Biomechanics-
Motion analysis

Lecture notes

Physiotherapist

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Schedule of the term

- 1st week, Motivation, Historical background
- 2st week, Basics in mechanics
- 3rd week, Motion Patterns
- 4th week, In vitro examination methods
- 5-6th week, In vivo examination methods
- 7th week, Midterm exam
- 8th week, Investigation methods of the spine
- 9th week, Applied motion analysis (guest lecturer)
- 10th week Walking analysis
- 11-12th week, Laboratory practice

- bencsik@mm.bme.hu
- Materials can be downloaded http://www.mm.bme.hu/~bencsik/education.html
- Requriments during the term:
  - Midterm exam should be passed
- Exam in the examperiod

Course material, recommended text book(s), professional literature and supplementary reading(s)

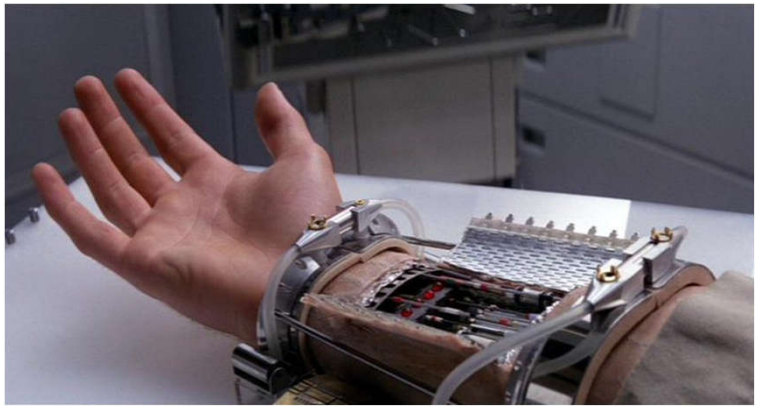
Obligatory:

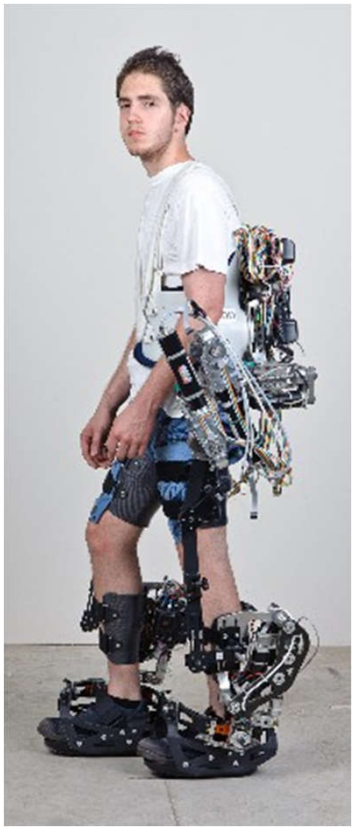
Nordin M., *Frankel V.H. Basic Biomechanics of the Musculoskeletal System*.
Lippincott Williams & Wilkins , 2001. 467 pages.
ISBN: 0683302477

Supplementary:

Nigg, B.M., MacIntosh, B.R., Mester, J.
Biomechanics and biology of movement.
Human Kinetics, 2000. 468 pages. ISBN: 0736003312.

Motivation





INTRODUCTION, DEFINITIONS

Defintion

- It is a part of biophisics, interdisciplinary research
- Webster: Studies the mechanical backgound of muscle activity and the related laws and connections.
- Dorland: The laws of mechanics applied to live organs especially for human locomotion.
- Nigg: The science which uses the knowledge of mechanics for study the structure and the operation of live organs.

Task of biomechanis

- Analyzes all the anatomical, physiological, psychological, mechanical issues which are raised in the inner and outer movements;
- **External biomechanics:** It studies the postion and the change of the postion of the body in space and in time, which is visible by an external observer.
- **Inner biomechanics:** Studies the coordination of nerves/muscles during the organization of the motion, the formation an energetics of the motion pattern.

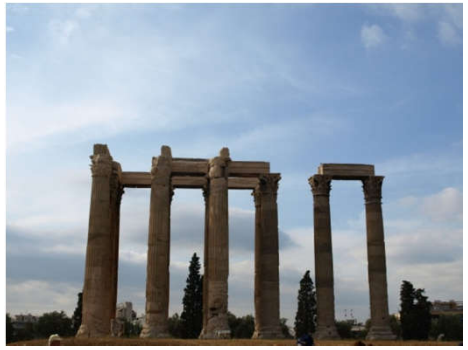
HISTORICAL BACKGROUND

Prehistory

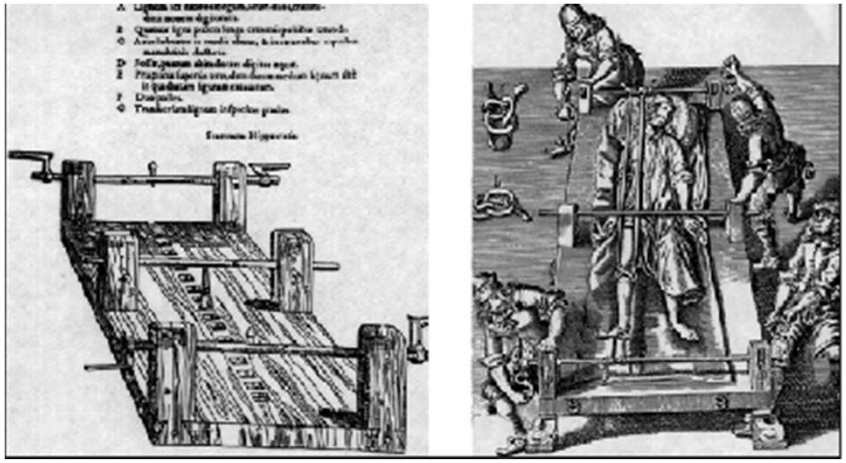
Cave drawings, from the culture of ancient Peru, ancient Greece and Egypt (decoration, teaching)

Altimira-Cave

Antiquity – greeks

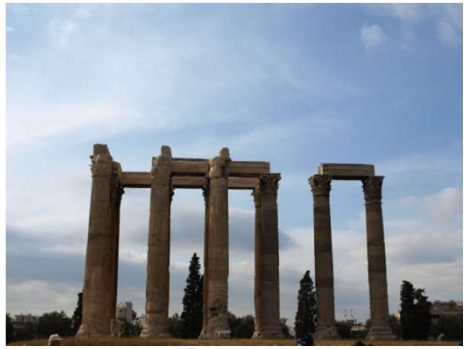


- Hippocrates (BC. 460-437): handling of fractures and dislocations, design of mechanical reposition adjustment and fixing device



Hippocrates scammonja (reposition of fractures)

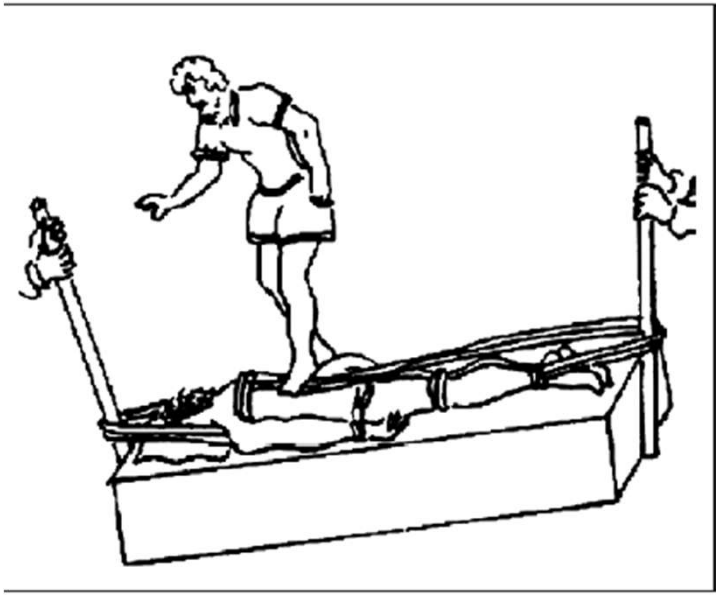
Antiquity – greeks



- Aristoteles (BC. 384-322), He is known as the father of kinesiology. In three of his work (The part the animals, The motion of animals, The progression of the animals) he analized the operation of the muscles, and different animal movement. He identified that the rotational movements has important role in the formation og translational movements. (The human motion is transformation of rotational motions into tranlational motions)
- *Archimedes* (BC. 287-212). Determined the hidrostatic pressure which is connected to the floating bodies, and worked on the simple determination and calculation of the centre of mass of human bodies

Antiquity – romans

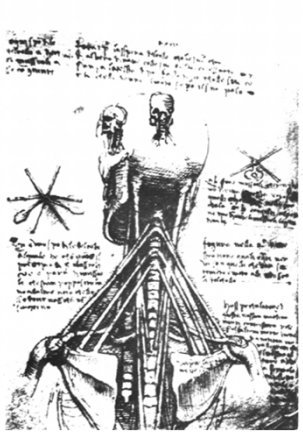
- *Galeneus* (AD. 131-201), Studied the operating of muscles as the doctor of gladiators from Pergamon. In his book about movements of muscles he distinguished the sensing and actuating nerves the agonis and antagonist muscles defined the muscle tone the diarthrosist and synarthrosit and the curvature of the backbone the scoliosis.

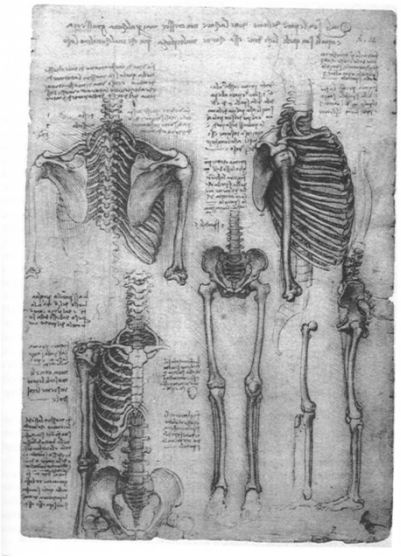


Correction techniques– combined application of elongatio and derotatio

Leonardo da Vinci and his era

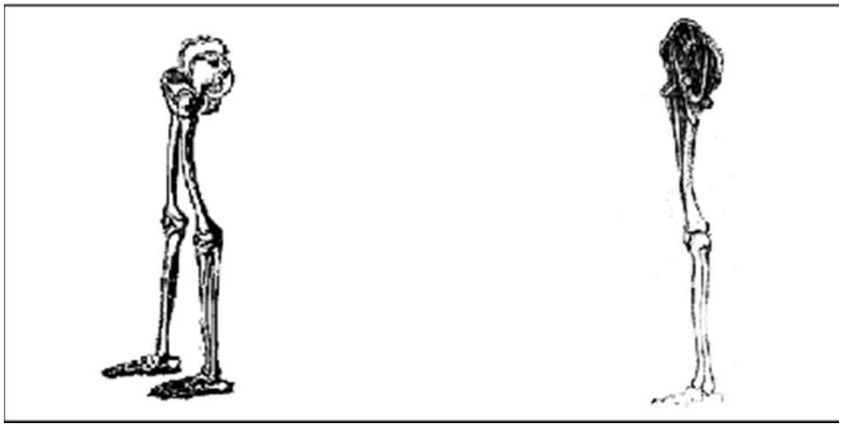
- *Da Vinci* (1452-1519): His drawings was artistic and scientificly accurate at the same time- the bones and muscles were marked by letters. The modeling of the shoulder joint and the hip joint as spherical joint is belongs to his name. A the figure about the ratios of the human body is the most famous biomechanical figure. In his work he also studied the human motions esspecially the walking, and he investigated the flying based the laws of mechanics

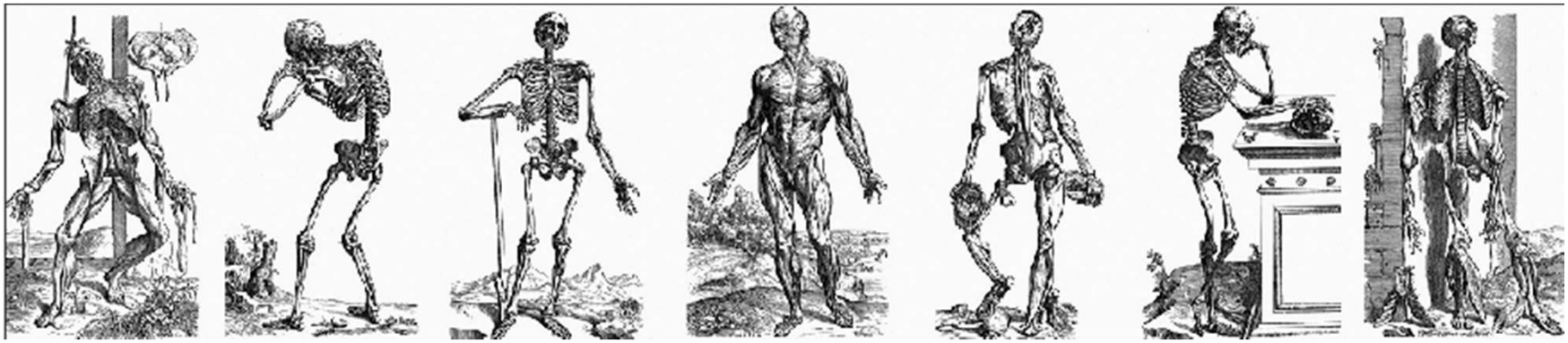




Leonardo da Vinci and his era

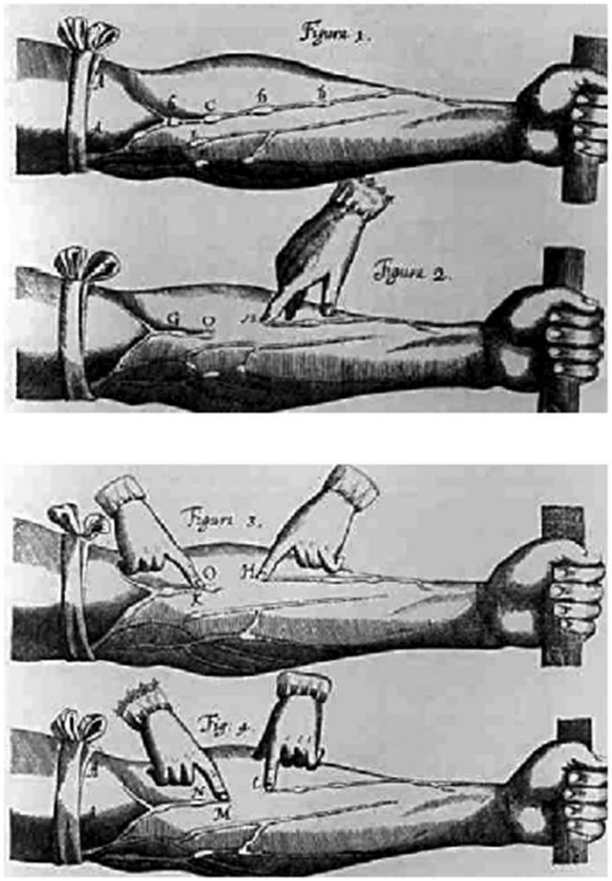
- *Veselius*(1514-1564)
  Summerized the functional anatomy of the organization, in his work titled: The structure of human body (De Humani Corporis Fabrica). His famous mistake the statically incorrect representation of the pelvic





Galileo Galilei and his followers

- *Galieo Galilei* (1514-1642) Based on the exact oscillation time of pendulum, he gave the heart rate with length of the pendulum
- Harvey (1578-1657) In 1628 he proved that the blood is circulating and the heart ventricle push the blood volume in one direction.



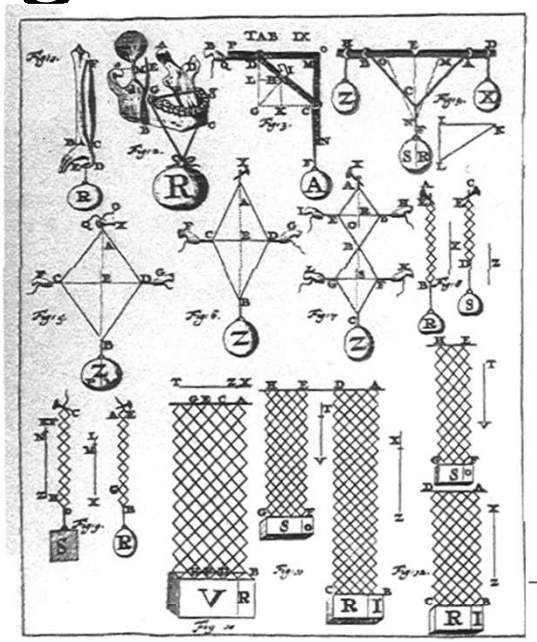
Age of enlightenment

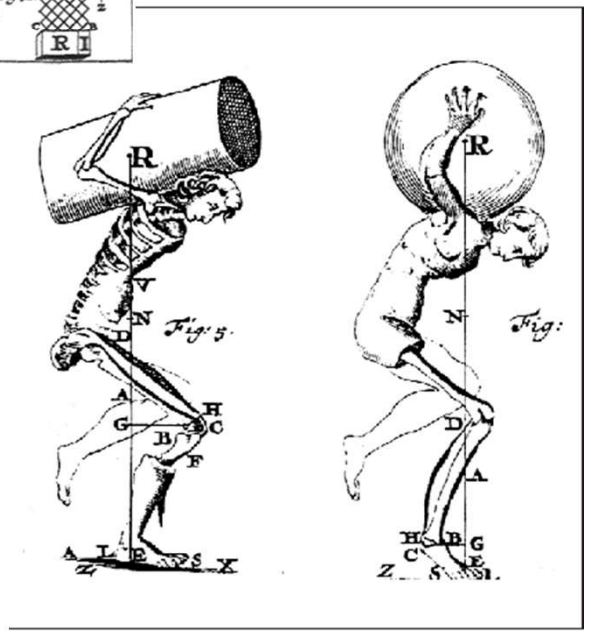
- *Descartes* (1596-1651)
- In his work about the formation of the human and fouetus (Tractus Homine et Formatione Foetus) he said that the people and animals are creatured by the God, thus it is investigated by methods of mechanic

In the spirit of Descartes

Age of enlightenment

- *Borelli* (1608-1679) His book about motion of the animals is the first biomechanics motivated book which uses the methods of geometry to analyze the motion of the animals, it presents the functioning of the muscles figures. For the center of mass determination he used principle of balance.





Age of enlightenment

- Griamaldi (1618-1661) Reported the sound effects of the muscle-contraction.
- Cronne (1633-1684) Investigates the signaling between the brain and muscle
- Stensen (1648-1686) Laid basics of the operation of the muscles and prooved that the heart is a muscle.
- Newton (1642-1727) Gave the basic dynamics anf motion analysis. He started to use vector quantities, used the paralelogram method to summarize vectors.
- Bernoulli (1667-1748), Euler (1707-1783), Coulomb (1736-1806) in the XVIII. Century they tried to determine the maximal and optimal quantity of the human work using in the function of force the speed and time. Euler introduced the notion of critical load, when the backbone loses the stability and it collapses.
- In the XVIII. Century research on the operation of muscle was continued Keill (1674-1719) identified, that during musclecontraction the muscle will be shorter, Whytt (1714-1766) proofed that the muscles can be stimulated by electricity.

Till nowadays

- The main part

  Motion analysis

- Big leap and and extensive development

  Main results are grouped

Determination of center of mass

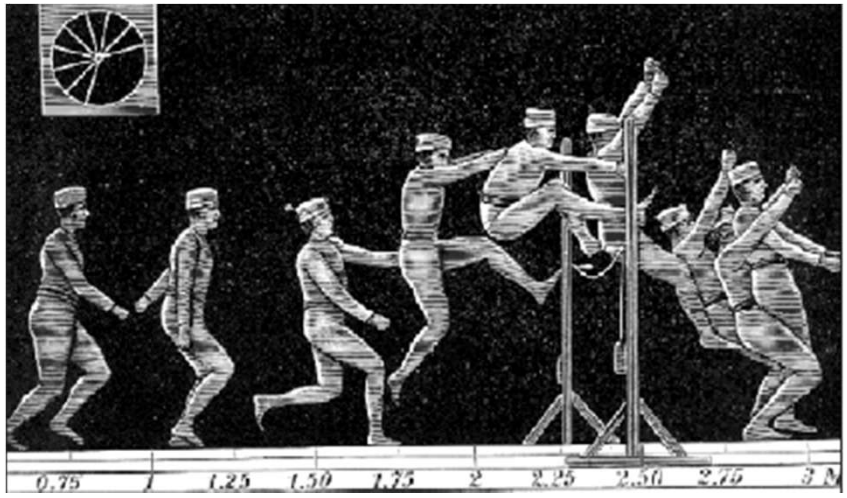
- Ernst Heinrich *Weber* (1795-1878), Wilhelm Eduard Weber (1804-1891) and Eduard Friedrich Wilhelm Weber (1806-1871) Developed a new method to calculate center of mass of body. They identified that the center of mass is moving in vertical direction during the walking.
- *Harless* (1820-1862) determied the center of gravity location of individual body segments autopsy.
- *Braune* (1831-1892) and *Fisher* (1861-1917) Further developed the work of Harles and they gave location of the center of mass of the body segments and the whole body, defined the three main plain of the human.
- *Dempster* (1905-1965) repeated the experiments of Braune and Fisher with the investigation of dead bodies they gave location of the center of mass, the inertia, the density of the body segments

Motion analysis, resources and results

- Ernst Heinrich *Weber* (1795-1878), Wilhelm Eduard Weber (1804-1891)and Eduard Friedrich Wilhelm Weber (1806-1871) The work titled: Mechanics of the human motion system (Die Mechanik der menschlichen Gewerkzeuge) gave the base for the analysis of muscle operations.
- DeBois *Reymond* (1818-1896) measured the electric potential during the motion, created the **Electromyography** (EMG)
- *Daguerre* (1787-1851) in 1837 invented the photography, which makes possible the recording of the human.

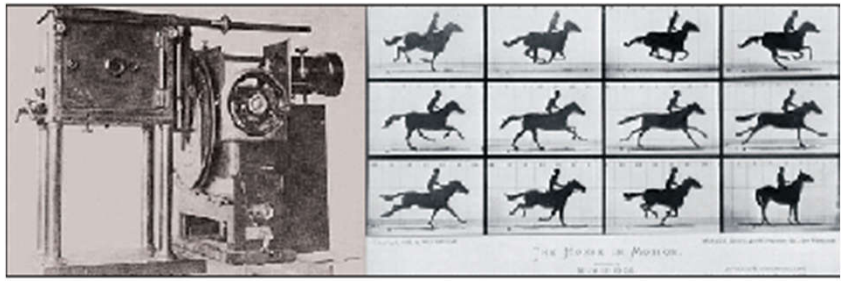
Marey (1830-1904)

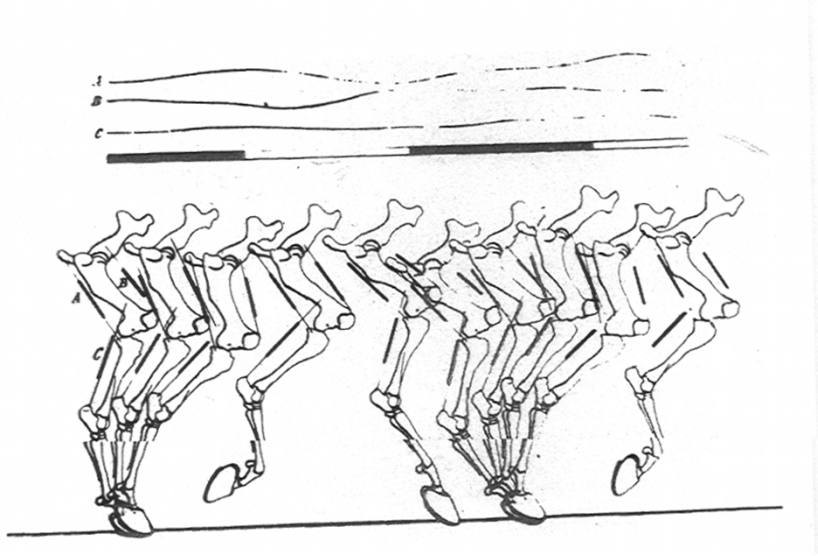
- Sequence of figure to record the motion sequence
- Walking analysis
- Force measurement in support phase
- Chronophotography



Muybridge (1831-1904)

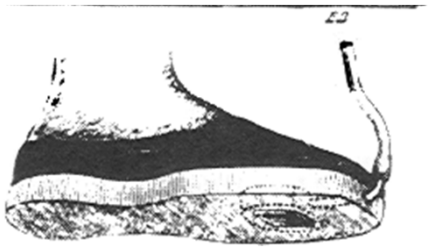
- Coeval with Marey also worked with photoseuenves. He summerized his work in two books whuch were titled (Animal Locomotion), and (Animals in Locomotion)
- His most famous statement is During the running of a horse there is a moment when none of legs of the horse thouches the ground (STANFORD).

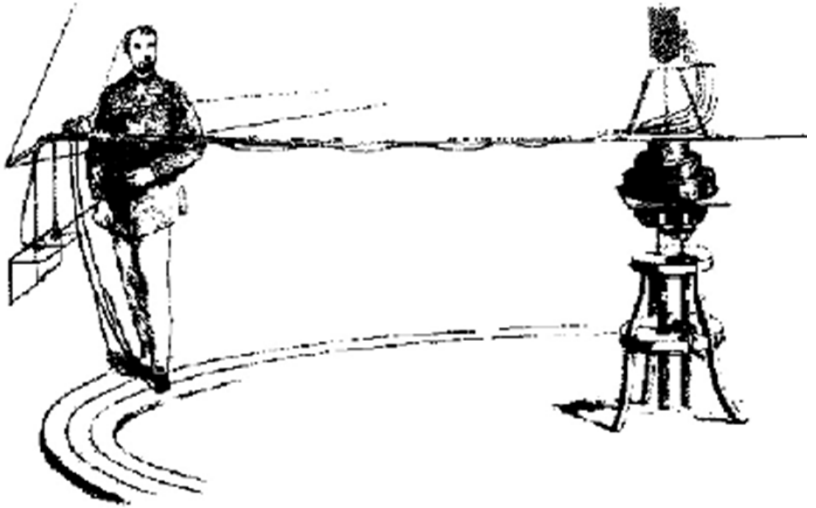




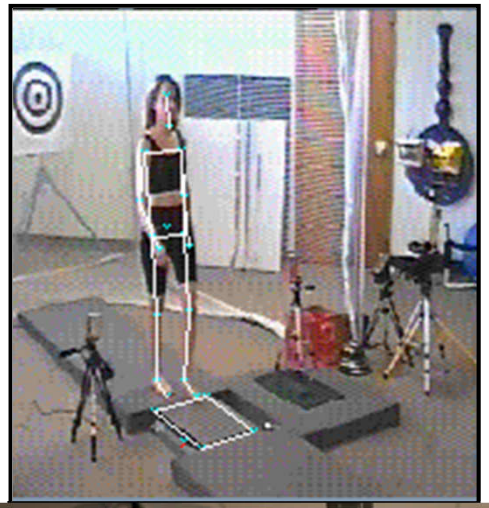
Force measurement syystem

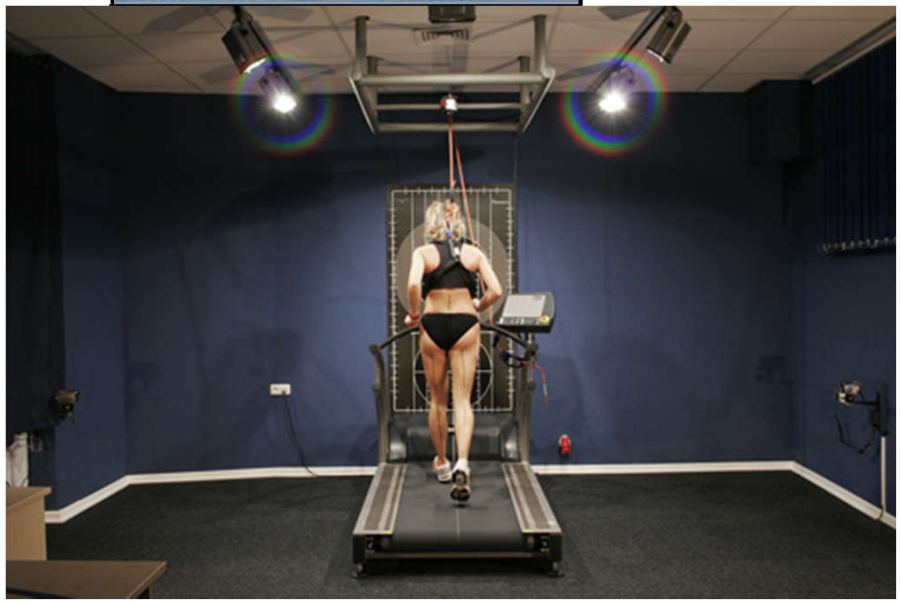
- Maray: In a given pont
- Carlet (1845-1892): can measure the pressure on the foot in different points (distribution measuremnt), and the oscillation

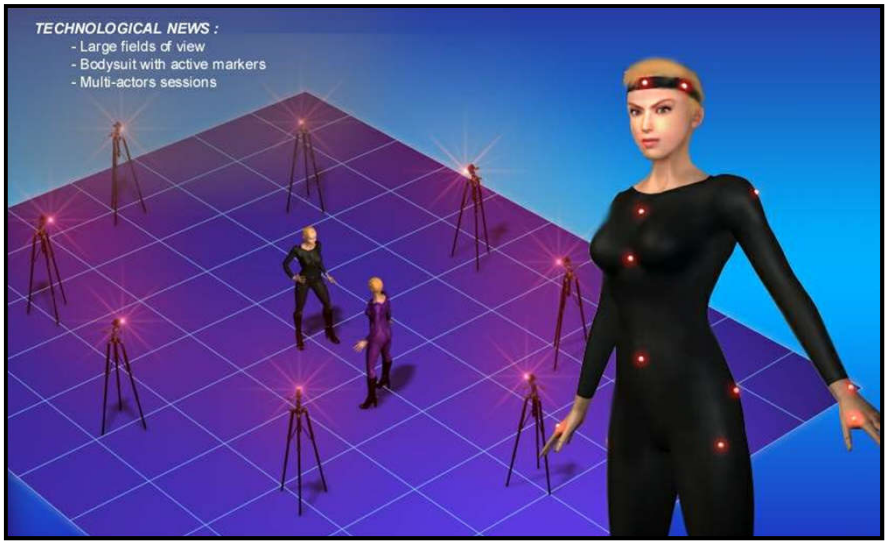




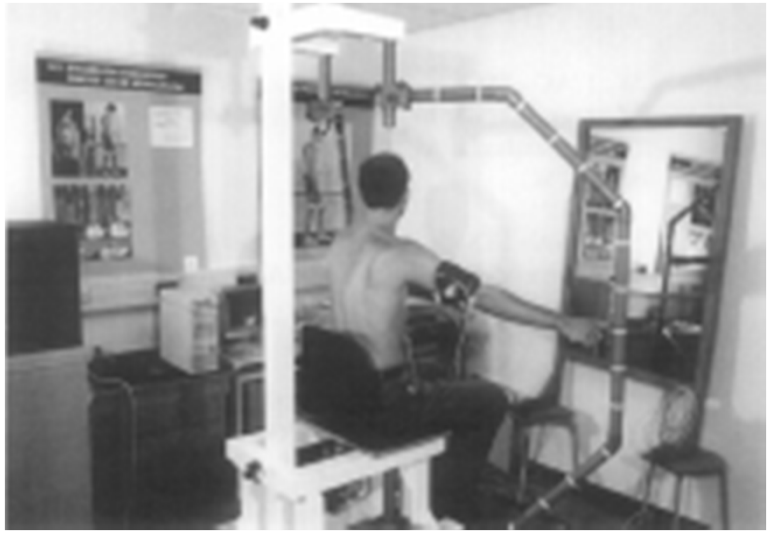
System of nowadays– optics based



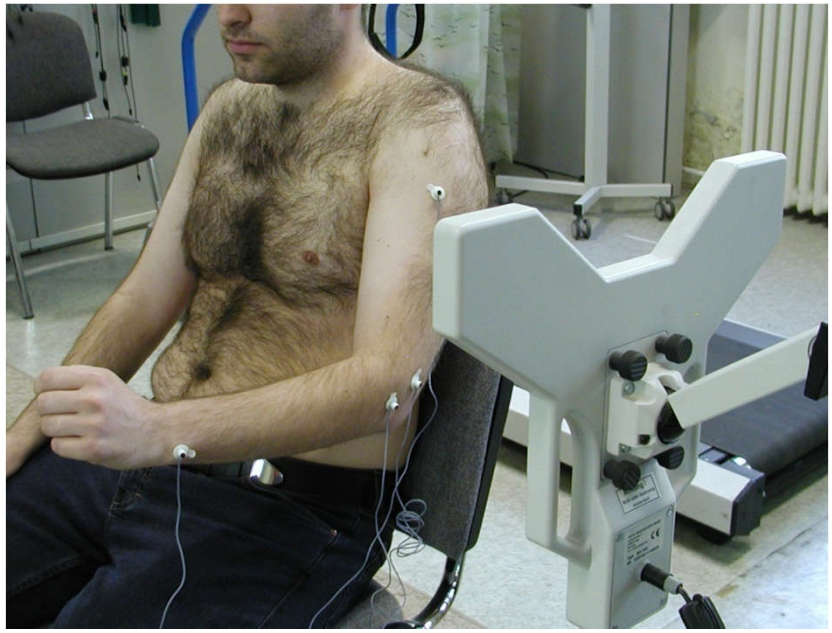




Electromagnet based



Ultrasound based systems



Individual sensors

Sensor triplets

BASIC KNOWLEDGE ON MECHANICS

Literature

Kocsis-Kiss-Illyés: Mozgásszervek biomechanikája, Terc Kiadó, 2006. 2. fejezet

Field of mechanics

- **Statics:** is the branch of mechanics that is concerned with the analysis of loads (force and torque, or "moment") on physical systems in static equilibrium.
- **Strength of materials:** Defines deformation and the stress in the loaded structure
- **Dinamics:** Describe the motion and the cause of the motion

NOTATIONS USED FOR THE DESCRIPTION OF THE HUMAN MOTIONS

Dinamics

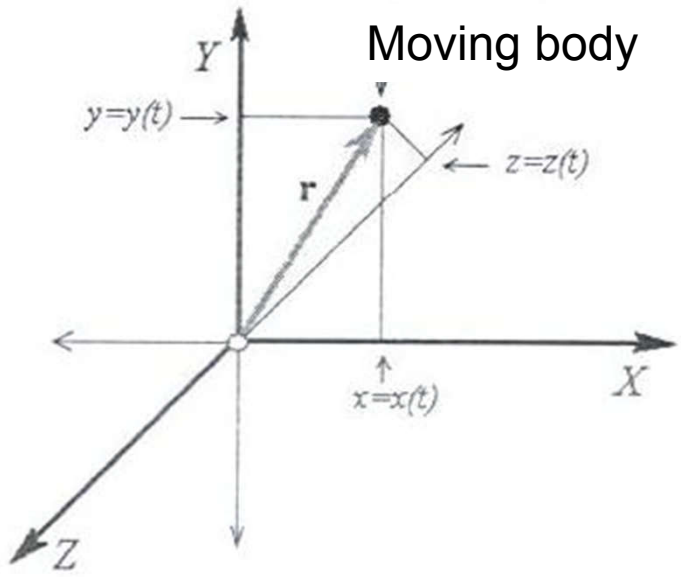
- **Kinematics**: Dealing with the description of the motion. Not concerns on the cause of the motion.

- **Kinetics:** Dealing with the cause of the motion

Definitions

The motion of particles are described in a reference frame in the function of time

- Point mass (no extension)
- Human motions, can be descriped in complex ways, while the position of the segments respects to each other is important.



Kinematics

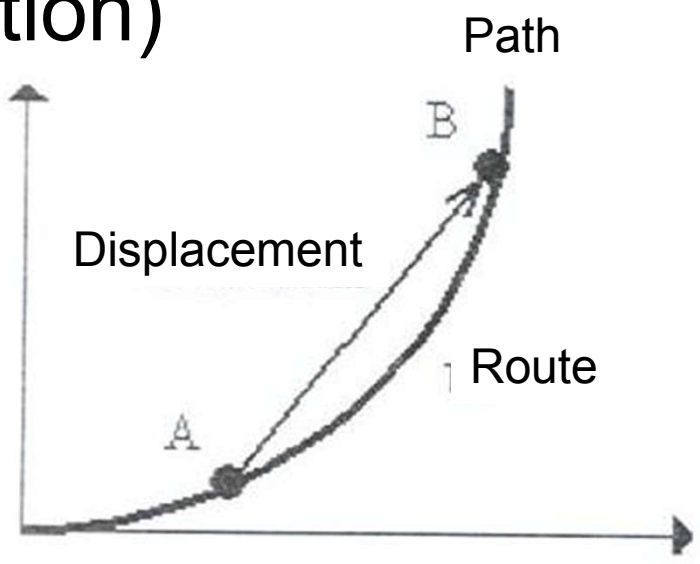
Newton Laws

- I. When viewed in an inertial reference frame, an object either is at rest or moves at a constant velocity, unless acted upon by an external force.
- II. (basic law of dynamics). The acceleration of a body is directly proportional to, and in the same direction as, the net force acting on the body, and inversely proportional to its mass. Thus, **F** = *m***a**, where **F** is the net force acting on the object, *m* is the mass of the object and **a** is the acceleration of the object.

  F=m a /if the mass is constant
- III. (action – reaction). When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction to that of the first body.

Notions in mechanics

- Path: the way, where the body is moving from point A to B
- Displacement: the vector quantity between the starting point and the endpoint (magnitude and direction)
- Time
- Velocity
- Acceleration
- Impulse I=m v

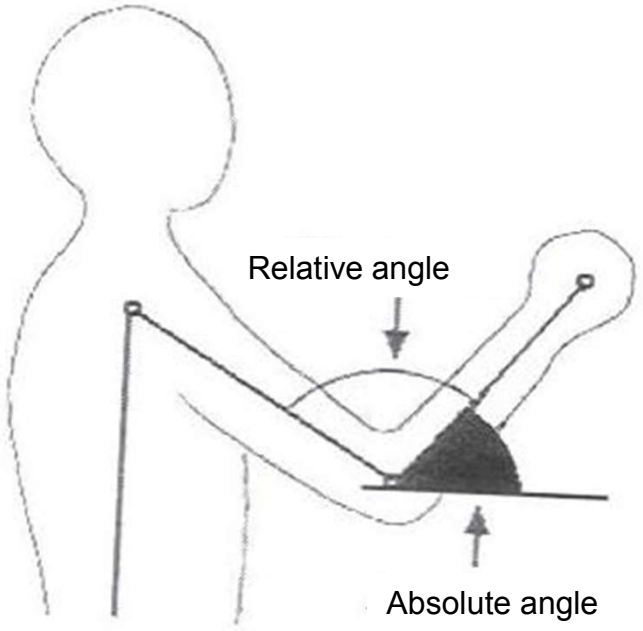


Parameters

- Distance – time parameters:
  - Position of points
  - Traveled distance between two momemt
  - Time parameters

Parameterss

- Degrees of freedom
- Angle-like parameters
  - Relative angle: the orientation of the body segments respect to each other
  - Absolute angles: the orientation of the body segments respect to the coordinate frame

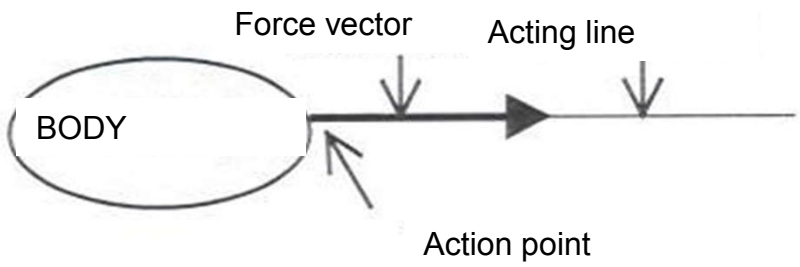


Ángyán: Az emberi test mozgástana

Kinetics

Definition

- Kinetics- Dinamics deal with the effects of forces during the acting on bodies. The force is an effect which modifies the state of the motion or effect deformation.

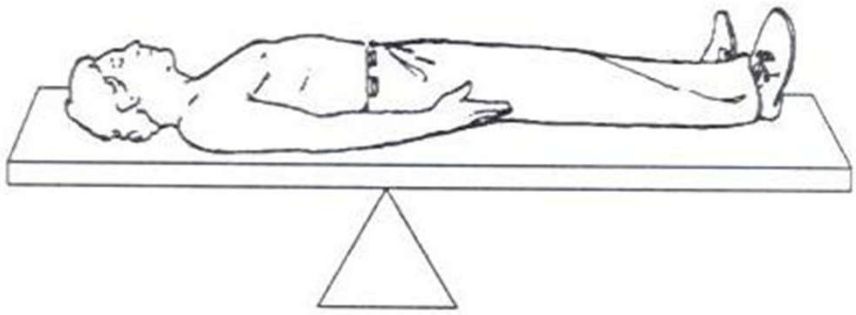


Mass

- Whole body mass
- Fat mass (sinking into water, skinfol measurement, bioelectric impedance measurement)
- Fat-free body mas testtömeg
- Whole muscle mass (formulas)
- Body-Mass-Index (BMI kg/m^2)

Center of mass

- Center of mass is the given supporting point when the body stays in equlibrium

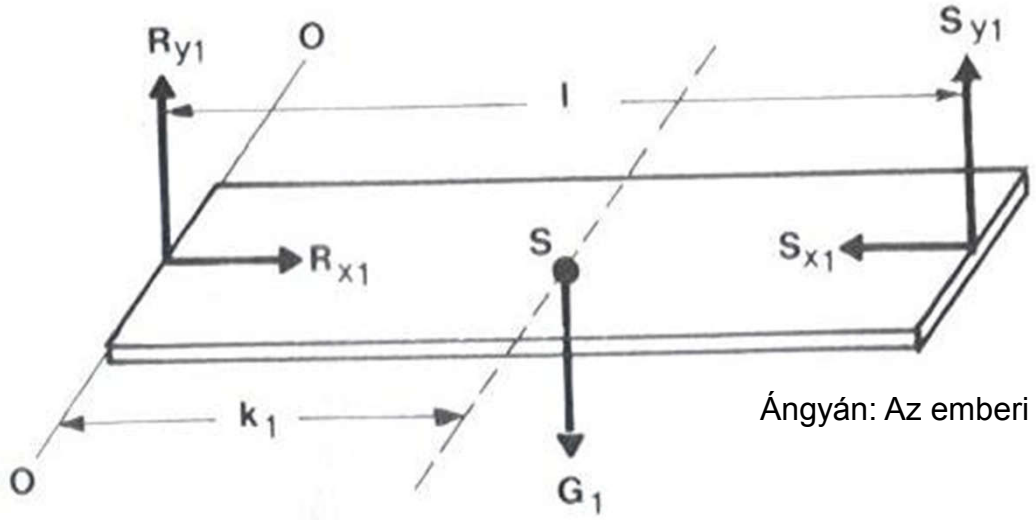


Determination of the center of mass

Histroical overview

- Borelli (scale)
- Weber brothers (point support a)
- Body segments studies:
  - Harless: center of mass of 18 bodysegments with balancing sinking of the volume
  - Braune, Fisher (Meeh): Determined the center of mass, volume density
  - Fisher: Determination of inertias
- In-vivo investigations:
  - Steinhaus: Borelli elve, for body segments
  - Bernstein: reaction force measurement

Reaction force measurement determination in one dimension (cente of mass)



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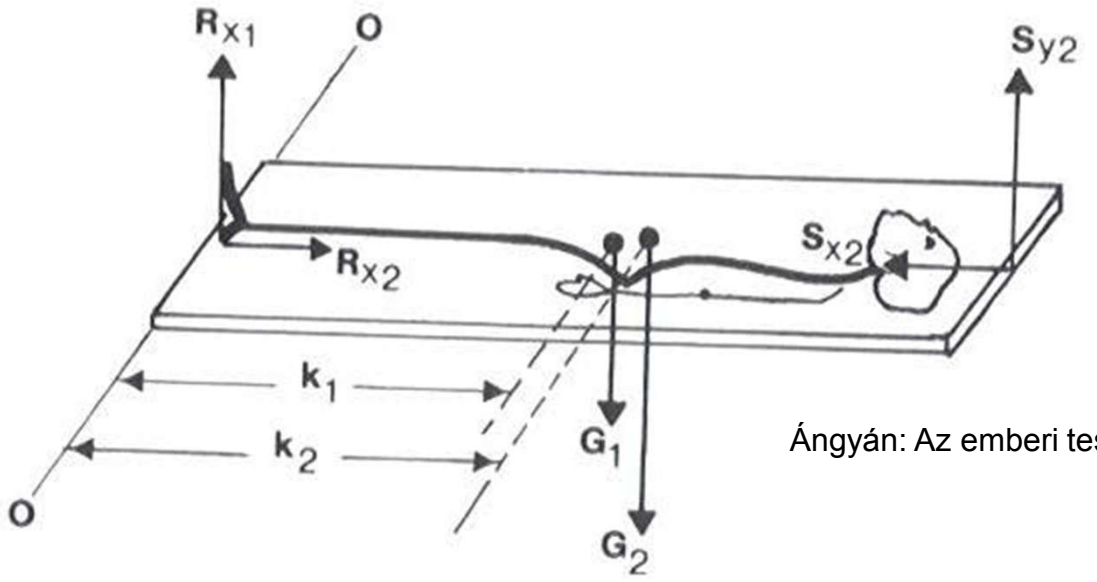
Sy1 determination
Center of mass of the board = measured weight(Sy1) x length / weight of the board

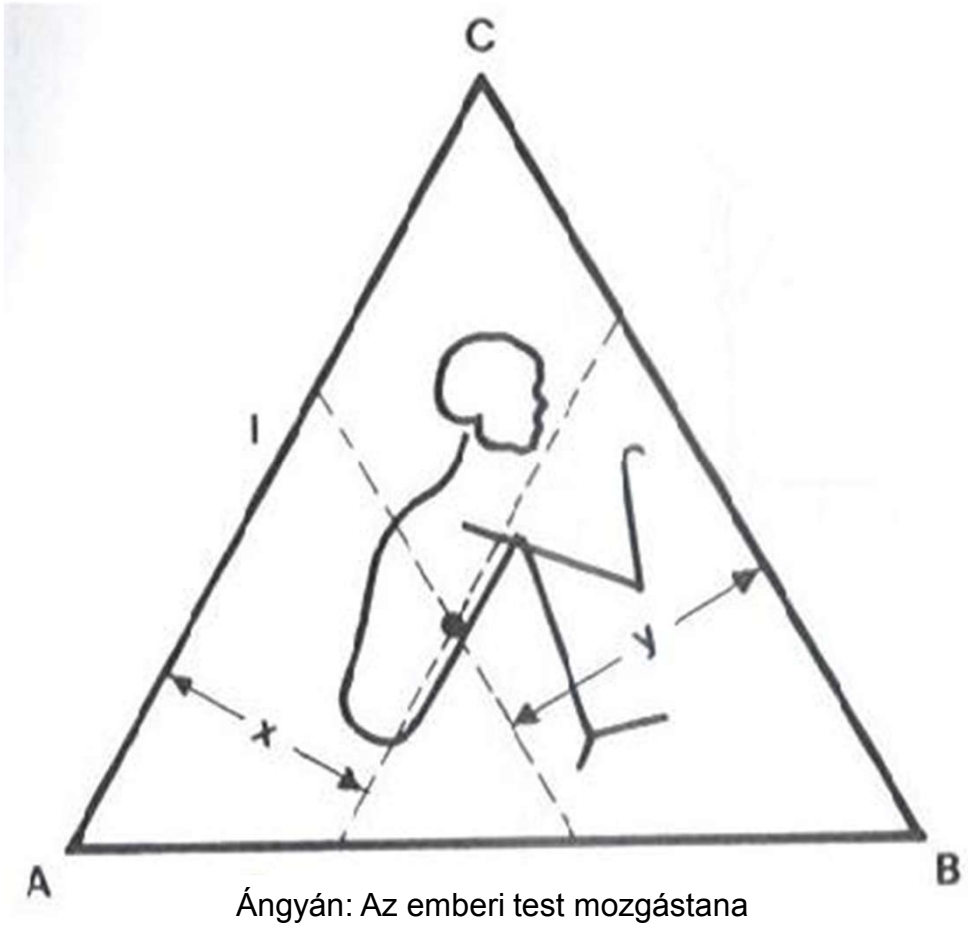
Reaction force (center of mass) determination in one dimension II.



Ángyán: Az emberi test mozgástana

Sy2 determination
Center of mass of the man =
[(measured weight on the scale (Sy2) x length)-(Sy1 x l)]/ weight

Reaction force measurement (center of mass) determination in two dimensions



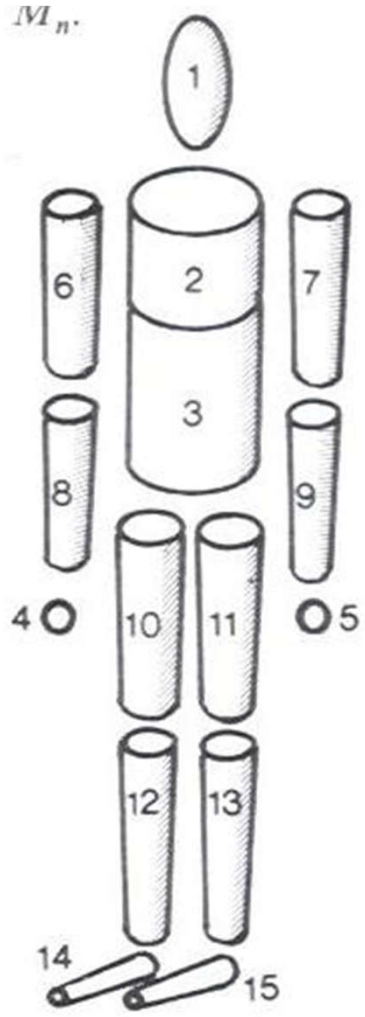
Ángyán: Az emberi test mozgástana

Analytical, segmentation method

- Widespread algorithm, calculated from the motion analysis
- Theoretical base: In the center of mass the moment of the forces are zero
- Steps:
  - Freeze
  - Divide into segments (rigid bodies)
  - Modelling of the segments, center of mass of part-segments (models)

Methods I.

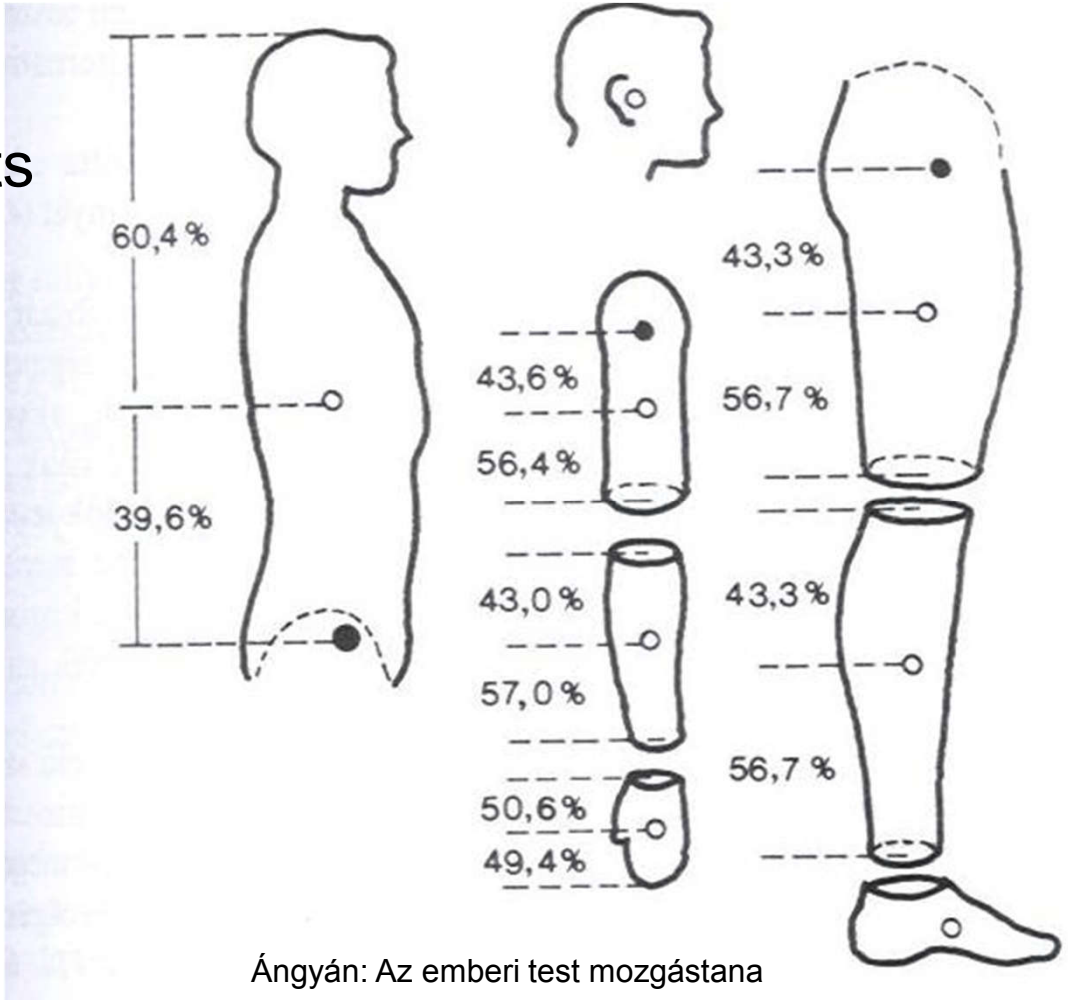
- Hanavan:
  - Approximate with geometrical bodies
  - One dimensional measurements for each segments
  - Egy dimenziós méréssel egyes szegmentumok meghatározása (determination of the limbs)



Ángyán: Az emberi test mozgástana

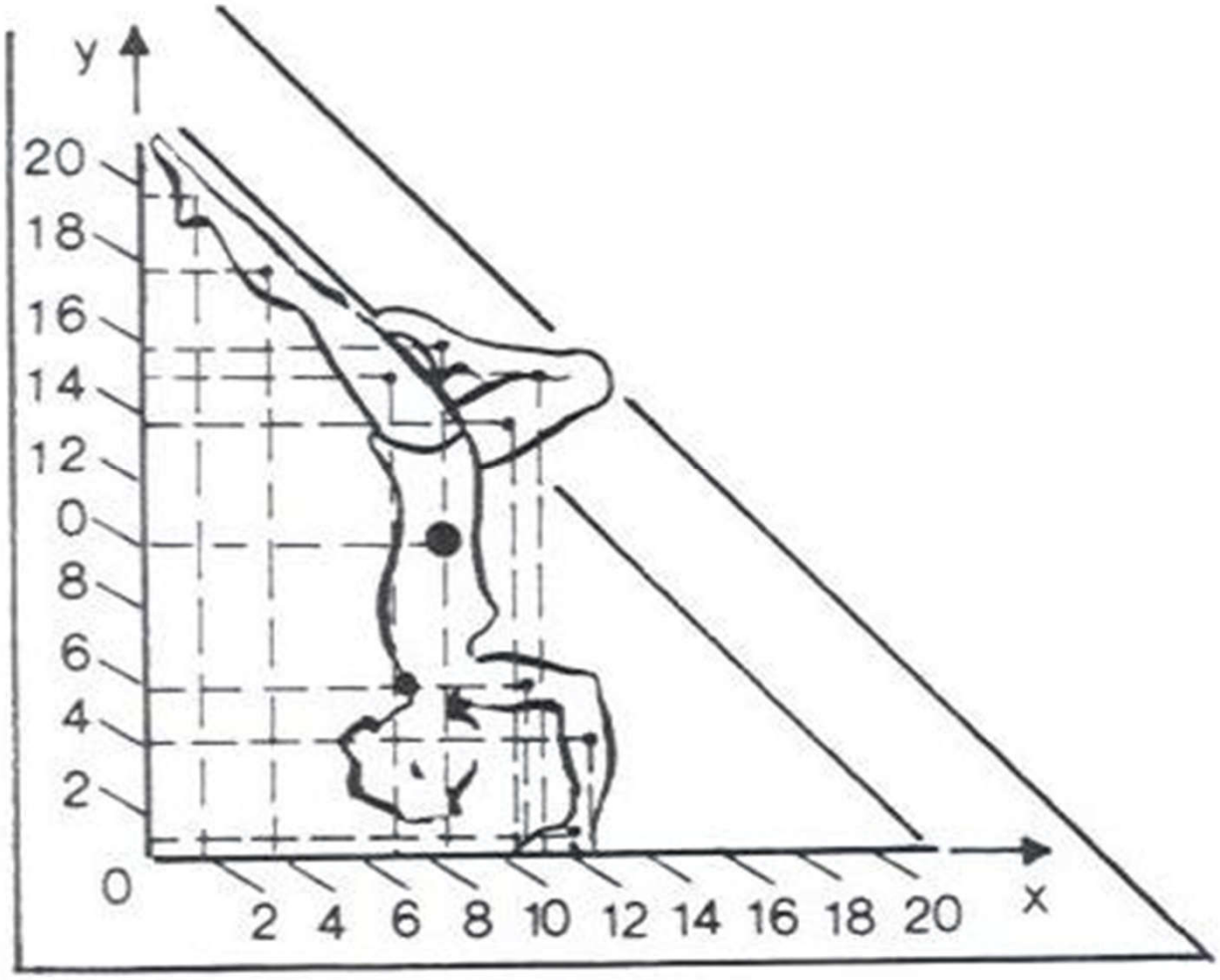
Methods II.

- Dempster:
  - Similar segments



Ángyán: Az emberi test mozgástana

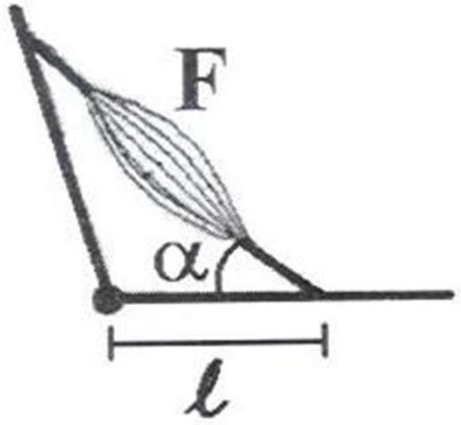
Determination



Ángyán: Az emberi test mozgástana

Force

- Force (modify the motion of the body, or load ot):
  - Inner force:
    - Almeoboid motion (chemical stimuli)
    - Ciliated, flagellated motion
    - Muscleforces (torque)



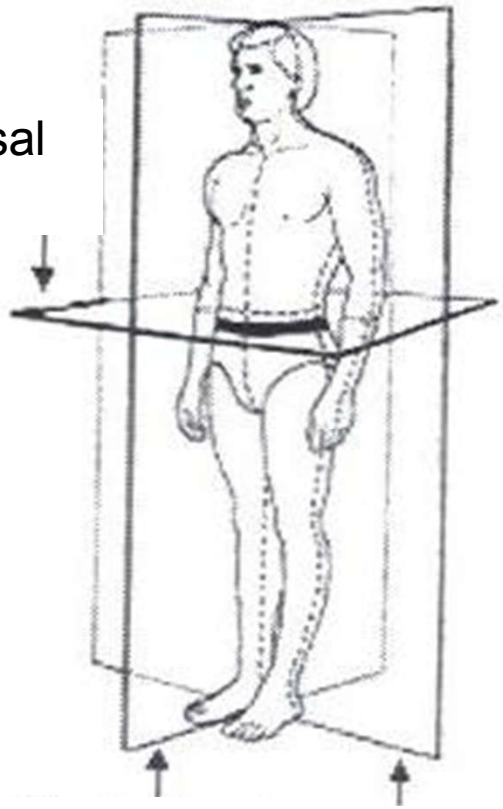
Muscle force

- Maximal force)
  - Age
  - Gender
  - Page Difference
  - Joint Situation
  - Motivation
  - Hardiness

ANATOMIC BACKGROUND

Literature

Planes of Human



Ángyán: Az emberi test mozgástana

MOTIONPATTERNS

Defintions

- The muscles are working together as a group

Motion Pattern: A motion established by the smooth operation of the muscles in space and time

Motion element: Moving a joint in one direction, The succesive activation of executive muscles in space and time is genetically determined

Complex: built up by elementary motions, the activation sequence is made up during the motion learning.

Motion set: A set of elementary and complex movement patterns, can be extended by learning

Muscle tone

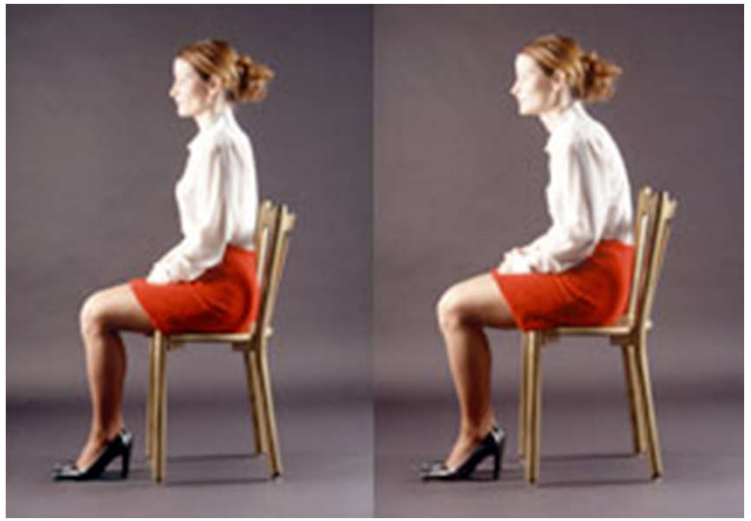
- Muscles are always in stretched state, that muscle tension is called muscle tone
- **Muscle tone** (**residual muscle tension** or **tonus**) is the continuous and passive partial contraction of the muscles, or the muscle's resistance to passive stretch during resting state
- Muscle tone can change:
  - nerve Condition
  - Hormonal status
  - diseases

Forms of motion

- posture
- change of position
- locomotion

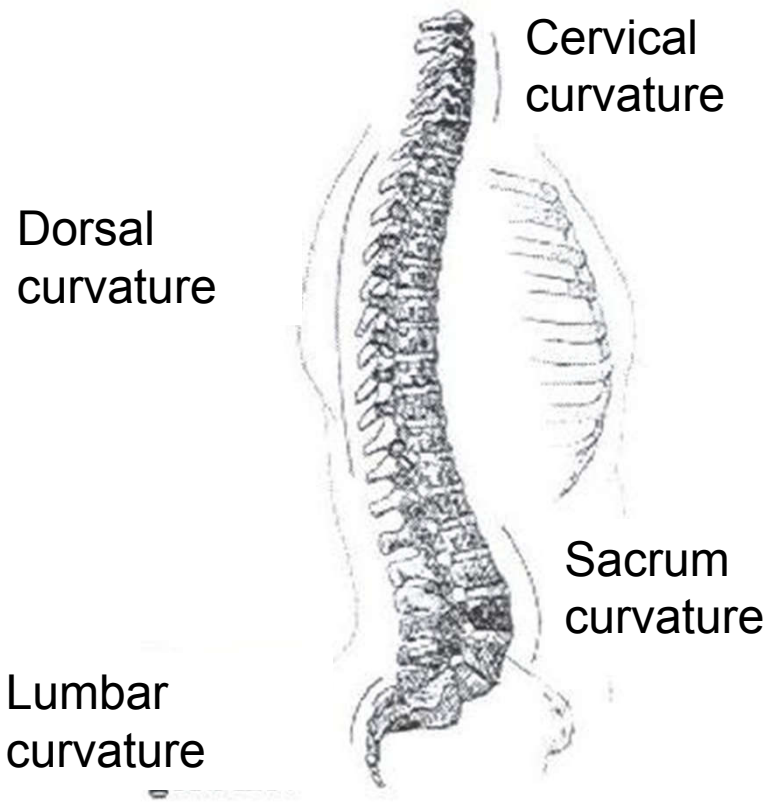
Posture

- **Definition:** The keeping in space of the relative position of body or body segments respect to each other.
- The body and it's muscles have determinative role
- Types:
  - Standing
  - Siting
  - Laying



Posture - Standing

- Upright posture (evolution)
- Pillar of the spine (four bends)



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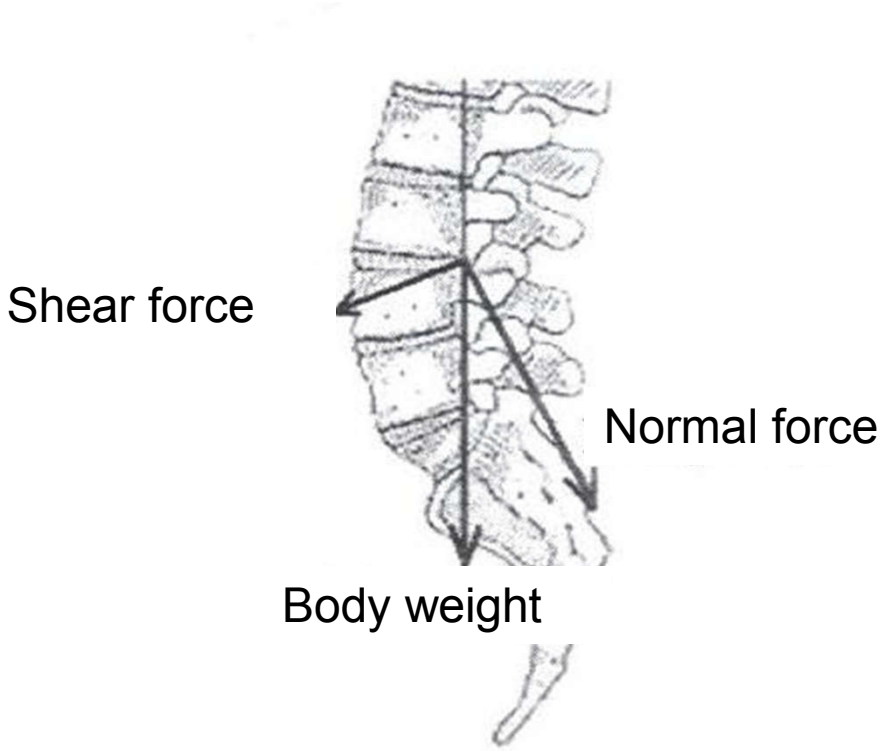
Posture - Standing

- Resulting stresses:
  - Normal force (compress)
  - Shear force (intervertebral disc, vertebral archs)

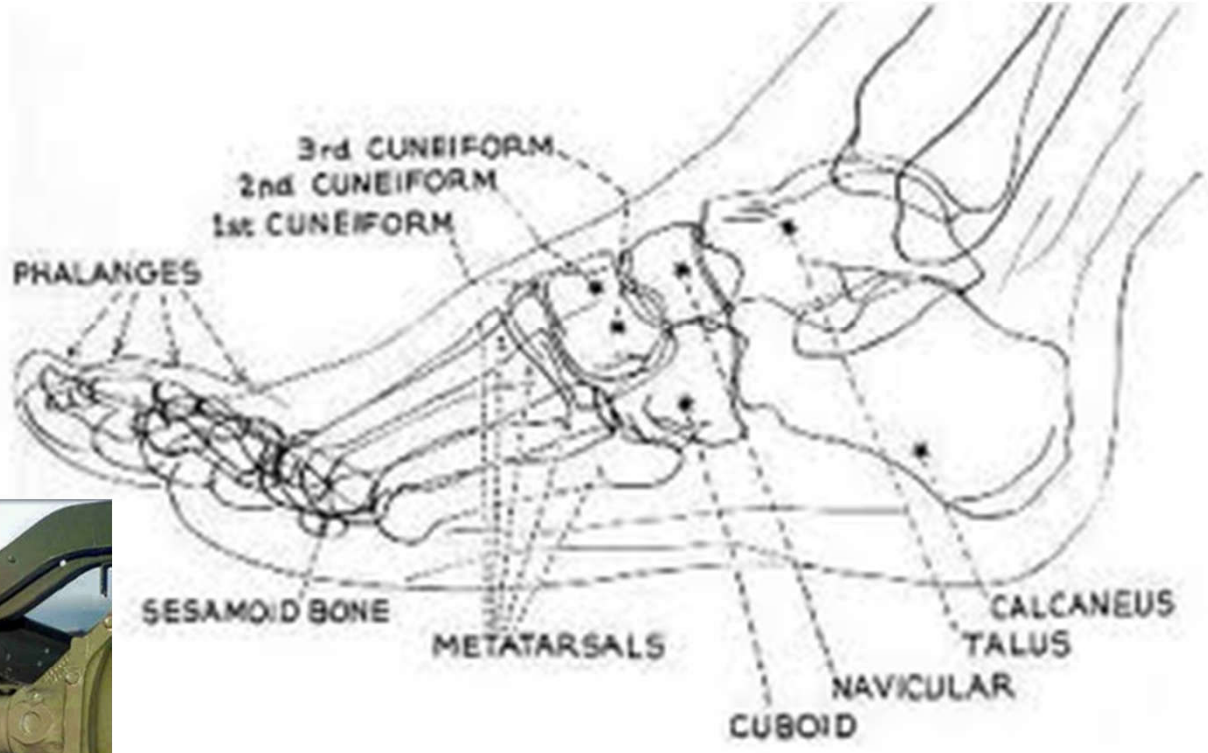


Posture- Standing

- The longitudinal axis of the body :
  - Shifting into the direction of heel
  - Problem of "Big Belly"

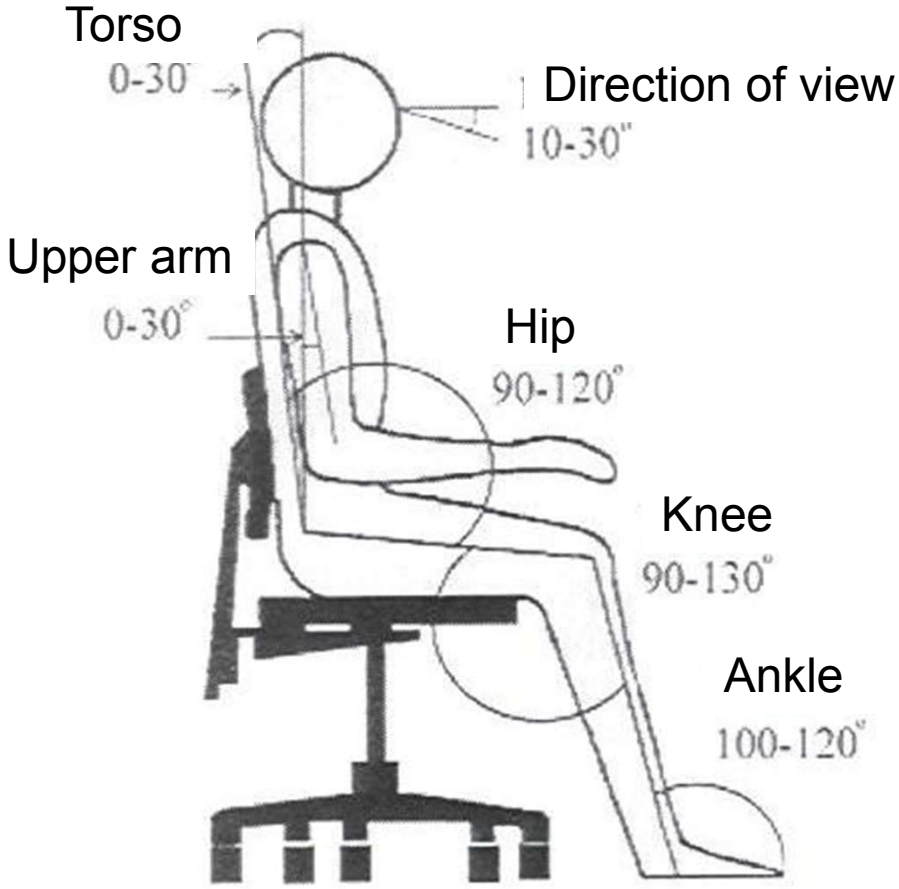
Posture-Standing

- Load transfer on foot (double curvature)
  Flatfoot problem



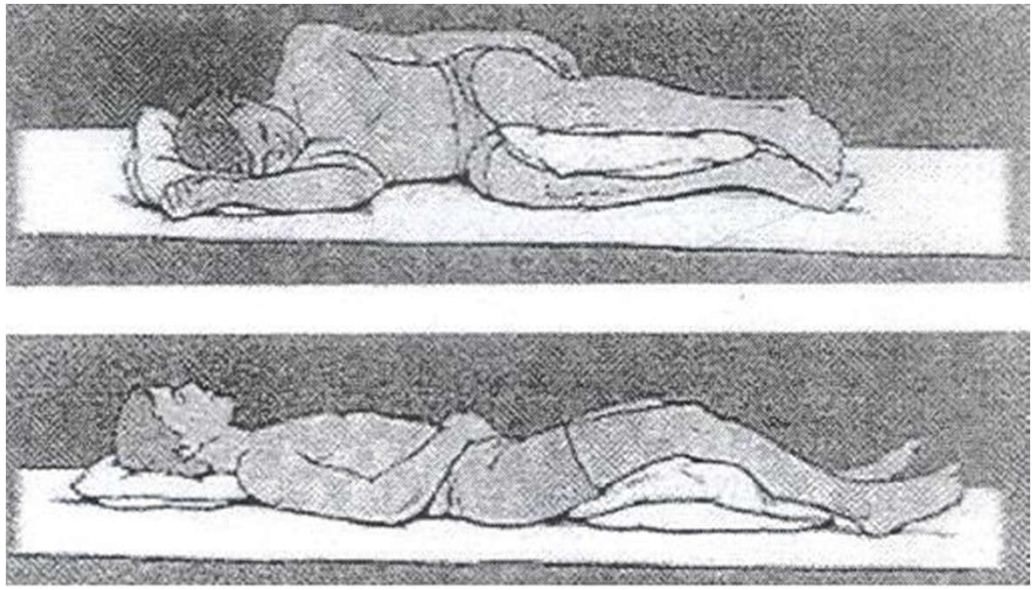
Posture – Sitting

- The role is increasing
- Ergonomically correct seating
- Head forward drive



Posture - Laying

- Minimum load
- Appropriate support
- Enhance the relaxation of muscles
- Upload intervertebral disc



Optimal position of the hip joints should be providedd

Posture changing

- Definition: the body changes the relative positions of body parts respect to each other
- types:
- Speech (articulation, articulation, body language)
- Movements by hand (writing)
  - arm lift
  - leg lift

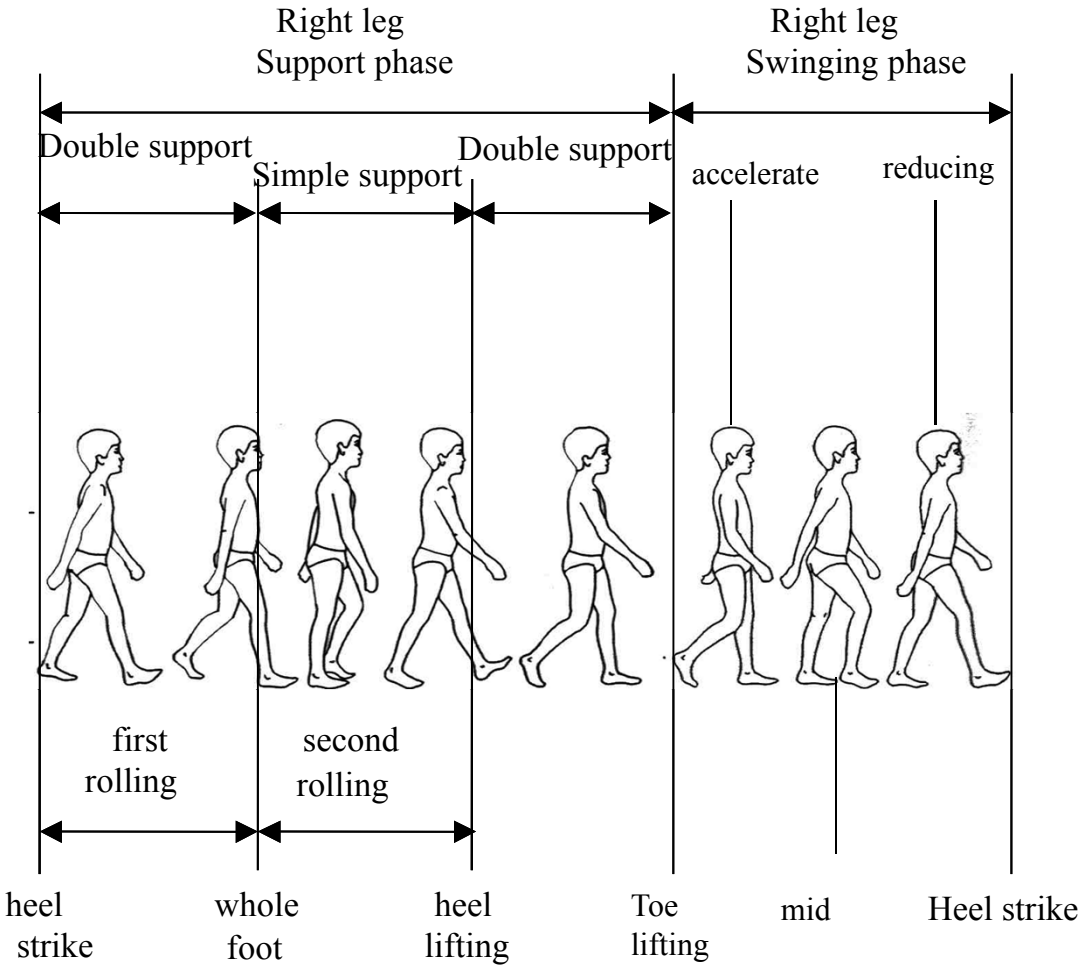
Position changing

- Definition: The body center of gravity moved respect to theglobal coordinate system.
- types:
  - walk
  - running
  - stop
  - Sports movements

Human walking (Gait)

- The most commion locomotions
- Types
  - Walk (there is a double support phase)
  - Running (there is a flying phase, that is a moment when neither foot is in contact with the ground)
- Motor , cyclic behavior
  - A **motor skill** is a learned sequence of movements that combine to produce a smooth
- Influencing factors:
  - Type (body parameters)
  - Learning (early childhood or re-learning)
  - Mood (excitation of the central nervous system)

Phases of walking



Walking

Cyclic symmetric motion because each section is repeated following each other.

Basics of gait analysis:

step cycle, which is the whole limb movement period, the limb heel strike until the next heel strike,

sections:

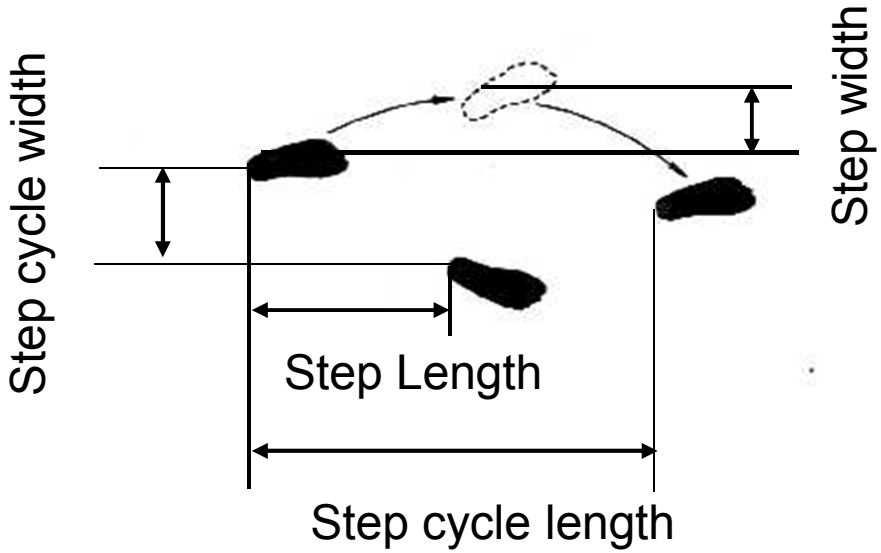
- Support phase
- Swing phase

step, which hold from one of the leg's heel strike until the other limb's heel strike

[Szendrői M (szerk): Ortopédia]

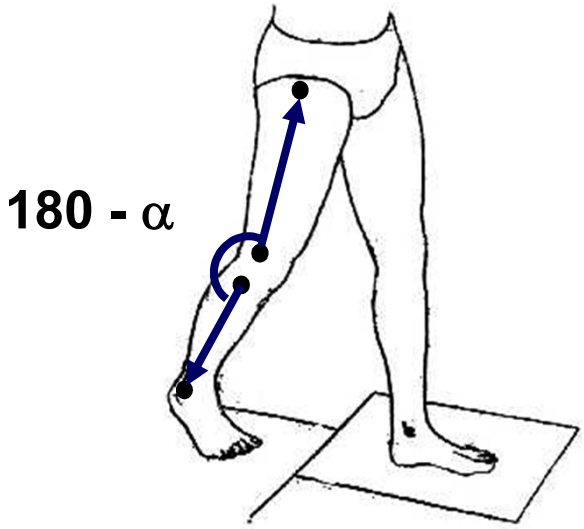
Kinematical description of gait

- Distance-time parameters:
  - Stride length
  - Step Cycle Length
  - step width
  - Cycle step width
  - The length of the time

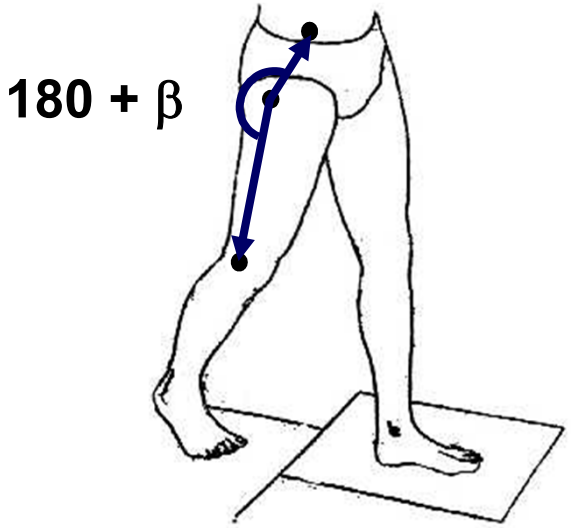


Kinematical description of gait

- Angle-type parameters:
  - Ankle, knee, hip angles can be measured in different planes (in terms of angles)
  - Body segment's characteristic angle between vectors (relative angles)



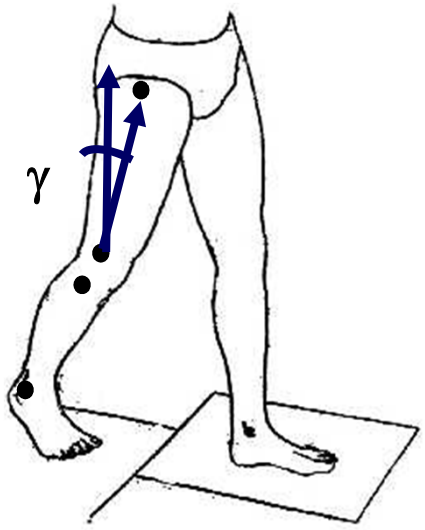
Knee angle



Hip angle

Kinematical description of gait

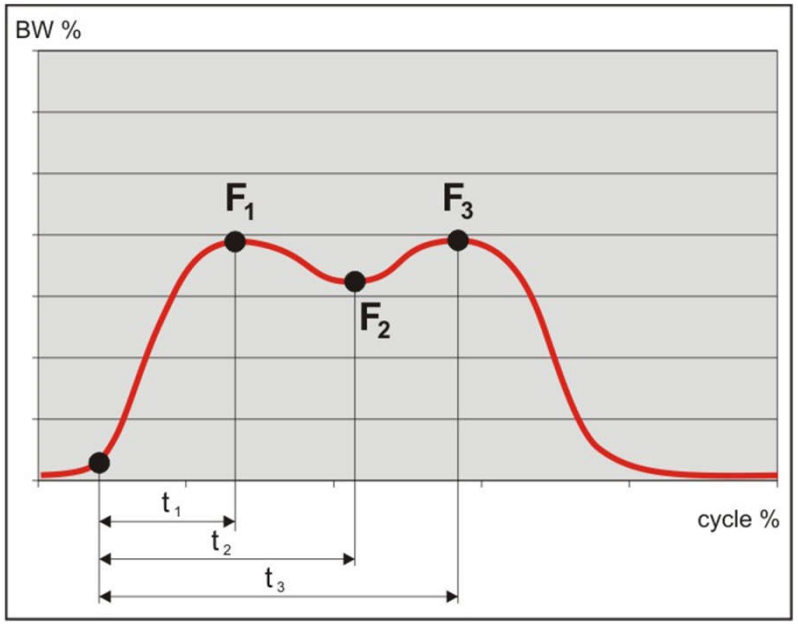
- Angle type paramteres
  - Angle of some segments respect to the global or local coordinate system of segments (Euler angles) (absolute angles)



Angle of shank

Kinematical description of gait

- Reaction force changing in time



F_1: Heel strike
F_2: Whole foot
F_3: Heel lifting

Gait- motion pattern of walking

The implementation of the individual gait characteristics:

- maintaining a balance
- Coordination between the two sides
- Keep rythm of walking