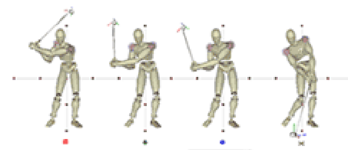
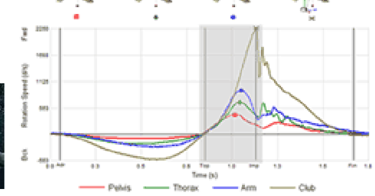
What is biomechanics?

Biomechanics is the science which describes and predicts the conditions of rest or motion of biological systems under the action of forces (Robertson, 2004).

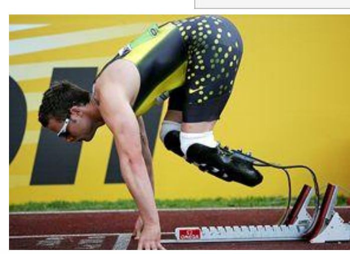
Biomechanics studies the mechanical aspects of human movement and explores the role of force, time and distance (Whiting & Rugg, 2006)

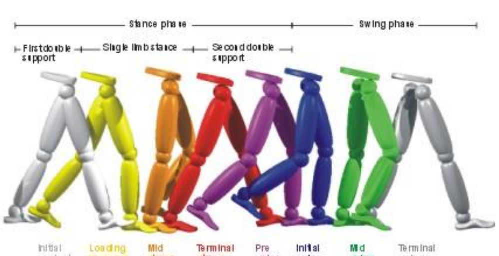


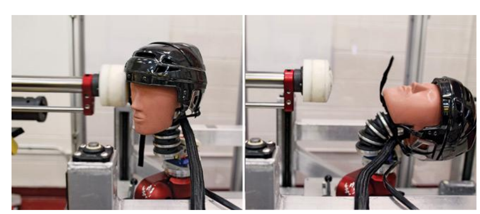
What is biomechanics used for?



- Development, evaluation and improvement of:
  - sporting techniques
  - athletic equipment
  - orthotics and prosthetics
- Coaching
- Evaluation of natural and synthetic materials
- Evaluations of work environments (ergonomics)
- Scene assessments
- Gait analysis
- Assessment, reconstruction, rehabilitation and prevention of injuries







Important definitions

Mechanics: Science which describes and predicts the conditions of rest or motion of bodies under the action of forces.

Rigid Body: A body which cannot be deformed, stretched or compressed. A body whose particles occupy fixed positions with respect to each other.

Statics: Branch of mechanics concerned with bodies at rest or in constant linear motion.

Dynamics: Branch of mechanics concerned with bodies in motion

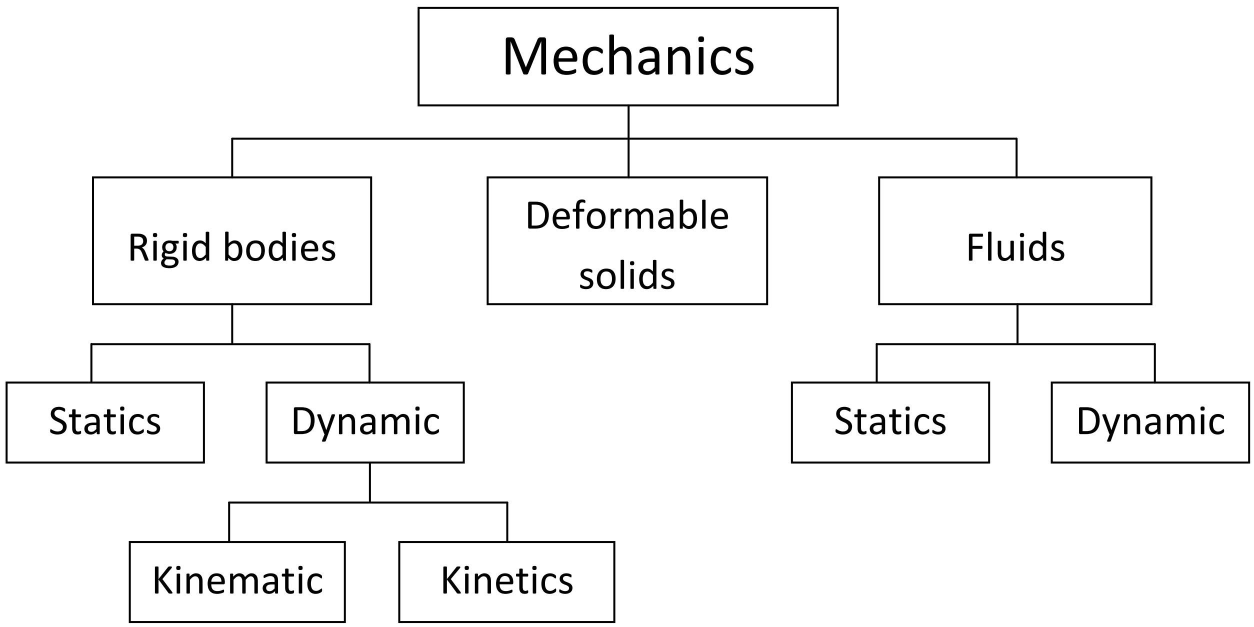
Kinematics: Branch of dynamics concerned with describing the state of motion of bodies, for example, their displacements, velocities and accelerations without regard to the causes of the motion.

mass is not involved in velocity, acceleration and displacement

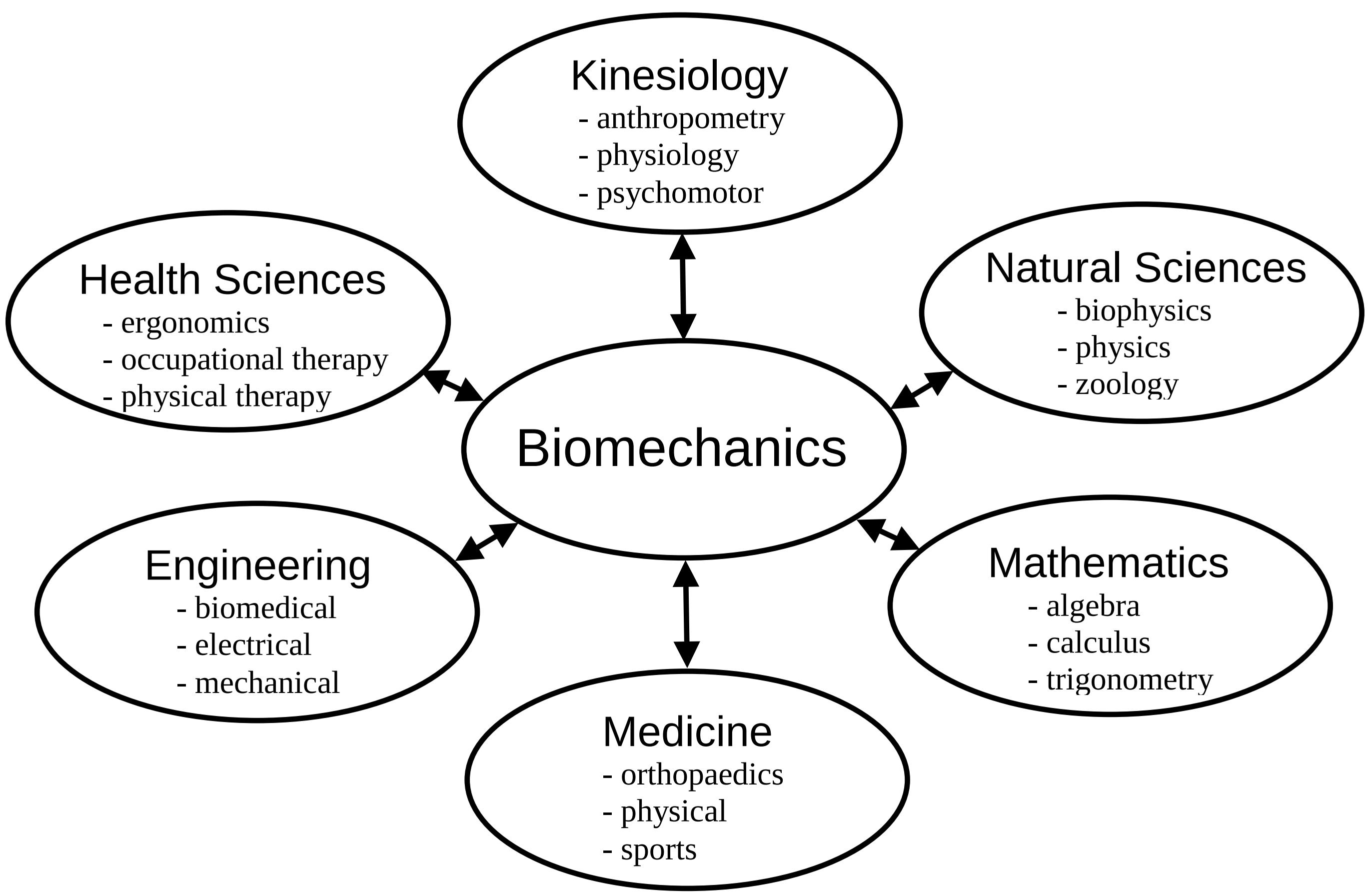
Kinetics: Branch of dynamics concerned with causes of motion and the action of forces, including the work, impulse, moment and power of forces.

mass is involved here

Subdivisions of mechanics



Biomechanics and allied fields



International system of units (SI)

Base units:	(abbrev.)	Quantity
the metre	(m)	length
the kilogram	(kg)	mass
the second	(s)	time
the ampere	(a)	electric current
the kelvin	(K)	temperature
the candela	(Cd)	luminous intensity
the mole	(mol)	amount of substance

Prefixes:	(abbrev.)	Quantity
mega	M	1 000 000
kilo	k	1 000
centi	c	0.01
milli	m	0.001

Reporting rules:

1) Use no decimal after the abbreviated versions of metric units unless at the end of a sentence.
   - Correct: 35.6 N 3.00 kg 0.500 s
   - Incorrect: 35.6 N. 3.00 kg. 0.500 s.

2) A centred dot (·) is used to separate abbreviated SI units involving combined quantities
   - Examples: N·s for newton seconds or kg·m^2 for kilogram metres squared.

   *A decimal point (.) is also acceptable (which is used throughout the textbook) and is easier to type.

3) Use a slash (/) to indicate an arithmetic division of units.
   - Examples: m/s for metres per second or N/m^2 for newtons per square metre.

4) Do not capitalize a unit derived from a proper name when spelling out the unit even though the unit's abbreviation is a capital letter.
   - Examples: the watt (W), the newton (N), the hertz (Hz), the pascal (Pa) and the joule (J).

5) Do not mix abbreviations and unabbreviated forms in an expression.
   - Correct: N/m, kg.m and N.s
   - Incorrect: newtons per m, kg.metres and N.seconds

6) The prefixes hecto, deca, deci, and centi should be avoided, excepting for the measurements of area, volume and length, such as hectare, centilitre and centimetre.

7) When pronouncing metric units that have a prefix, the accent should always be placed on the complete prefix, that is, kilo'-metre versus ki-lo'-metre or kilo-metre'.

8) Always type a space between the numeric part and the unit except for °C, ° (angle) and %.
   - Correct: 76.4 W 20.4°C 13% 678 N.m
   - Incorrect: 76.4W 20.4 °C 13 % 678N.m

9) When writing out numbers with greater than four digits on either side of the decimal point, use a space instead of a comma to separate digits into groups of three. It is acceptable to omit the space in four digit numbers.
   - Examples: 23 400 J 0.001 63 kg 7988 m

SI units of measure and abbreviations

Quantity	Name	Symbol	Formula
Kinematic domain:			
length, linear displacement	**metre**	**m**	
area	square metre		m^2
volume	cubic metre		m^3
	litre	L	dm^3
linear velocity, speed	metre per second		m/s
linear acceleration	metre per second squared		m/s^2
plane angle, angular displacement	radian	rad	
	degree	deg	**π/180** rad
	minute	'	**1/60** deg
	second	"	**1/360** deg
	revolution	r	**2π** rad
angular velocity	radian per second		rad/s
angular acceleration	radian per second squared		rad/s^2
Inertial property domain:			
mass	**kilogram**	**kg**	
	tonne	T	**1000** kg
moment of inertia	kilogram metre squared		$kg{\cdot}m^2$
density	kilogram per cubic metre		kg/m^3
Temporal domain:			
time	**second**	**s**	
	minute	min	**60** s
	hour	h	**3600** s
frequency	hertz	Hz	**1**/s
Kinetic domain:			
force	newton	N	$kg{\cdot}m/s^2$
moment of force, torque	newton metre		N·m
pressure, stress	pascal	Pa	N/m^2
energy, work	joule	J	$kg{\cdot}m^2/s^2$
power	watt	W	J/s
linear momentum/impulse	kilogram metre per second		kg·m/s or N·s
angular momentum/impulse	newton second		$kg{\cdot}m^2/s$ or N·m·s
Electrical domain:			
current	**ampere**	**A**	
voltage	volt	V	W/A
charge	coulomb	C	s·A
power	watt	W	J/s
resistance	ohm	Ω	V/A
capacitance	farad	F	C/V
Temperature domain:			
temperature	**kelvin**	**K**	
degree	Celsius	°C	

SI unit prefixes

Multiplication Factor	Prefix	Symbol
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deca	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

Conversion of units

Converting between units is a four step process.

Example: Convert speed of 22.0 metres per second (m/s) to the equivalent speed in miles per hour (mph).

Step 1 Write out the number and its units using a horizontal format for the denominational part.

$$22.0\ m/s \text{ becomes } 22.0\ \frac{m}{s}$$

Step 2 Multiply the expression by the ratio of the units you are converting from to the units you are converting to.

$$22.0\ \frac{m}{s} \text{ x } \frac{1\ mile}{1609\ m}$$

Step 3 Cancel units where appropriate and reduce the numerical parts.

$$22.0\ \frac{\not{m}}{s} \text{ x } \frac{1\ mile}{1609\ \not{m}} = 0.01367\ \frac{miles}{s}$$

Step 4 Repeat steps 2 and 3 if other units need to be converted.

$$0.01367\ \frac{miles}{\not{s}} \text{ x } \frac{3600\ \not{s}}{1\ h} = 49.2\ mph$$

Common Conversion factors

Angle	1 π rad	=	3.14 rad
	1 π rad	=	180°
	1 rev	=	360°
Force	1 kg	=	9.807 N
Length	1 inch	=	2.54 cm
	1 foot	=	12 inches
	1 mile	=	1.609 km
Mass	1 kg	=	2.205 lbs

Numerical accuracy

(a.k.a. rules for rounding numbers)

- To achieve an accuracy of 0.2%, round numbers to three significant figures unless the first significant figure is a one (1), then use four significant figures. Consider the following:

  (i) 568 is only as accurate as 568±0.5

  Expressed as $\frac{\pm 0.5}{568} \times 100 = \pm 0.088\%$

  Therefore, it is within the 0.2% accuracy level.

  (ii) 103 is only as accurate as 103±0.5

  Expressed as $\frac{\pm 0.5}{103} \times 100 = \pm 0.485\%$

  This is NOT within the 0.2% accuracy level.

(iii) 103.0 is accurate to 103.0±0.05

Expressed as $\frac{\pm 0.05}{103.0} \times 100 = \pm 0.0485\%$

Now, it is within the 0.2% accuracy level.

- If a problem has multiple steps, carry an extra significant figure until the final answer.

- Leading zeroes do NOT count as significant digits.

- Trailing zeroes must be added if there are not 3 (or 4) significant digits.

- From 0-4 round down, from 5-9 round up.

Rounding examples:

25.333 becomes 25.3

1.4526 becomes 1.453

3452.067 becomes 3450

0.004 568 becomes 0.004 57

1.3333 becomes 1.333

7605.25 becomes 7610

Basic concepts: Space

Space:

- a boundless three-dimensional volume
- the concept that a body occupies a volume
- a particle may be located by describing its position with respect to three orthogonal (right-angled) axes and an origin

Measured by the S.I. unit **metres (m)**. Other acceptable units include the kilometre (km), millimetre (mm) and for human dimensions, centimetre (cm).

Instruments for measuring space include:

tape measures

micrometers

anthropometers

GPS

photography

cinematography

sonic devices

Point: A location in space which occupies no volume, and has no defined length, depth or width (**0 dimensions**); also called a **particle**.

Line: An infinite series of points that are "straight" having infinite length and no width or depth (**1 dimension**). A **ray** starts from a point and extends infinitely in one direction. A **line segment** begins at a point and ends at another point.

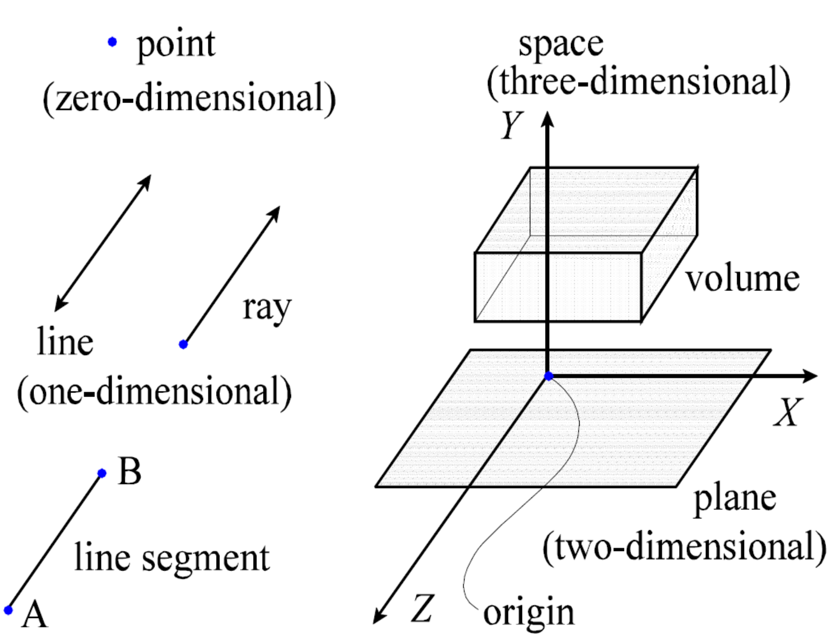
e.g. sagittal (anteroposterior) axis, frontal (mediolateral/transverse) axis, longitudinal (vertical) axis

Plane: A boundless **two-dimensional** "flat" surface which has no width.

e.g., sagittal plane, frontal (coronal) planes, transverse (horizontal) plane.

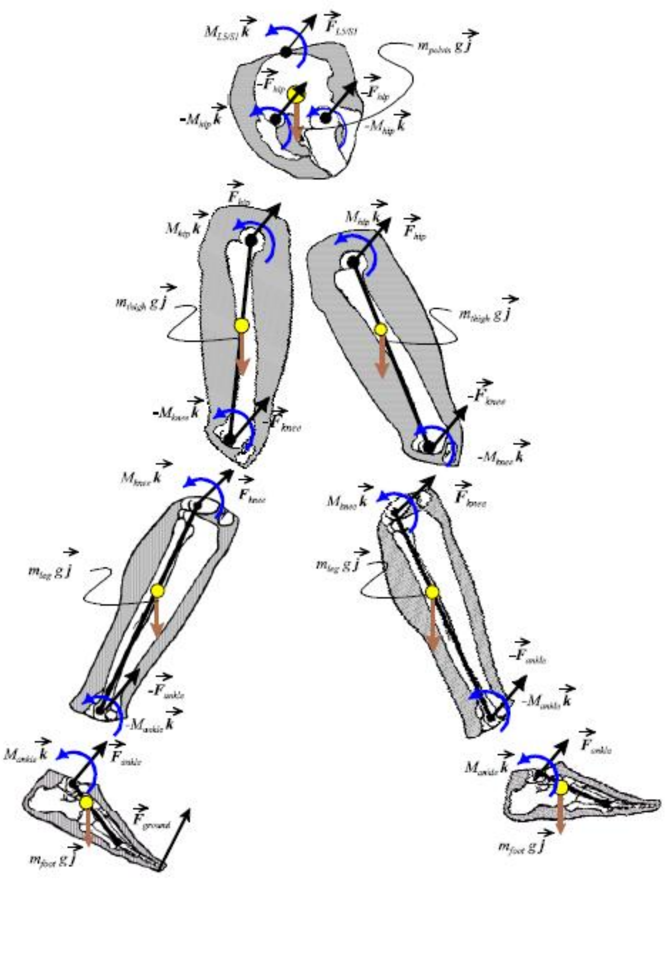
Volume: A bounded **three-dimensional** space.

e.g., cube, sphere, parallelepiped or conic section.



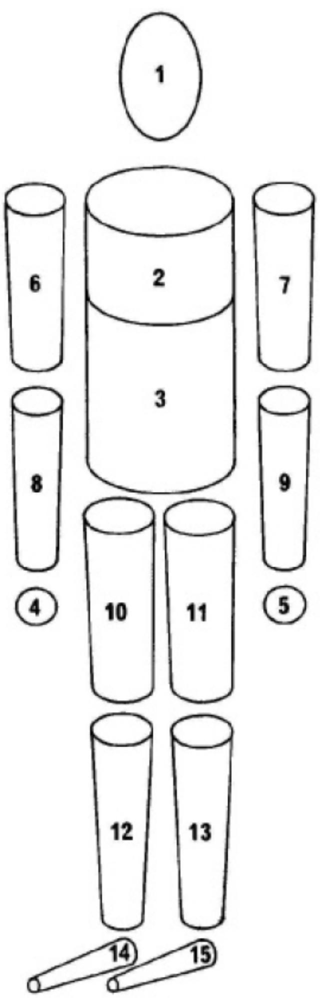
Two-dimensional model of the human body

- **line segments** represent body segments
- yellow **dots** represent centres of gravity
- **rays** represent forces



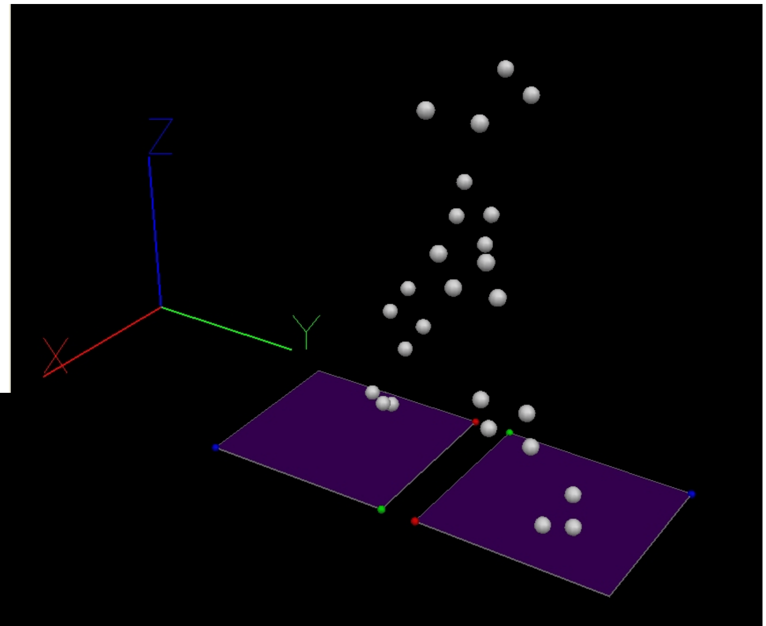
Three-dimensional model of the human body

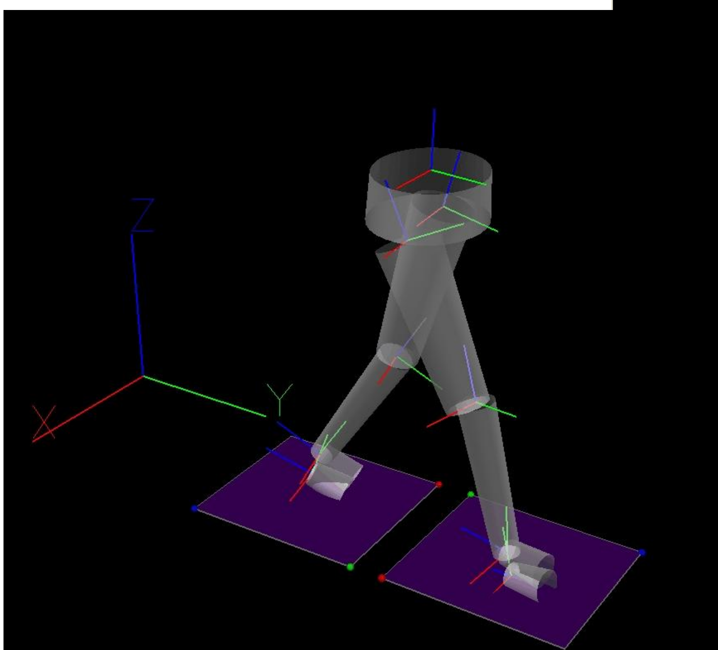
- Hanavan's 15-segment model of the human body is based on various **solids of revolution** (i.e. frusta of cones, ellipsoid, elliptical cylinder, spheroids)



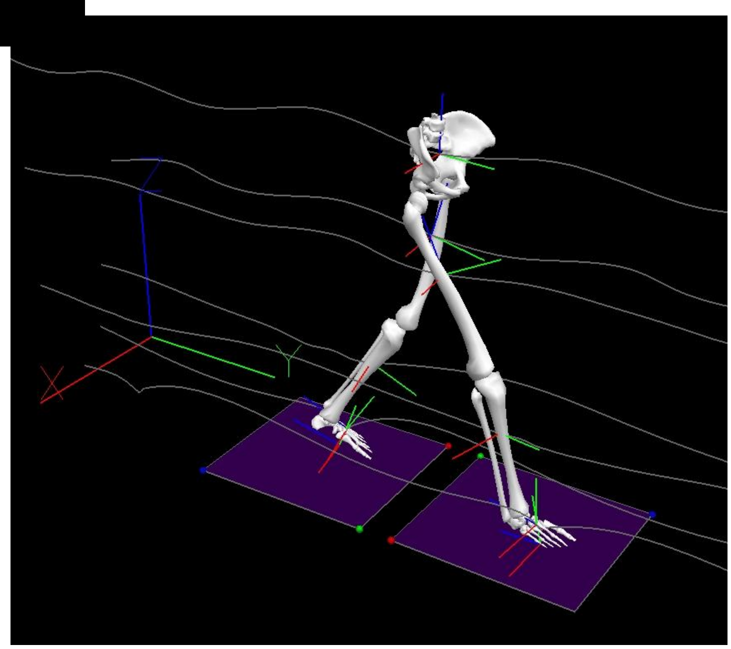
Obtaining a 3D model using VICON

→ reflective markers are attached to the skin (at least 3 per segment)





← solids of revolution are created based on locations of skin markers



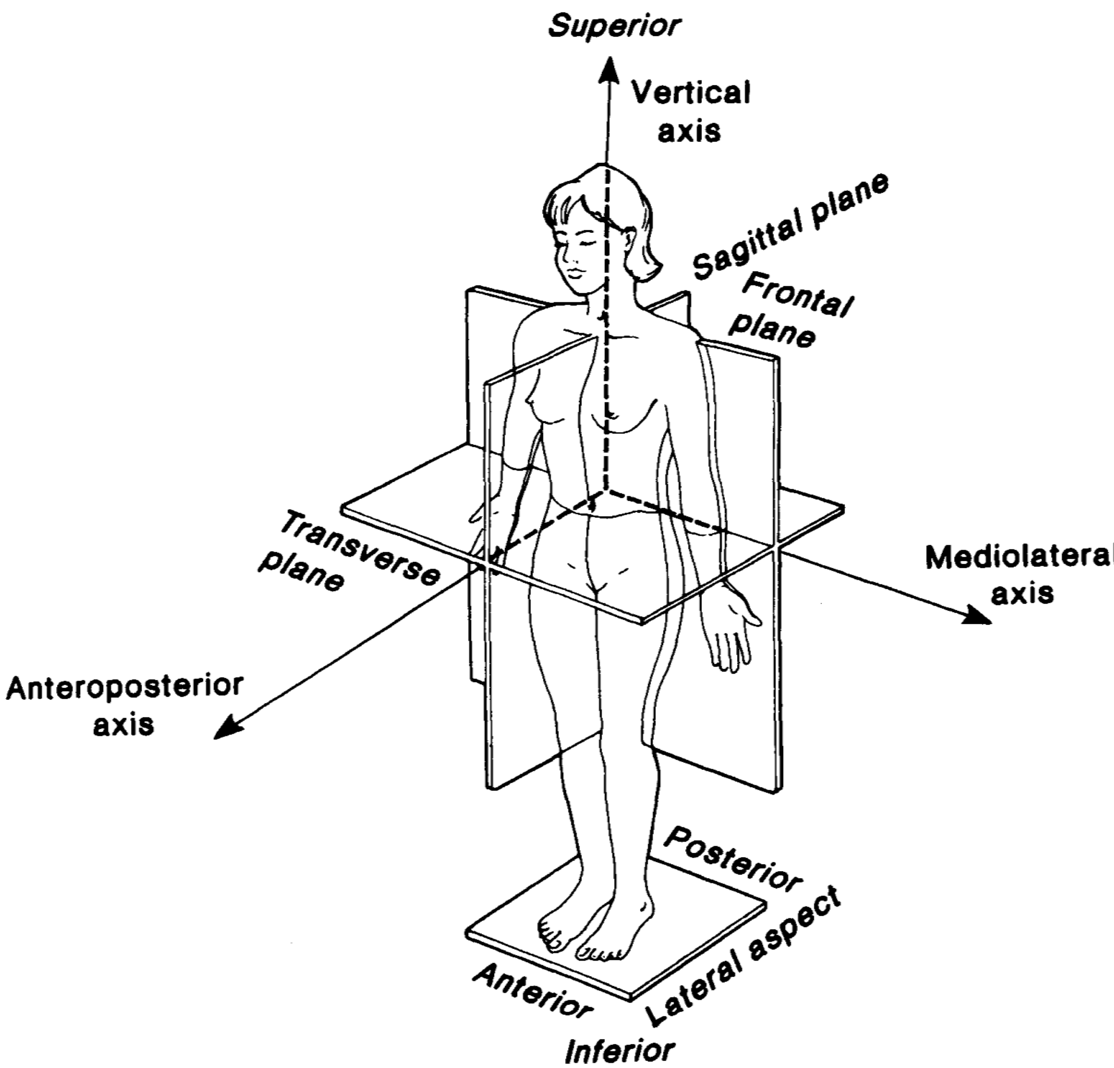
→ bone models are added to reflect human anatomy (not actually used for computations)

Frames of reference

Frames of reference consist of two or three orthogonal (right-angled) axes and a starting point called the **origin**, where the axes intersect.

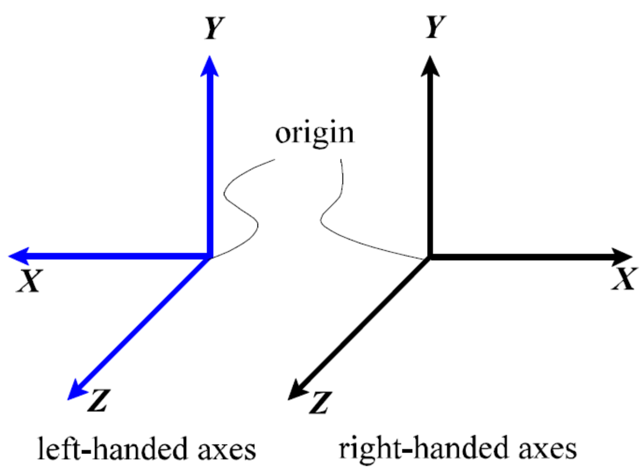
Cardinal or relative frame of reference

The origin of cardinal axes is usually set at the centre of gravity of the body and moves with the body.



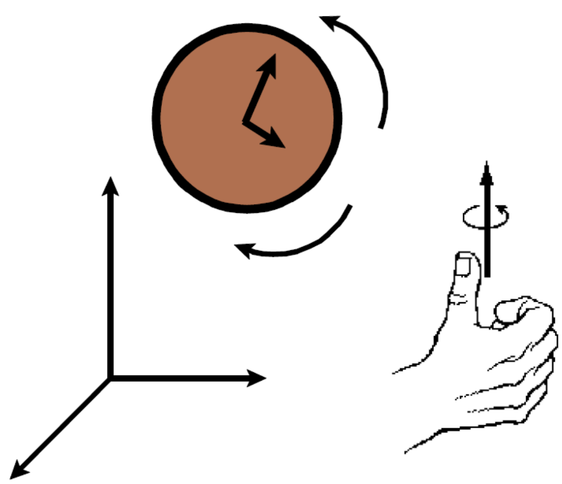
Newtonian or absolute frames of reference

Origin is usually set at some arbitrary point on the ground and in principle does not move. Axes are also fixed to the ground and do not move. Two **orientations** are possible–right-handed and left-handed. The axes labelling below (*X*, *Y*, *Z*) are the standard order as set by the International Society of Biomechanics (ISB).



Right-hand rule

The right-handed axis is accepted as the standard orientation. Thus, **clockwise** rotations are **NEGATIVE**.



Basic concepts: Mass

Mass:

1) Fundamental property of a body which characterizes its **resistance to change of motion**, called its **inertia**. A means by which two bodies may be compared based upon their mechanical properties. For example, two bodies in vacuum will accelerate towards the earth in the same manner and offer the same resistance to changes in their translational motion.

2) Mass is also a body's **gravitational potential**. It is the measure of a body's ability to exert gravitational force. In biomechanics, this property is only significant when the body is exceptionally large, such as the earth. Among small bodies, gravitational forces are too small to affect their motions.

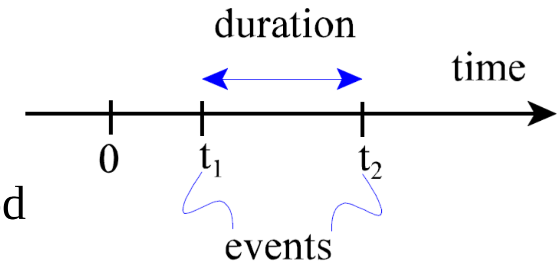
3) Mass is also a measure of **energy**, according to Einstein's $E = m c^2$, which has little application in biomechanics.

Measured by the S.I. unit of **kilograms (kg)**. Standard kilogram masses are maintained at three sites around the globe. Other standard masses are derived from these three.

Instruments for measuring mass include: force transducers and force platforms (see "additional biomechanical tools" for photos) as well as balance scales.

Basic concepts: Time

Time:



The dimension that orders the sequence of events in the universe. A designated instant in time is called an **event**; a period of time is called a **duration** or a **phase**, as in stance phase, airborne phase or push-off phase. The study of the sequence of events or durations between events is called **temporal analysis.**

Measured by the S.I. unit of **seconds (s)**. Other units include the millisecond (ms), minute (min), hour (h) and year (a).

Instruments for measuring time include:

stop watches (chronographs)

stroboscopes

reaction timers

phototimers

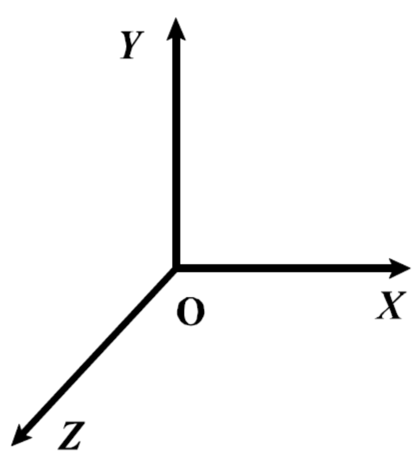
video recordings

Newtonian mechanics

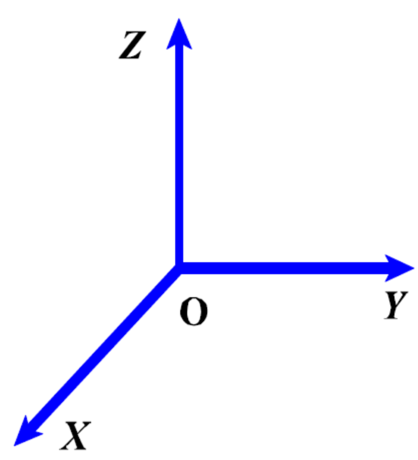
Newtonian mechanics asserts that **space, mass and time are independent** of each other, lines are infinitely straight, mass is unchangeable and time proceeds in uniform steps. Einsteinian or relativistic mechanics has shown these principles to be flawed, however, they may be applied without significant error for most practical purposes (even some impractical ones).

Newtonian mechanics requires an axis whose **origin is fixed in space** and not moving. Such a point does not exist but an origin attached to the ground is sufficiently accurate for most biomechanical purposes.

The following is a typical Newtonian axis system. Positions of bodies are measured with respect to the origin, **O**.



ISB standard labels (used for 2D mechanics)



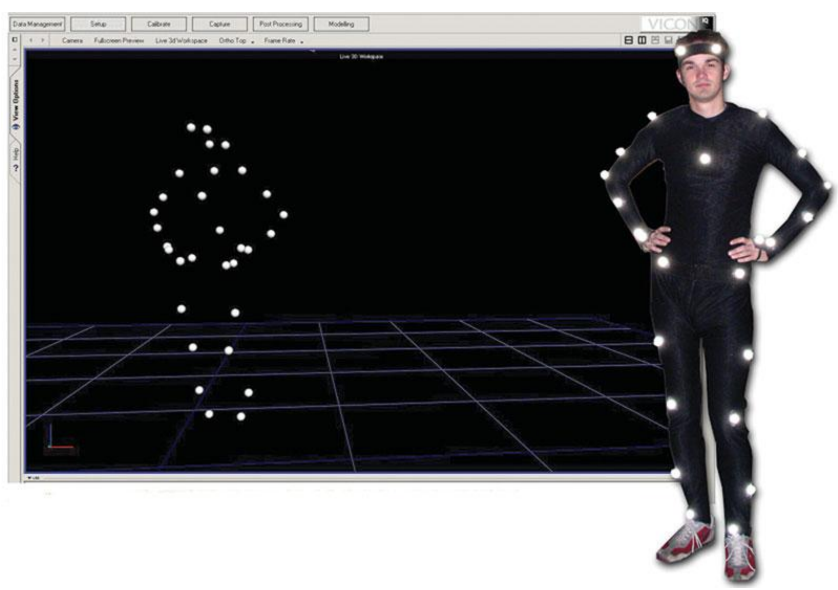
Alternate axes labels (used in 3D mechanics)

Newton’s laws describe the concept of a **force**, which is dependent upon space, mass and time. A force is the action of one body upon another. It is measured in newtons (N) by force platforms or force transducers or indirectly through inverse dynamics. Forces are caused by gravity, electromagnetism or the interaction of particles at the atomic level.

Additional biomechanical tools

Motion capture systems

- devices for recording movement which is then translated onto a digital model
- used in a variety of fields (e.g. research, film-making, etc.)
- with the use of reflective surface markers and various camera technologies, the motion of humans, animals and inanimate objects can tracked and evaluated
- in biomechanics, it is especially useful for assessing joint angles and gait
- Example: VICON



VICON

- uses infrared cameras
- allows for 3D analysis of motion

Electromyography (EMG) systems

- devices for measuring the electrical signals generated by muscles
- used to determine which muscles are active during the various phases of a movement
- can be wired (cabled) or wireless
- can be surface EMG (electrodes on surface of skin) or indwelling (single needle or two wires implanted in the muscle)
- surface EMG requires a clean, dry, hair-free surface for data collection
- use various types of surface electrodes (disposable adhesive surface electrodes, parallel-bar electrodes)
- Examples: Bortec, Delsys

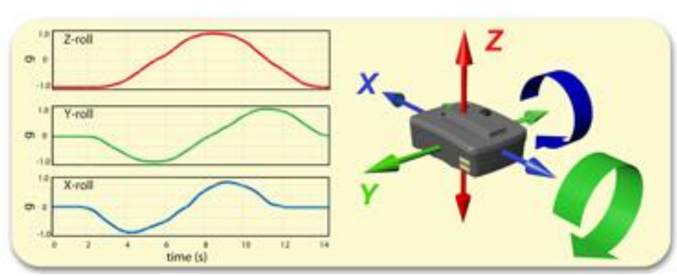
measures electrical output of muscles, how many muscle fibers are engaged so spikes in electrical output will be higher

Bortec

- cabled system
- uses disposable adhesive surface electrodes (DASEs)
- available in 8- or 16-channel systems

Delsys

- wireless system
- uses reusable parallel-bar electrodes
- 16-channel system
- combines EMG ability with triaxial (x, y, z) accelerometry (accelerometers embedded in each sensor used to resolve orientation and capture dynamic movements and impacts)



Force platforms

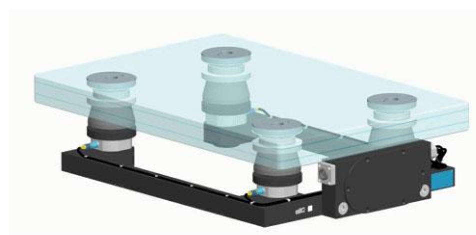
- devices usually embedded in a laboratory walkway for measuring ground reaction forces
- typically measure at least three components of ground reaction force (F_x, F_y, F_z) and can include centre of pressure (a_x, a_y) and vertical (free) moment of force (M_z)
- Examples: Kistler (strain gauge), AMTI (piezoelectric)

Kistler force platforms

Standard

Portable

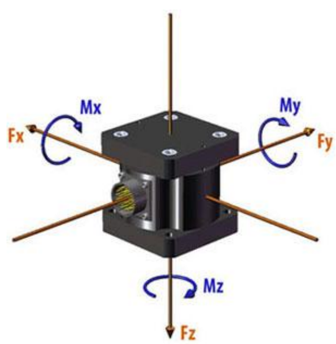
Clear top



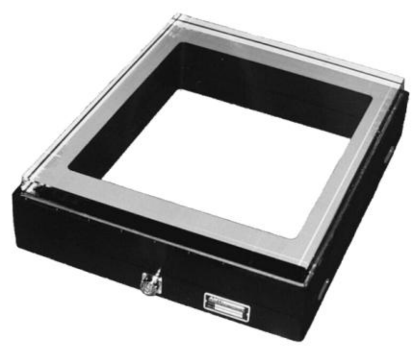
AMTI force platforms

Standard

Small



Glass top



Special applications of force platforms

Force transducers

- devices for changing force into analog or digital signals suitable for recording or monitoring
- typically require power supply and output device
- types:
  - spring driven (tensiometer, bathroom scale)
  - strain gauge (most common)
  - linear variable differential transformer (LVDT)
  - Hall-effect (in some AMTI force platforms)
  - piezoelectric (usually in force platforms)
- Examples: tensiometer, strain links, strain gauge transducers, strain gauge levers, force platforms

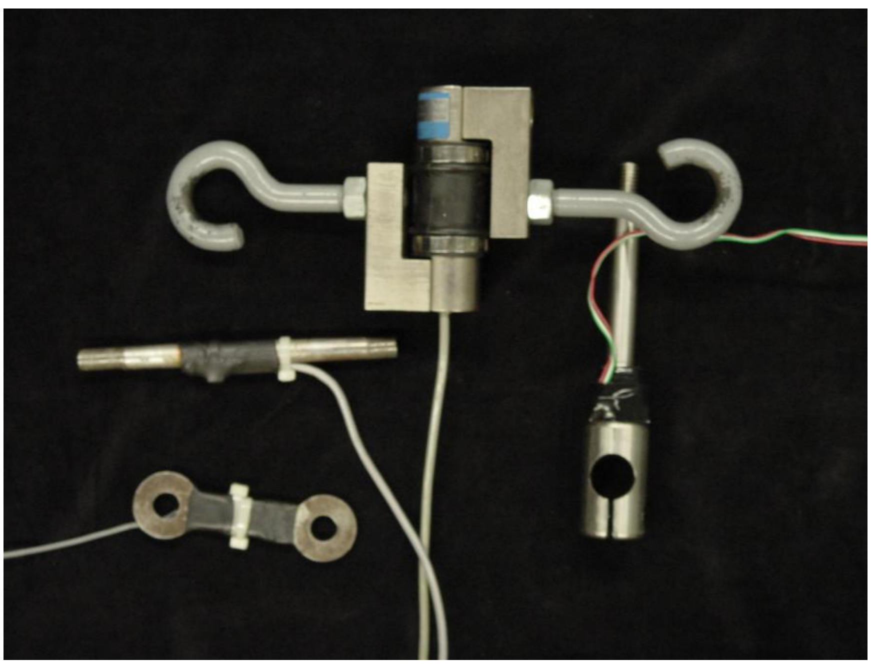
Tensiometer

- essentially a spring scale
- measures tension (magnitude of a force)

Strain link

- uses strain gauges to measure tiny length changes in a material that are proportional to the applied force

Strain gauge transducers



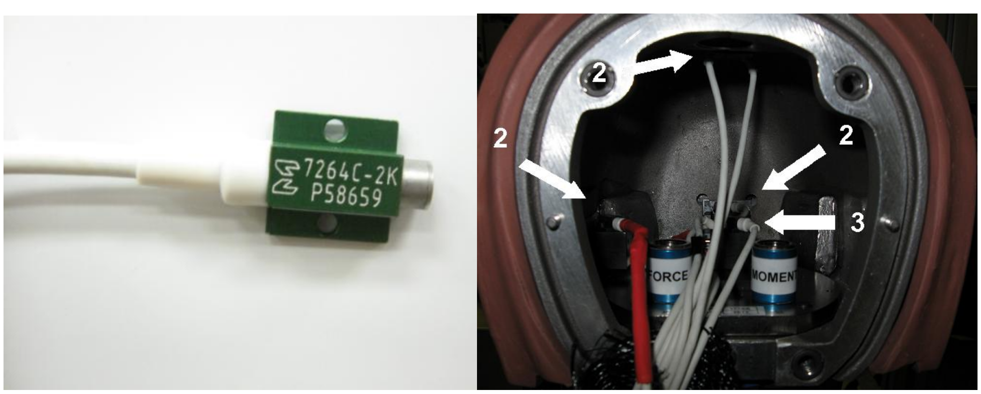
- use one during underwater weighing to compute body density and lean body mass

Strain gauge lever

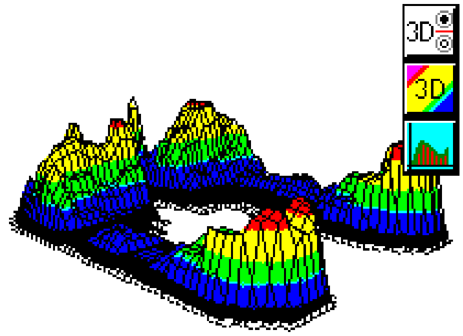
- uses strain gauges to measure bending moment, which can then be used to compute applied force (Cybex, Kincom, Biodex)

Accelerometers

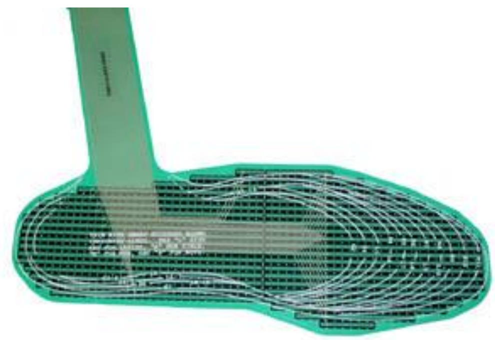
- devices for measuring accelerations
- can be uni-axial or triaxial (x, y, z)
- especially useful for collecting acceleration data at joints and of the head upon impact



Pressure mapping systems



- **Pedar** measures pressures from a matrix of cells to display a pressure map



- **Tekscan F-Scan** measures normal forces to display a force tensor of the pressure distribution

Random fact #1: If you’ve played with a Wii remote, you’ve used accelerometers and infrared technology!

Random fact #2: If you’ve played with a Wii fit board, you’ve used a pressure sensor system!