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Body Equilibrium

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1. The nature of gravity and its biomechanical implications

To understand how the muscular system maintains body equilibrium, it is necessary to examine the very nature of gravity and its implications for the distribution of forces throughout bodily structures.

Newtonian physics describes gravity as a reciprocal attraction between masses: two bodies attract each other with a force proportional to the product of their masses and inversely proportional to the square of the distance between them.

In this model, the weight we perceive results from the interaction between our mass and that of the Earth.

Einstein's general relativity later demonstrated that gravity is not a force in the classical sense, but rather a deformation of space–time caused by mass.

In this view, objects in free fall follow the most direct path within a curved space–time.

For biomechanical analysis of the forces acting on the human body, however, the Newtonian model remains sufficiently accurate and more practically applicable.

This physical understanding implies that the muscular system does not need to "oppose" gravity, since gravity is an intrinsic interaction between masses.

The objective of the muscular system in maintaining equilibrium is not to overcome the global Weight Force **G**, but to ensure its vertical alignment through the counterforce **R** exerted by the supporting surface.

Its role is therefore to manage the distribution of the weight force throughout bodily structures, maintaining segmental alignment so that forces are optimally transmitted through the joints, minimising potentially harmful load concentrations.

This perspective allows a clearer understanding of the role of the muscular system in maintaining equilibrium.

In common language, gravity is often interpreted as a force that “crushes” the body downward, against which the muscular system must react.

From a biomechanical perspective, this representation is misleading: gravity acts constantly and uniformly on the entire body, whereas what truly varies is how its components are distributed throughout bodily structures.

It is therefore not gravity itself that determines load concentration, but rather the alignment—or misalignment—of body segments and their respective centres of mass.

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2. Newton’s principles of equilibrium

Newton’s third law of motion states that “for every action, there is an equal and opposite reaction.”

Beyond defining inertial force, this principle explains why a body resting on a solid surface does not sink toward the centre of the Earth: the surface applies a force equal and opposite to the body’s weight.

Any body resting on a solid surface is constantly subjected to two forces: the Weight Force (mass multiplied by gravitational acceleration) and the counterforce, equal and opposite, applied by the surface **R**.

The Weight Force corresponds to the value measured by a scale on which the body is placed.

Both forces are applied and distributed over the entire support surface.

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3. Equilibrium analysis: from general to specific

The analysis of a body’s equilibrium can be approached at two levels:

General level: the global force **G** applied at the centre of mass, counteracted by an equal and opposite force **R** ($R = -G$).

Detailed level: for each square centimetre, a component **g** (a portion of **G**) acting on the supporting surface, which reacts with a component **r** equal and opposite to **g** ($r = -g$).

Where **G** equals the sum of all **g** components ($G = \Sigma g$) and **R** equals the sum of all **r** components ($R = \Sigma r$).

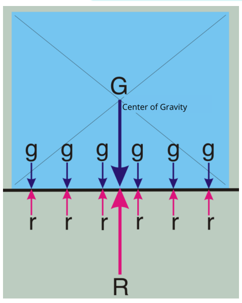

Fig. 1

$G = \Sigma g$
$R = \Sigma r$
$g = G$ / area of the support polygon
$r = -g$
$R = -G$

The global force **G**, applied at the body's centre of mass, is given by the sum of all **g** components applied over each square centimetre of the support base. The global force **R**, equal and opposite to **G**, is given by the sum of all **r** components. Components **g** and **r** have equal and opposite magnitude.

4. Conditions of equilibrium

A body is defined as being in stable equilibrium when the two forces lie on the same vertical line and at the centre of the support polygon.

When **G** and **R** lie on the same vertical but at the limits of the support polygon, equilibrium remains possible, but the forces **g** and **r**, instead of being distributed, converge at a point.

When the two forces are no longer aligned on the same vertical, a moment of force **M** is generated, rendering equilibrium unstable.

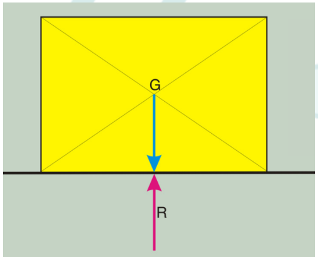

Fig. 2 – Forces **G** and **R** are aligned on the same vertical and at the centre of the support polygon: equilibrium is stable. Components **g** and **r** are uniformly distributed over the support surface.

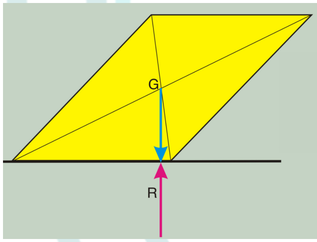

Fig. 3 – Forces **G** and **R** are aligned on the same vertical but at the limits of the support polygon. Equilibrium is possible, but components **g** and **r** are concentrated at the intersection of **G** and **R**.

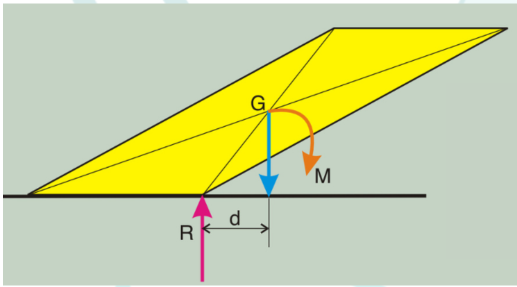

Fig. 4 – The projection of **G** lies outside the support polygon. Forces **G** and **R** generate a moment **M**, given by the sum of the moments generated by **G** and **R**, multiplied by half the distance:

$M_1 = G \times ½d$
$M_2 = R \times ½d$
$M = M_1 + M_2$

5. The multi-element system: the stacked boxes analogy

When multiple boxes are stacked, each box interacts with the one below it.

Overall equilibrium depends on alignment.

Each individual box is subjected to forces **G** and **R**, and the global forces are given by their summation.

Components **g** and **r** are applied and distributed across all support surfaces.

If box alignment is not on the same vertical but still allows equilibrium, **g** and **r** forces concentrate at specific points, creating compressive structural phenomena.

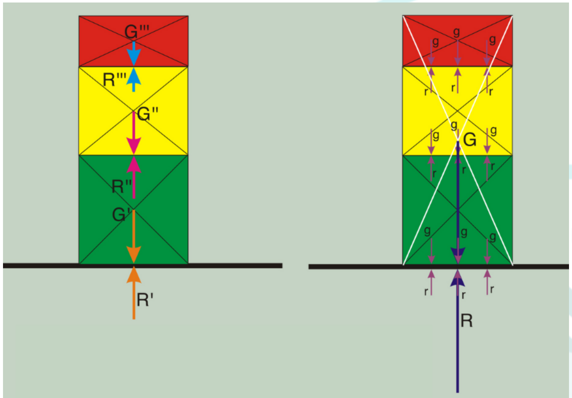

Fig. 5 – All boxes are aligned on the same vertical. Each centre of mass has its own **G** force with corresponding **R** reaction in stable equilibrium. Components **g** and **r** are uniformly distributed. Structural compression is optimally distributed.

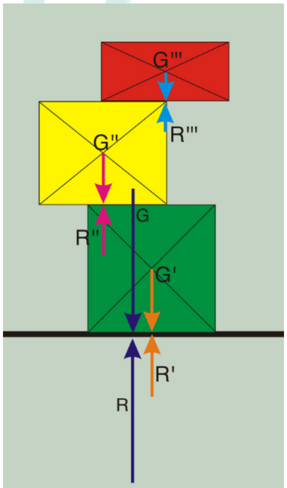

Fig. 6 – Boxes are misaligned but equilibrium remains possible because resultant **G** and **R** remain within the support polygon. However, **g** and **r** components concentrate on restricted surfaces, creating excessive compression that may damage structures over time.

6. Application to the human body: the role of the muscular system in equilibrium

Each part of the human body has its own centre of mass, and the overall body centre of mass is the resultant of their sum.

At each individual centre of mass, forces **G** and **R** are applied.

If individual centres of mass are misaligned, they behave like the boxes in the previous example: **g** and **r** components concentrate at specific points instead of being uniformly distributed, creating compressive phenomena at joint structures.

The objective of the muscular system is therefore to maintain the global force **G** and counterforce **R** along the same vertical through optimal alignment of segmental centres of mass, minimising joint load concentration.

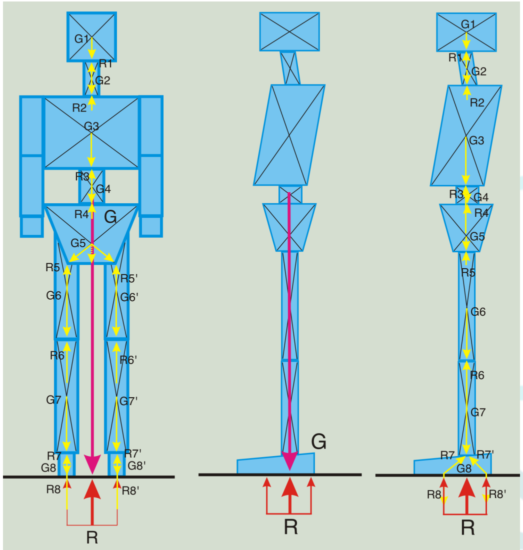

Fig. 7 – With skeletal elements aligned, global forces **G** and **R** and individual forces applied to each segmental centre of mass are correctly positioned along the same vertical. Components **g** and **r** are uniformly distributed across joint structures. In this condition, the tonic-muscular control system operates at low intensity, with muscular Work capacity prevailing over resistant force.

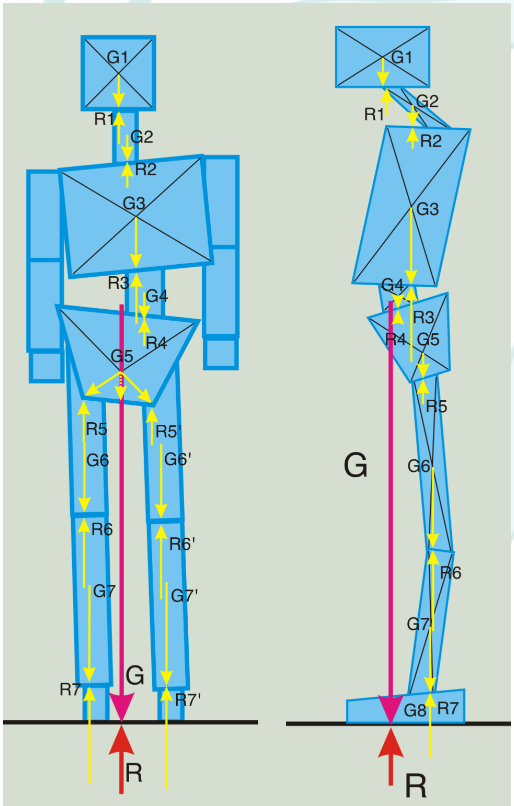

Fig. 8 – With skeletal elements misaligned, equilibrium remains possible but individual **G** and **R** forces are no longer on the same vertical. Components **g** and **r** concentrate on restricted joint surfaces, creating asymmetric stress. To maintain equilibrium, the tonic-muscular control system must activate at high intensity, increasing resistant force at the expense of Work capacity.

7. The dynamics of human equilibrium

Except in clinostasis, human equilibrium is inherently unstable, as the body's centre of mass is in constant motion due to respiration and other physiological variables.

Tonic-postural muscle activity, under nervous system control, continuously modulates tone in order to:

- maintain **G** and **R** on the same vertical for upright stance
- generate moment **M** when movement is required

Fig. 9 – Posterior view: counterforce **R** (red arrow) is applied at the centre of the support polygon. Equilibrium is possible if global force **G** (blue arrow) lies on the same vertical. Due to misaligned segmental centres of mass, both patients must increase basal muscle tone, increasing Resistant Force at the expense of Working Force.

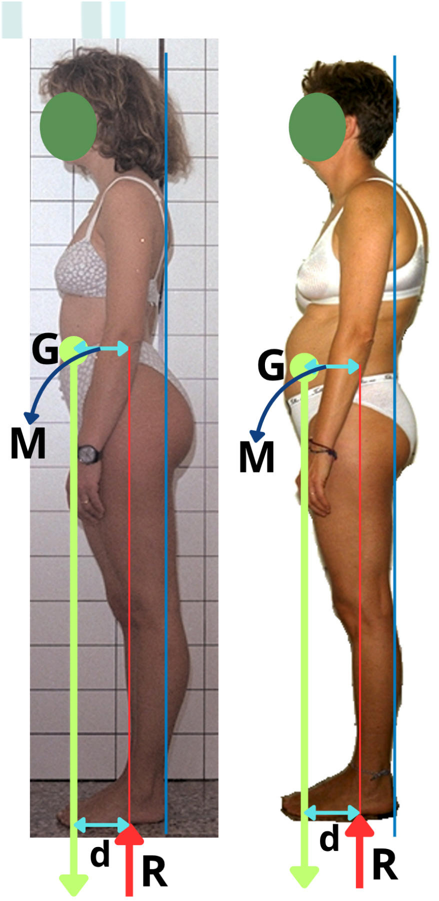

Fig. 10 – Lateral view: counterforce **R** (red arrow) is applied at the centre of the support polygon. Weight force **G** (green arrow) lies anterior to **R**, creating a distance **d**. A moment **M** is generated which, without adequate tone increase, would cause forward collapse. Muscular activation neutralising **M** increases Resistant Force (RF) and reduces Working Force (WF). The light-blue line represents ideal skeletal alignment: along this line the upper third of the calf, sacrum, D5 spinous process, and occiput should be in contact.

8. Connection with the concept of resistant force and Work capacity

When segmental centres of mass are misaligned, certain muscle groups must continuously increase tone to maintain equilibrium.

This chronic tone increase raises resistant force at the expense of Work capacity, as analysed in the previous chapter.

Muscle fatigue therefore does not arise from gravity itself, but from energetic inefficiency caused by maintaining non-optimal alignment.

A system with correctly aligned centres of mass requires minimal muscular effort to maintain position.

Understanding these concepts has direct implications for evaluation: analysis must identify the shortenings that alter centre-of-mass alignment and map the compensatory strategies adopted by the system to maintain equilibrium.

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9. Consequences of muscle shortening on equilibrium

Shortened muscles, as analysed in the previous chapter, alter the position of segmental centres of mass.

This alteration forces the neuromuscular control system to implement compensatory strategies through tone modulation to maintain the global centre of mass **G** along the vertical of counterforce **R**.

Misalignment of segmental centres of mass inevitably leads to concentration of **g** and **r** components on restricted joint surfaces.

These load concentrations represent the mechanical effect of the system's attempt to maintain equilibrium in the presence of muscle shortening, not the primary cause.

These adjustments occur through automatic integrative processes of the nervous system.

Shortening of one muscle group may therefore trigger a chain of adaptations. For example, if the hamstrings are shortened, the pelvic centre of mass may shift posteriorly relative to the vertical passing through the medial plantar arch where **R** is applied.

To maintain global **G–R** equilibrium, the system automatically modulates tone in other muscle groups, creating a cascade of adaptations involving the entire musculoskeletal system.

The bidimensional model used here represents a didactic simplification.

In clinical reality, equilibrium control involves three-dimensional movements with rotations across all planes and continuous physiological oscillations.

The fundamental principle remains unchanged: the muscular system pursues equilibrium in space as its primary objective, and when shortenings are present, this objective is achieved through compensations that generate load concentration on restricted joint surfaces.

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10. Chapter summary

This chapter has analysed the physical principles governing human body equilibrium and the role of the muscular system in its maintenance.

The key concepts addressed are:

- gravity as an interaction between masses and its biomechanical implications: the muscular system does not "oppose" gravity but manages force distribution through bodily structures
- application of Newton's third law to body equilibrium: every body is subjected to weight force **G** and ground counterforce **R**, with corresponding **g** and **r** components distributed over support surfaces
- equilibrium conditions: stable when **G** and **R** lie on the same vertical at the centre of the support polygon; unstable when a moment **M** is generated
- the stacked-box analogy of the musculoskeletal system: misalignment of segmental centres of mass leads to concentration of **g** and **r** components on restricted surfaces
- the role of the muscular system in maintaining segmental centre-of-mass alignment to optimise joint force distribution
- the relationship between centre-of-mass misalignment and increased resistant force at the expense of Work capacity
- systemic consequences of muscle shortening: altered segmental centres of mass, chained muscular compensations, and joint load concentration as an inevitable mechanical effect

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