be set arbitrarily.

Phasic Behavior of Muscles During Gait

Human walking requires **coordinated activation of many muscles simultaneously**.

This figure shows EMG activation patterns of **28 lower limb muscles across the gait cycle**.



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The cycle is divided into:

- Stance phase
- Swing phase

Muscles with similar activation timing are grouped together.

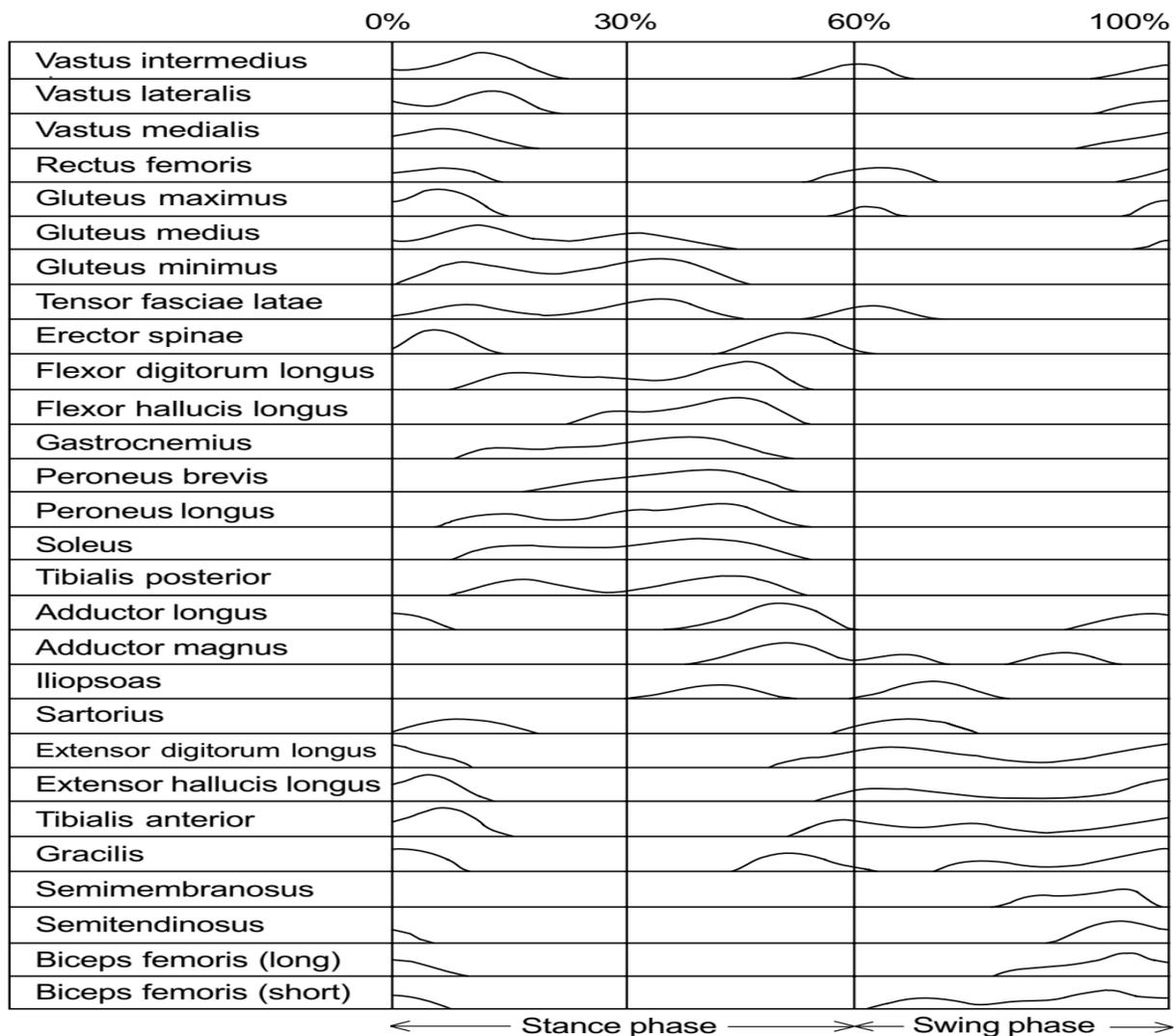


Figure 4.9 Normal EMG patterns for 28 of the major muscles in the lower extremities plotted as a function of the gait cycle.



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Muscle Activity During the Gait Cycle

The figure illustrates activity of seven major muscle groups from posterior and lateral views.

Major muscle groups:

1. Gluteus maximus
2. Gluteus medius
3. Adductor magnus
4. Quadriceps
5. Hamstrings
6. Tibialis anterior
7. Triceps surae

Shading represents activity level:

- black → high activity
- grey → moderate activity
- white → inactive.

General Observations

Major muscle activity occurs around:

- **heel strike**
- **toe-off**

These phases correspond to **deceleration and acceleration of the limbs during weight transfer**.

During:

Midstance Most muscles are relatively inactive except:

- gluteus medius



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- triceps surae

Their functions:

- pelvis stabilization
- controlling ankle dorsiflexion.

Midswing

Tibialis anterior is active to:

- dorsiflexion the ankle
- prevent toe drag.

Overall principle:

Muscles primarily function to **accelerate and decelerate limb segments during walking.**



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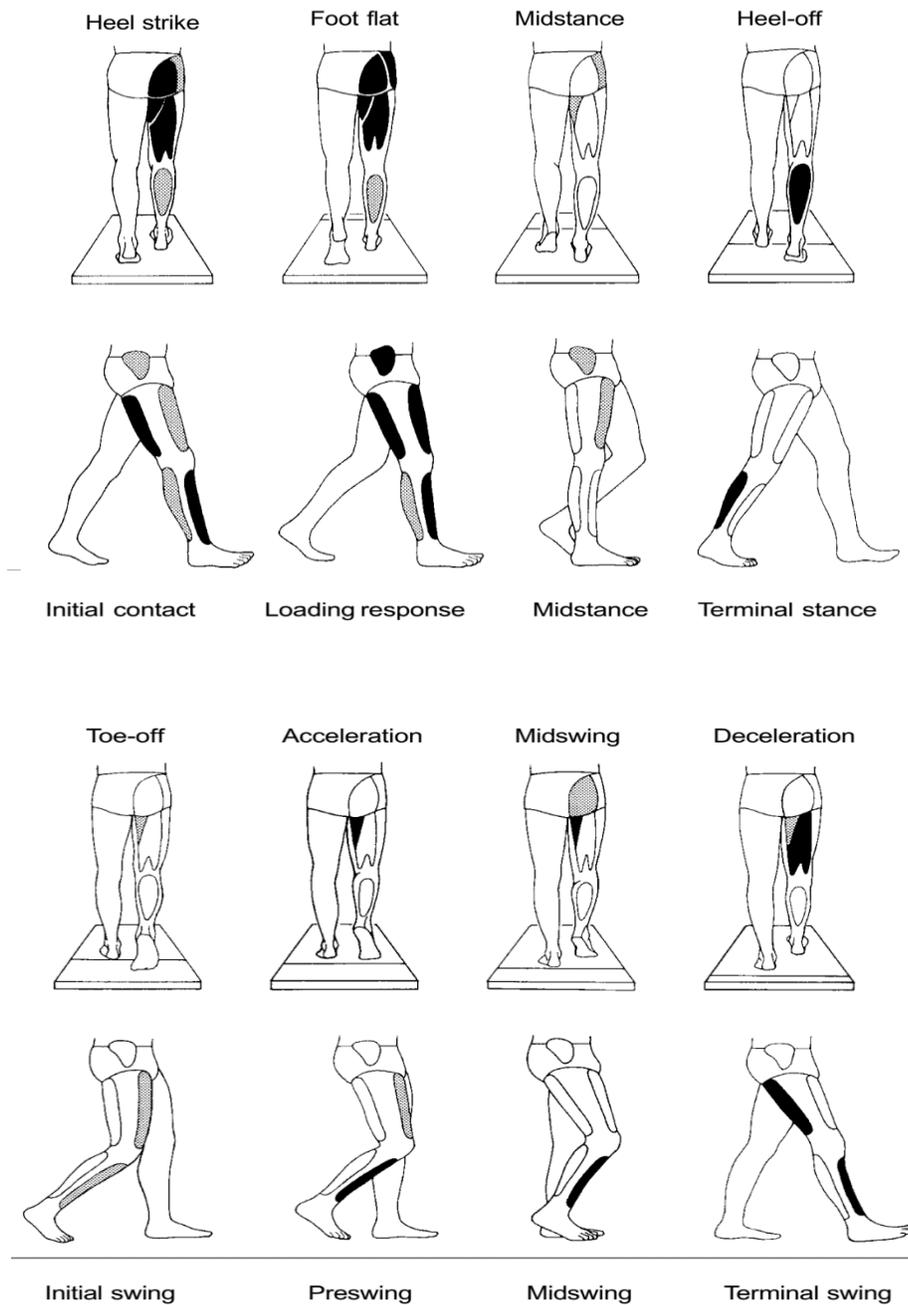


Figure 4.10 Posterior and lateral views of seven of the major muscles of the lower extremities, showing the activity of the muscles at key phases of the gait cycle.