Biomechanics and Motion Analysis:

Mechanical Principles

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Overview

1 Introduction: Definitions and fields of application

2 Mechanical principles (Kinematics, Dynamics)

Introduction

Introduction

Biomechanics is an interdisciplinary science that describes, analyses and assesses human motion.

Biomechanics as an outgrowth of both life and physical sciences, is built on the basic body of knowledge of physics, chemistry, mathematics, physiology and anatomy.

(*Winter, 1990*)

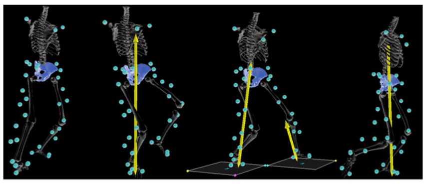
Biomechanics is the science which studies structures and functions of biological systems using the knowledge and methods of mechanics (*Hatze, 1971*)

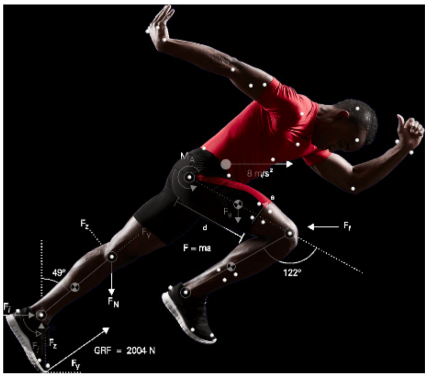
Biomechanics is the science that examines forces acting upon and within a biological structure and effects produced by such forces. (*Nigg, 1994/1999*)

Introduction

Fields of application

- **Performance Biomechanics**
  - analysis of the technique of the movements in order to identify and evaluate the main variables involved
  - individual diagnosis





- **Anthropometric Biomechanics**
  - identification of talents, prognosis of performance

- **Preventive Biomechanics**
  - analysis of joint loads, ergonomics

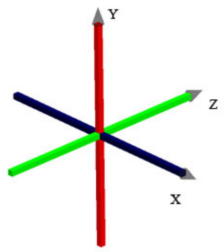
Mechanical Principles

Mechanical Principles

Mechanics investigates the motion of physical bodies and the effect of forces acting on these bodies

Kinematics – deals with the geometry of movement without reference to forces

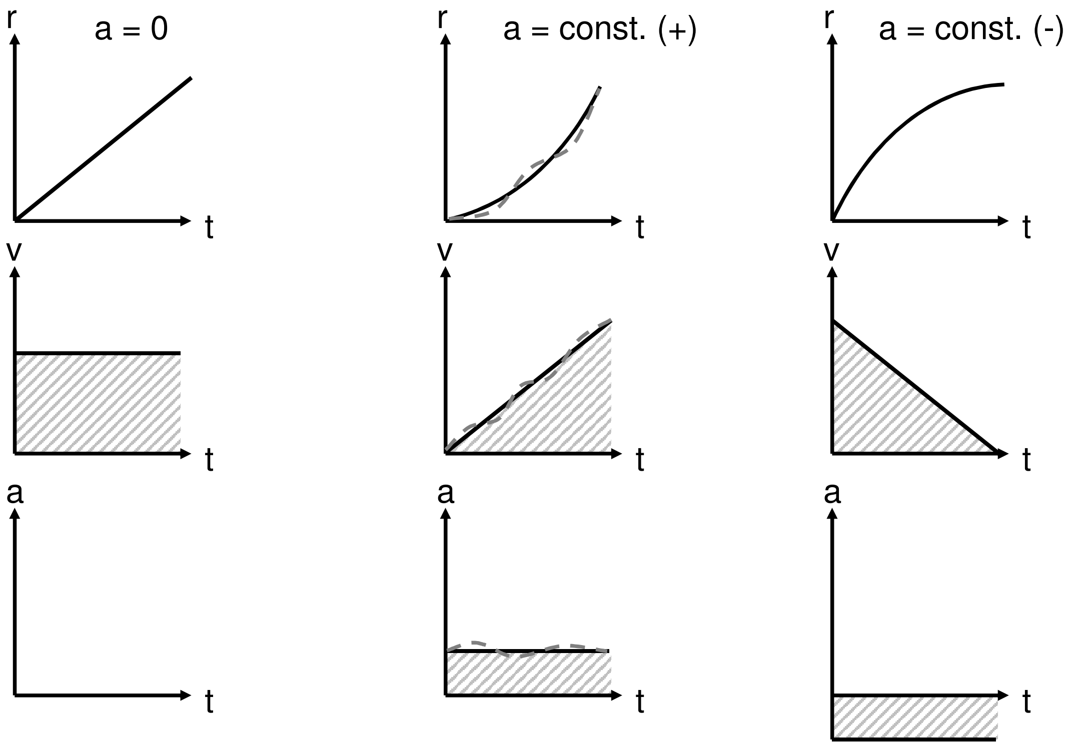
Dynamics – deals with effect of forces on the motion of objects



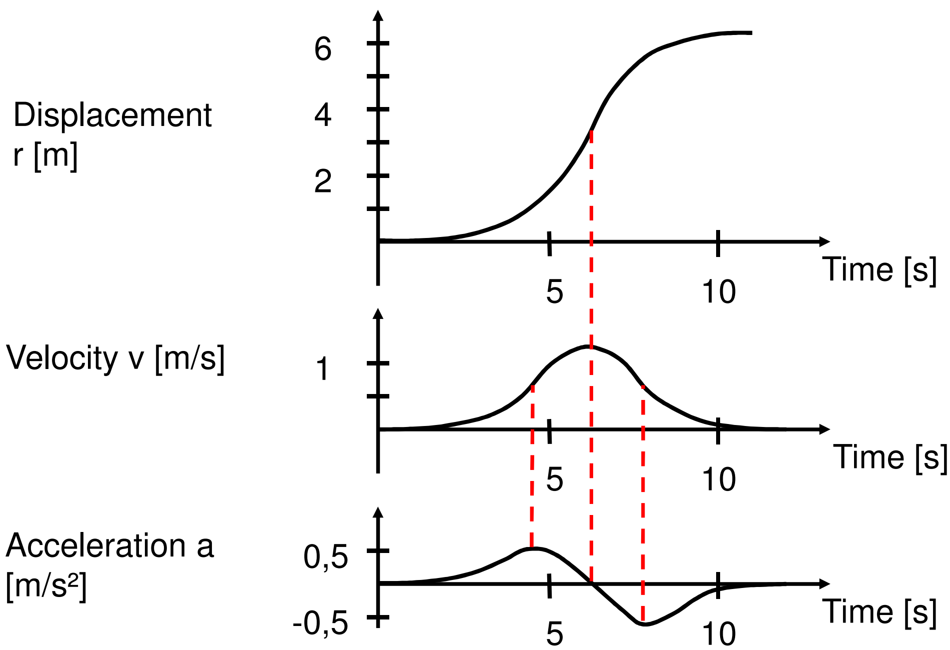
Mechanical Principles – Kinematic Parameters

Linear displacement:	Change in position in space
Velocity:	Rate of change of displacement (position) with respect to time
Acceleration:	Rate of change of velocity with respect to time
Angular displacement:	Change in angular position
Angular velocity:	Rate of change of angular displacement with respect to time
Angular acceleration:	Rate of change of angular velocity with respect to time
Instantaneous- .... :	Instantaneous rate of change ....

Mechanical Principles - Diagrams



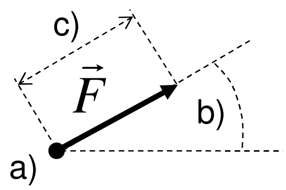
Mechanical Principles – r-/v-/a -Curves



Mechanical Principles – Dynamics

Dynamics: Change of motion (acceleration) or deformation of physical bodies affected by forces .

Force is a vector defined by:
- a) point of application (point on object, where force acts; e g. gravitational force at center of gravity)
- b) direction (e. g. push angle in shot putting),
- c) magnitude (e. g. weight of barbell),



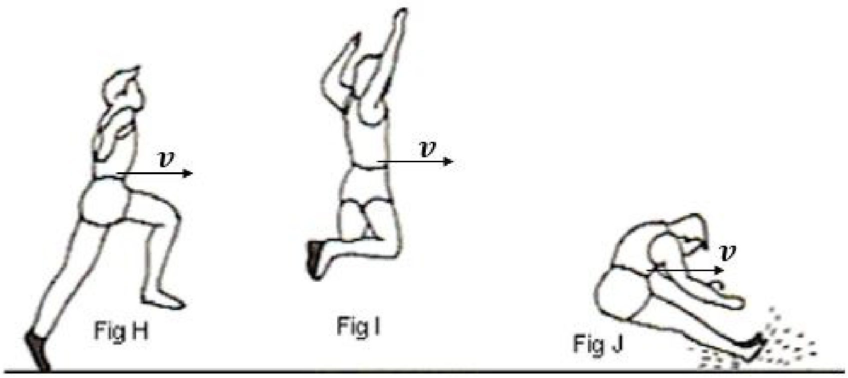
Mechanical Principles – Newton‘s Laws

1. Law of inertia

An object will continue in a state of rest or of uniform motion in a straight line unless acted upon by external forces.

$$\sum_i \vec{F}_i = 0 \Rightarrow \vec{v} = const$$

Mechanical Principles – Newton‘s Laws



Law of Inertia during Long Jump

Mechanical Principles – Newton‘s Laws

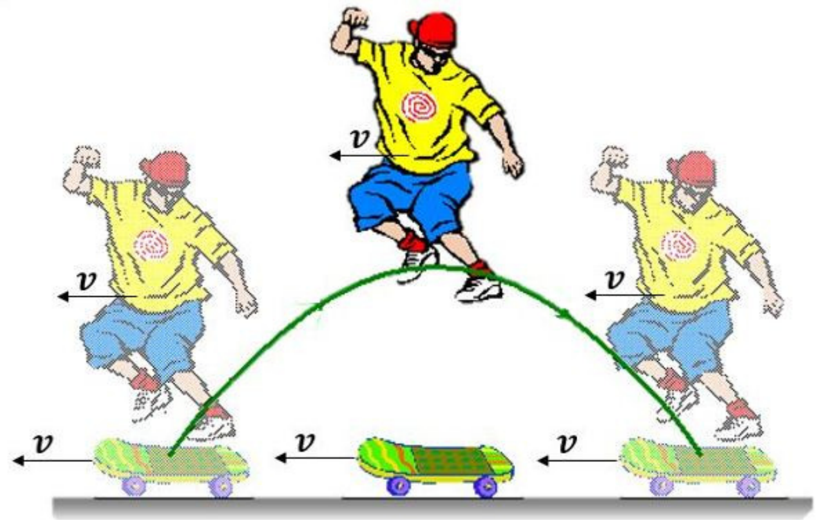
2. Law of momentum

The rate of change of momentum of an object is proportional to the force causing it and takes place in the direction, in which the force acts.

$$\vec{F} = m \cdot \vec{a} = m \cdot \frac{\Delta \vec{v}}{\Delta t}$$

The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

Mechanical Principles – Newton‘s Laws

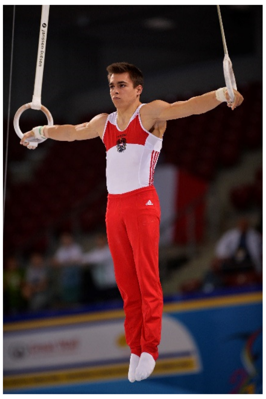


Law of Inertia – Vertical Jump from Skate board

Mechanical Principles – Newton‘s Laws

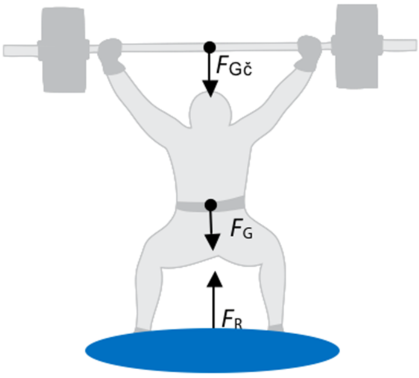
3. Law of interaction

For every action (force) exerted by one object on a second, there is an equal and opposite reaction (force) exerted by the second object to the first.



Mechanical Principles – Newton‘s Laws

Law of interaction



Reaction forces at weight lifting (left) and at sprinting (right)

Mechanical Principles – Dynamics

Examples of Forces

- Weight (gravitational force)
- Friction forces (static friction, kinetic friction)
- Air- and water resistance forces
- Muscle forces

Mechanical Principles – Dynamics

Linear momentum

$$F \cdot \Delta t = m \cdot a \cdot \Delta t = m \cdot \frac{\Delta v}{\Delta t} \cdot \Delta t = m \cdot \Delta v$$

Mechanical Principles – Dynamics

Conservation of linear momentum

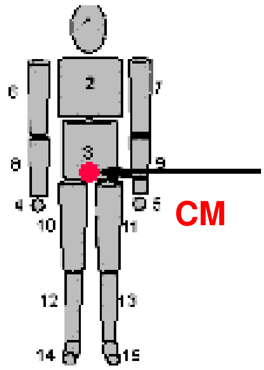
$$\sum_i p_i = \sum m_i \cdot v_i = m_1 \cdot v_1 + m_2 \cdot v_2 + \ldots + m_n \cdot v_n = const$$

When external force on a system of particles is zero, the linear momentum of a system of particles can not change.

Center of mass

The center of mass is the point, which moves, as if the mass of the object would be concentrated within this point and all the acting external forces would apply on it.

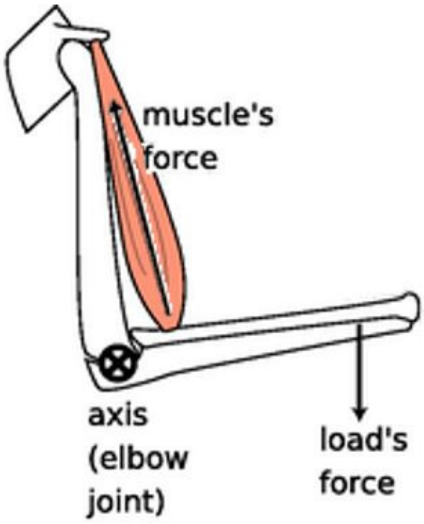
When an object is supported at its center of mass there is no net torque acting on the body and it will remain in static equilibrium.



Mechanical Principles –
Dynamics of rotatory motions

Rotational analogues to force, linear momentum and mass are moment of force, angular momentum and moment of inertia.

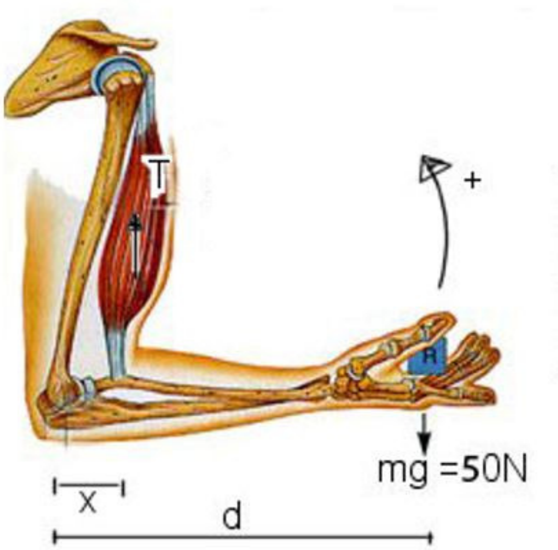
Moment of Force



Muscle torque

M=r.F

Example:



m=5 kg

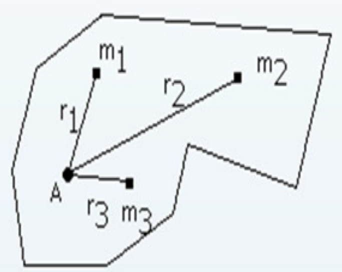
x=3,5 cm

d=35 cm

A force of about 500 N is
required to hold the cube (mass from
forearm and hand neglected)

Mechanical Principles – Moment of Inertia

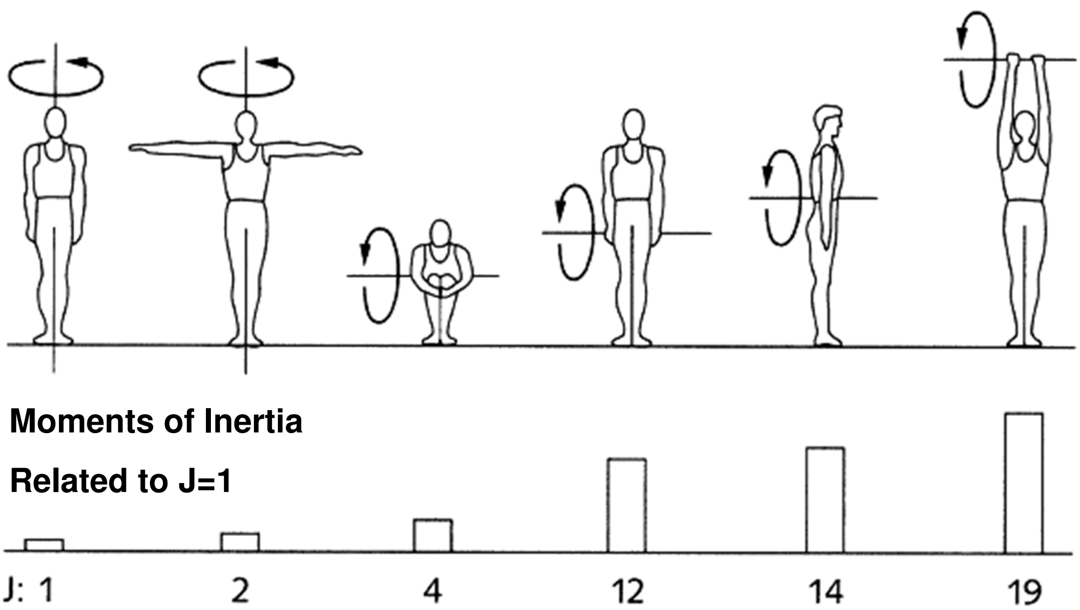
$$J = (m_1 r_1^2) + (m_2 r_2^2) + (m_3 r_3^2) + \ldots (m_n r_n^2)$$



The **Moment of Inertia** is often given the symbol J. It is the rotational analogue of mass. In Newtonian physics the acceleration of a body is inversely proportional to mass. In Newtonian rotational physics angular acceleration is inversely proportional to the moment of inertia of a body. You can think of the moment of inertia as the ability to resist a twisting force or torque.

Source: https://astronomy.swin.edu.au/cosmos/M/Moment+of+Inertia

Mechanical Principles – Moment of Inertia



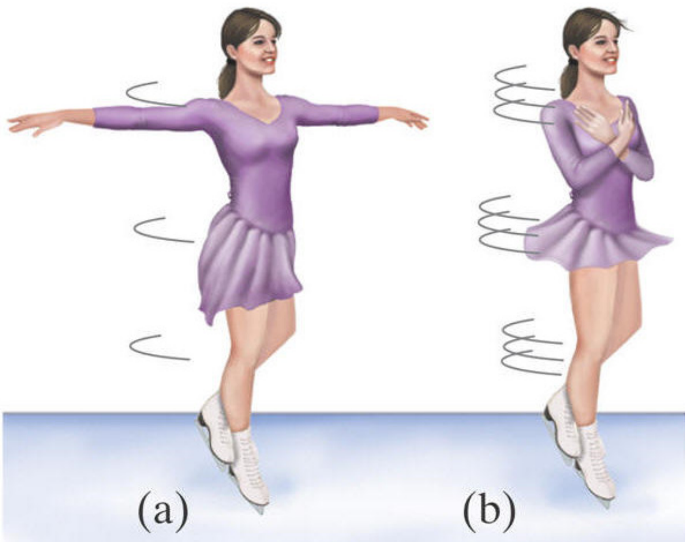
Roth & Willimczik, 1999

Mechanical Principles – Angular momentum

$$L = J \cdot \omega$$

[kg*m²/s]

The property of any rotating object given by moment of inertia times angular velocity.



Mechanical Principles – Angular Momentum

Conservation of angular momentum

If sum of all moments/torques = 0 $\Rightarrow$ **L = J*ω = const.**

$\Longrightarrow$ J smaller $\Rightarrow$ ω larger and vice versa

Example: somersault