In Search of the Homunculus, Top-Down Analysis of Gait, Measurements and the Inverse Approach.

1. The Homunculus as a Control Model

In the analysis of human gait, the concept of the **homunculus** is used as a theoretical control model representing the central authority responsible for coordinating movement. It serves as a functional analogy for the neural control of locomotion rather than a literal or historical entity.

This model provides a structural framework that helps explain how movement commands are generated, transmitted, and executed during walking, forming the basis for systematic gait analysis.

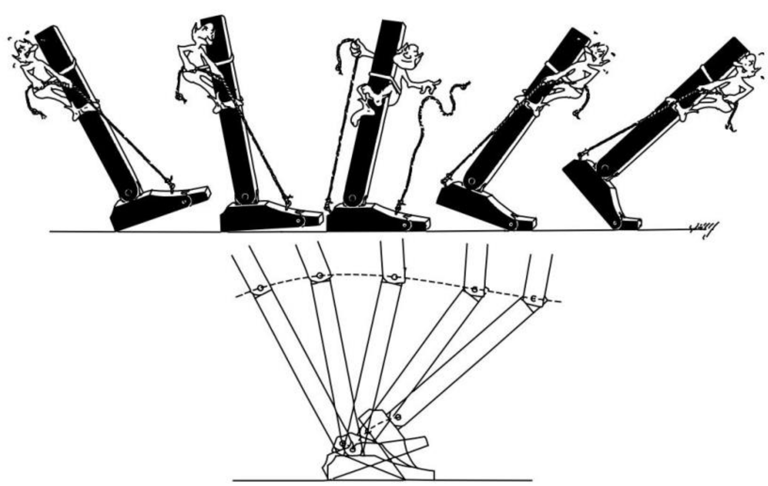

Figure1.1 A homunculus controls the dorsiflexors and plantar flexors of the ankle, and thus determines the pathway of the knee. *Note*. From *Human Walking* (p. 11) by V.T. Inman, H.J. Ralston, and F. Todd , 1981, Baltimore: Williams & Wilkins. Copyright 1981 by Williams & Wilkins. Reprinted by permission.

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Top-Down Analysis of Gait

The study of **Dynamics of Human Gait** adopts a **top-down analytical approach**, in which gait is examined as a sequence of cause-and-effect processes.

The gait process:

- Begins with a neural impulse in the **central nervous system**
- Ends with the generation of **ground reaction forces**

This approach emphasizes understanding the origins of movement rather than focusing solely on observable outcomes.

Sequence of Gait-Related Processes

We need to recognise that locomotor programming occurs in **supraspinal centres** and involves the conversion of an idea into the pattern of muscle activity that is necessary for walking.

The neural output that results from this supraspinal programming may be thought of as a central locomotor command being transmitted to the brainstem and spinal cord.

The execution of this command involves two components:

1. Activation of lower neural centers that establish the sequence of muscle activation patterns
2. Sensory feedback from muscles, joints, and receptors that modifies movement during execution

This interaction between the central nervous system, peripheral nervous system, and musculoskeletal effector system is illustrated in Figure 1.2 For the sake of clarity, the feedback loops have not been included in this figure. The muscles, when activated, develop tension, which in turn generates forces at, and moments across, the synovial joints.

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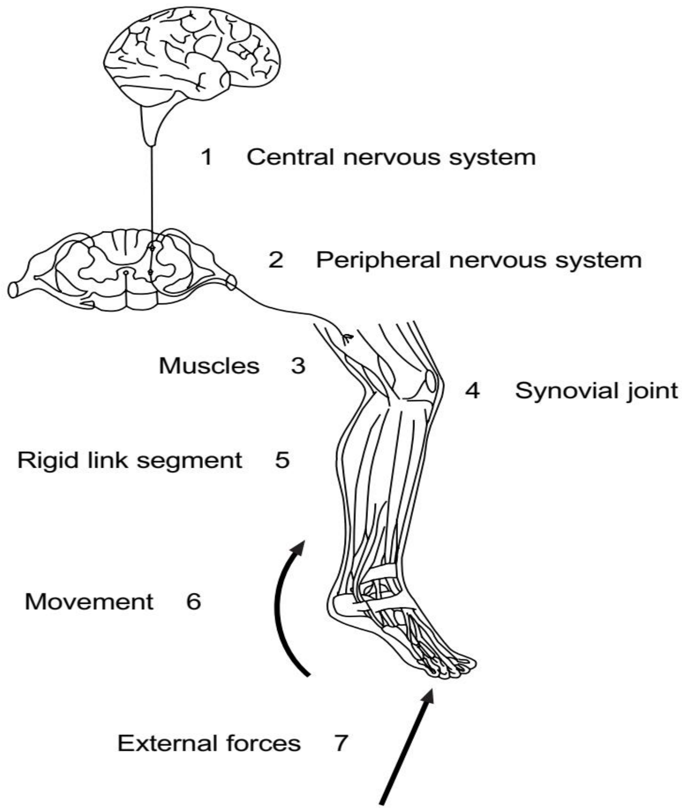

Figure 1.2 The seven components that form the functional basis for the way in which we walk. This top-down approach constitutes a cause-and-effect model.

The joint forces and moments cause the rigid skeletal links (segments such as the thigh, calf, foot, etc.) to move and to exert forces on the external environment.

The Seven Links in the Chain of Walking

The sequence of events that must take place for walking to occur may be summarized as follows:

1. Registration and activation of the gait command in the central nervous system
2. Transmission of the gait signals to the peripheral nervous system
3. Contraction of muscles that develop tension

4. Generation of forces at, and moments across, synovial joints
5. Regulation of the joint forces and moments by the rigid skeletal segments based on their anthropometry
6. Displacement (i.e., movement) of the segments in a manner that is recognized as functional gait
7. Generation of ground reaction forces

These seven links in the chain of events that result in the pattern of movement we readily recognize as human walking are illustrated in Figure 1.3.

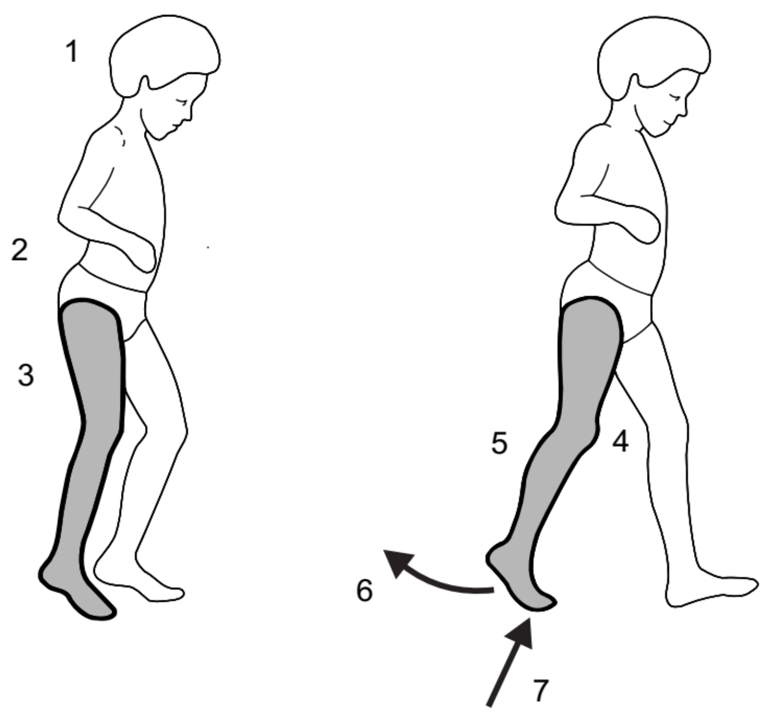

Figure 1.3 The sequence of seven events that lead to walking. Note. This illustration of a hemiplegic cerebral palsy child has been adapted from Gait Disorders in Childhood and Adolescence.

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Clinical Usefulness of the Top-Down Approach

The model may also be used to help us:

- understand pathology
- determine methods of treatment
- decide on which methods we should use to study patient's gait

A patient's lesion could be at different levels, such as:

- Central nervous system (cerebral palsy)
- Peripheral nervous system (Charcot-Marie-Tooth disease)
- Muscular level (muscular dystrophy)
- Synovial joint (rheumatoid arthritis)

The higher the lesion, the more profound the impact on all the components lower down in the movement chain.

Treatment and Assessment Based on the Model

Depending on the indications, treatment could be applied at any of the different levels, including:

- Rhizotomy
- Neurectomy
- Tenotomy
- Osteotomy

In assessing gait, we may choose to study:

- Muscular activity
- Anthropometry of the rigid link segments
- Movements of the segments
- Ground reaction forces

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Measurements and the Inverse Approach

Measurements should be taken as high up in the movement chain as possible, so that the gait analyst approaches the causes of the walking pattern, not just the effects.

There are two types of problems in rigid body dynamics:

- **Direct Dynamics Problem**
- **Inverse Dynamics Problem**

The gait analyst adopts the **inverse approach**, in which the motion of the mechanical system is defined and the objective is to determine the forces causing that motion.

Components Measured in Gait Analysis

Four components may be readily measured by the gait analyst:

- Electromyography
- Anthropometry
- Displacement of segments
- Ground reaction forces

These components are used in equations of motion to give resultant joint forces and moments.

These have been highlighted by slightly thicker outlines in Figure 1.4. Strictly speaking, electromyography does not measure the tension in muscles, but it can give us insight into muscle activation patterns. $\mathbf{A_s}$ seen in Figure 1.5, segment anthropometry $\mathbf{A_s}$ may be used to generate the segment masses ms, whereas segment displacements $\mathbf{p_s}$ may be double differentiated to yield accelerations $\mathbf{a_s}$. Ground reaction forces $\mathbf{F_G}$ are used with the segment masses and accelerations in the equations of motion which are solved in turn to give resultant joint forces and moments $\mathbf{F_J}$.

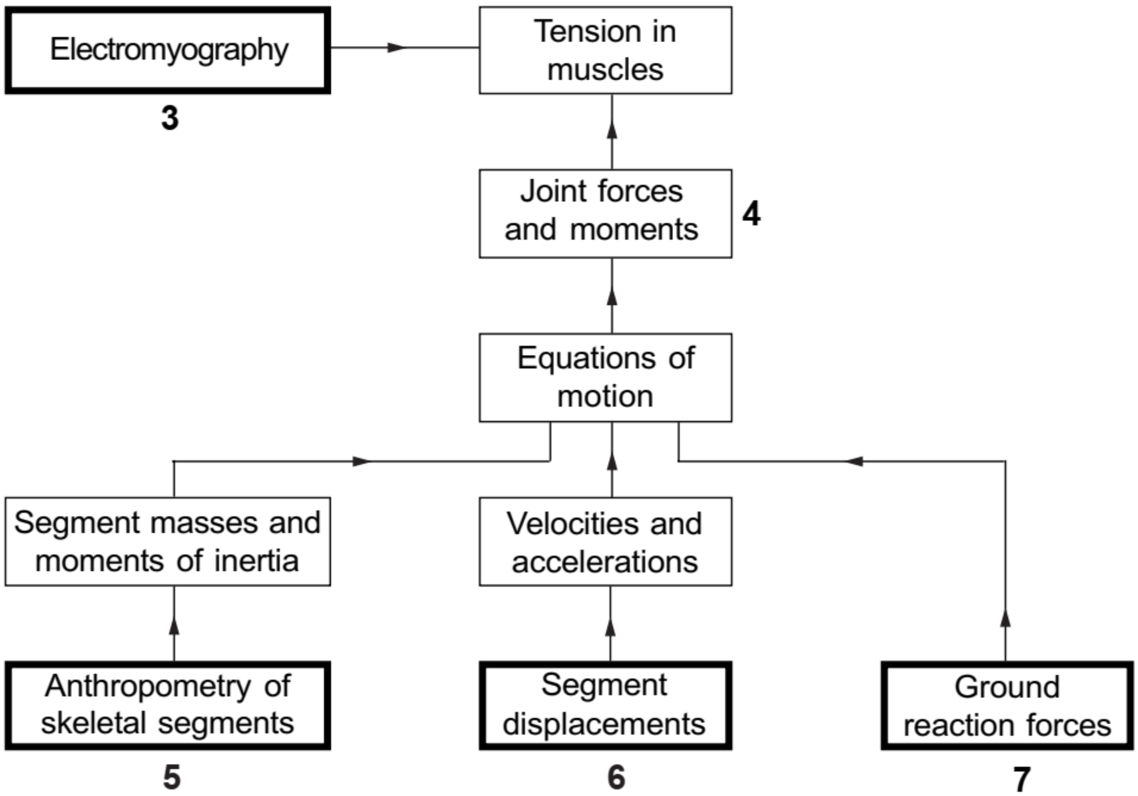

Figure 1.4 The inverse approach in rigid body dynamics expressed in words.

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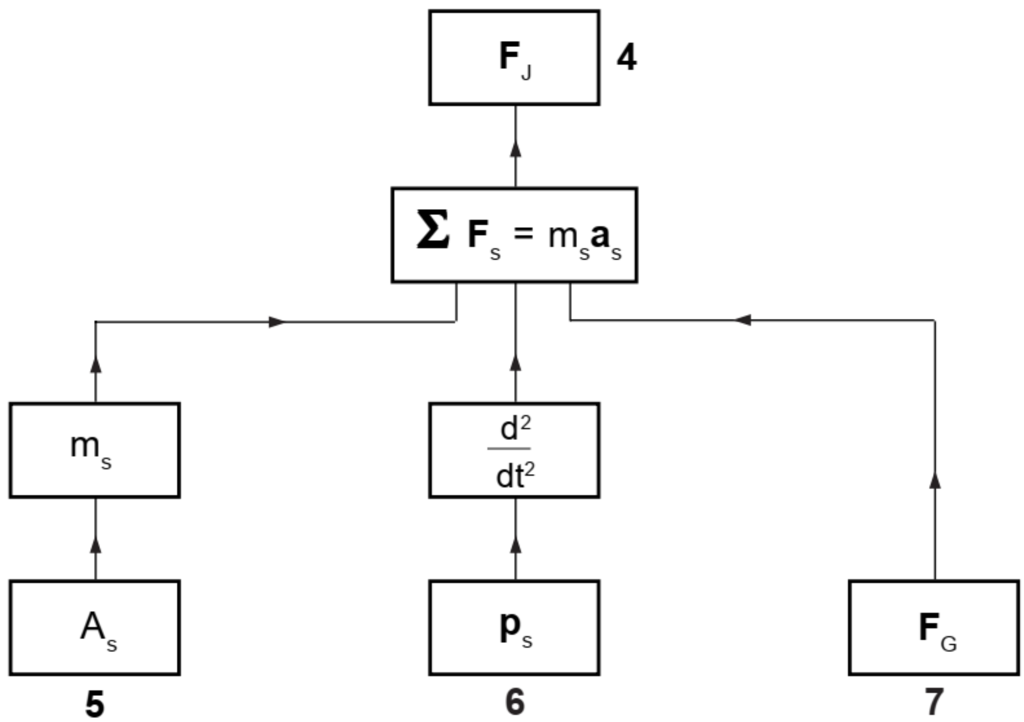

Figure 1.5 The inverse approach in rigid body dynamics expressed in mathematical symbols.

Many gait laboratories and analysts measure one or two of these components. Some measure all four. However, as seen in Figures 1.2 to 1.5, the key to understanding the way in which human beings walk is integration. This means that we should always strive to integrate the different components to help us gain a deeper insight into the observed gait. Good science should be aimed at emphasizing and explaining underlying causes, rather than merely observing output phenomena the effects in some vague and unstructured manner.

Whereas Figures 1.4 and 1.5 show how the different measurements of human gait may be theoretically integrated, Figure 1.6 illustrates how we have implemented this concept in Gait Lab.

Measurable Components in Gait Analysis

Key components commonly measured in gait analysis include:

- Electromyography (EMG)
- Anthropometric measurements
- Segment displacements and kinematics
- Ground reaction forces

These measurements are integrated through equations of motion to determine joint forces and moments.

Integration as a Core Principle in Gait Analysis

A fundamental principle of gait analysis is **integration**.
Understanding human walking requires combining neural, muscular, kinematic, and kinetic data into a unified framework.

Effective scientific analysis focuses on explaining underlying causes rather than merely observing movement outcomes.

Application of the Model Using GaitLab

In gait analysis systems such as **GaitLab**, measured data include:

- EMG
- Anthropometry
- Segment kinematics
- Force plate data

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Derived parameters include:

- Joint positions
- Reference frames
- Centers of gravity
- Joint angles
- Dynamic joint forces and moments

These parameters are generated through integrated processing routines.

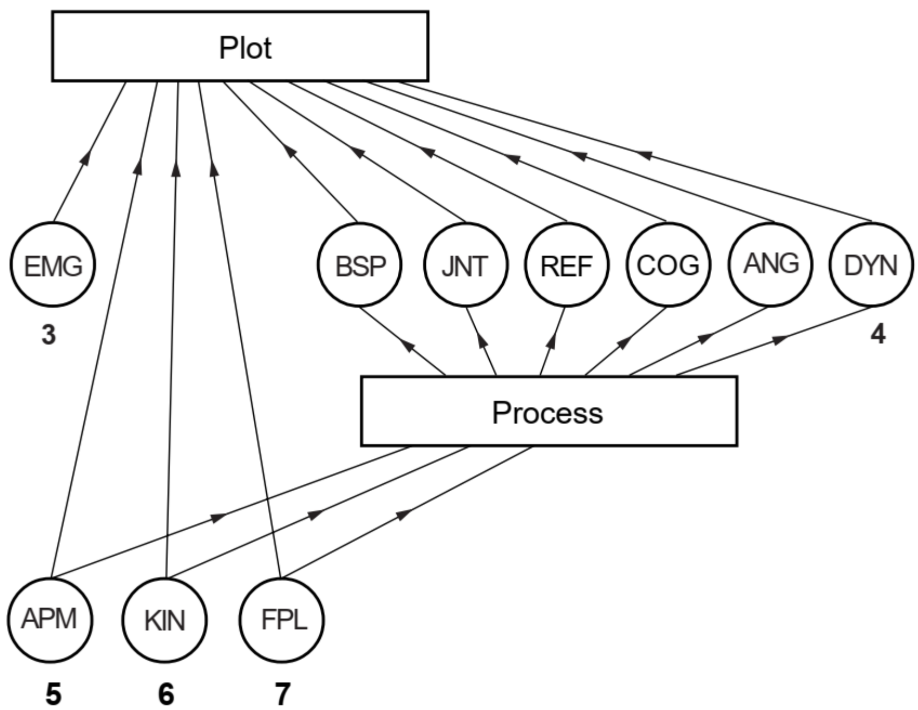

Figure 1.6 The structure of the data (circles) and programs (rectangles) used in part of Gait Lab. Note the similarity in format between this figure and Figures 1.2 to 1.5