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TEACH

MODULE BIOMECHANICS FOUNDATIONS

Didactic Unit B: FORCES AND PRESSURES

Politechnika Śląska
IBV INSTITUTO DE BIOMECÁNICA DE VALENCIA
VNIVERSITAT DE VALÈNCIA
AMSE THE ASSOCIATION OF MEDICAL SCHOOLS IN EUROPE

Index

1. Objectives

- To know the causes that produce movements: kinetics.

- To describe important concepts to understand kinetics: forces, pressure, torque, power, work and energy.

- To define other concepts of interest in biomechanical field: centre of gravity and centre of pressure.

2. Causes that produce movement: kinetics

The part of mechanics that study the causes of bodies motion (forces) is called **kinetics*.** Kinetics describes the **forces** that act over a body to produce movement.

Examples of kinetic variables related to movement are any type of force (friction, ground reaction, gravitational, etc.), work, momentum, torque, energy, power and resistance.

In summary:

Kinetics answer the questions about why a body moves.

This concept has been introduced in previous notes but It is worth to remember it because is the starting point to this module.

If there are still doubts about the differences between kinematics and kinetics, please review the content of this video. You can access to some example videos through the following links: https://ocw.mit.edu/courses/physics/8-01sc-classical-mechanics-fall-2016/week-1-kinematics/week-1-introduction/

The material that the hyperlinks lead to, is public and available for viewing online. It has been selected for its adequacy with the subject covered in this teaching unit (movements), after performing a search using the terms "Classical Mechanics", on the web indicated above. Like these, you can find and revise other interesting public didactic videos by using the same searching terms.

**Although they are not exactly the same, Kinetics and Dynamics are often used interchangeably.*

3. Concepts of interest related to kinetics: forces, pressure, torque, power, work and energy.

3.1. Forces [1]

Force is the physical magnitude used to quantify the causes of the changes in the movement of bodies.

> Example: A body is resting. It will continue resting unless something or someone makes it to change its velocity (for example, exerting a force). So, its velocity will change from 0 to a value and an acceleration will appear (because there has been a change in the velocity) being the concept of acceleration and force always associated (as will be explained).

Therefore, force can be also understood as the physical magnitude that produces a change in the state of movement of a body and/or changes its shape.

The relationship between a body and the forces acting upon it and its motion in response to these forces is described by Newton´s laws in 1686:

Newton's First Law: It states that an object will remain at rest or in uniform motion in a straight line unless acted upon by an external force. It may be seen as a statement about inertia, that objects will remain in their state of motion unless a force acts to change the motion [2].

Newton's Second Law: It states that the total forces over a body are proportional to the acceleration and its mass (it is assumed to be constant). They are related by the following equation:

$$\vec{F} = m\vec{a} = mass * acceleration$$

The international system (SI) units for force are $Newtons = \left[kg\frac{m}{s^2}\right]$.

Remember that the presence of acceleration involves change in the velocity of the body; it means that there are external forces producing changes in the velocity of that body.

Newton's Third Law: All forces in the universe occur in equal but oppositely directed pairs. There are no isolated forces; for every external force that acts on an object there is a force of equal magnitude but opposite direction which acts back on the object which exerted that external force [2].

It means that when one body (A) exerts a force on a second body (B), the second body (A) simultaneously exerts a force equal in magnitude and opposite in direction on the first body (A) (Figure 1):

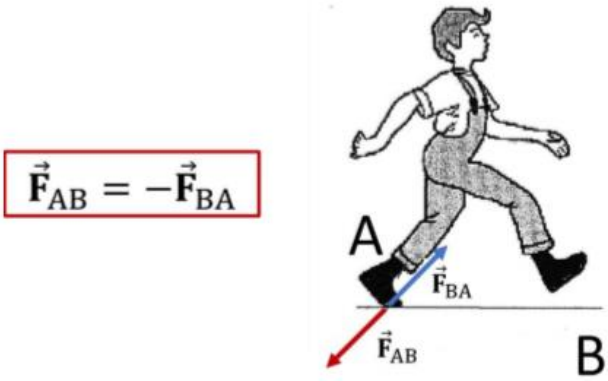

Figure 1: Third Newton´s law. Extracted from: https://commons.wikimedia.org/wiki/File:Walking_reaction_forces.png. Modified by IBV

3.3.1 Forces acting over a human body [1]

There are different types of forces: electromagnetic, gravitational, etc. but, there are out of the scope of these contents. Only those forces (that are mechanical forces) related to the human body are described:

Weight

It is the force of gravity on the body. It is calculated:

$$\vec{W} = mass * \vec{g}$$

The weight of the body segments is a very important force because to maintain static postures or to perform slow movements, muscles and ligaments should counteract this weight.

External loads

Daily activities imply to perform any type of load, pushing, pulling or holding an object. The effect of these external loads over joints and muscles can be very high.

Normal and friction forces

They appear when a body is supported by any type of surface. In the case that the surface is the ground, it will exert a force equal but different sign over our feet. This force is called "ground reaction force" (the surface can also be a seat, for example). These reaction forces are composed by two different forces: Normal force ($\vec{N}$), perpendicular to the surface of support and friction force ($\vec{R}$), parallel to it (Figure 2):

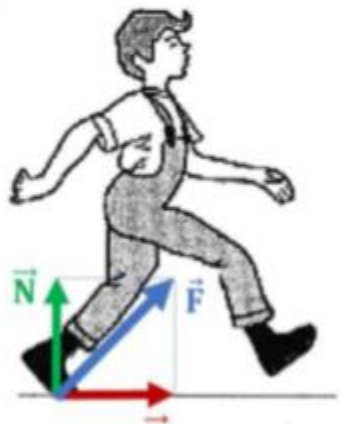

Figure 2: Components of ground reaction force [1].

Internal forces

They are produced by tendons, muscles, ligaments and joint internal components.

3.2 Pressure

When forces are applied to a material, they create loads/stresses over the material. These loads/stresses try to change the shape of the material exerting compression, tension, shear, torsion or bending stress. In biomechanical field, pressure can be understood as compression loads exerted on a body. Therefore, the concept of pressure in biomechanics is similar to stress (symbolized by σ) as long as it refers to compression stress. Pressure and stress (compression) are thus defined as the force per unit area [3]:

$$Pressure = \frac{Force}{Area}$$

The international system (SI) units for pressure/stress are $Pascals = \left[\frac{Newtons}{meters^2}\right]$.

3.3 Energy

Energy is a measurement of the ability of someone or something to do work. It is not a material substance. Energy can be stored and measured in many forms. Although people often talk about energy consumption, energy is never really destroyed. It is just transferred from one form to another, doing work in the process [4].

The transformation of energy is a powerful concept that are involved in a vast number of processes [5]. Energy related to motion is called kinetic energy.

Kinetic Energy (E_K): Energy that an object possesses because of its motion. The kinetic energy of a point mass m is given by:

$$Kinetic\ Energy: \frac{1}{2}mv^2$$

$m = mass$

$v = velocity$

$m = metres$

The international system (SI) units for Kinetic energy are $Joules = Newton * m.$

Kinetic energy is an expression of the fact that a moving object can do work on anything it hits; it quantifies the amount of work the object could do as a result of its motion.

Potential energy (E_p) is energy which results from position or configuration [6].

$$Potential\ Energy = mgh$$

$m = mass$

$g = \ gravitational\ acceleration\ (9{,}8\ m/s^2)$

$h = height$

The international system (SI) units for potential energy are $Joules = Newton * m$.

Example: An object may have the capacity for doing work as a result of its position in a gravitational field (gravitational potential energy).

Only conservative forces like gravity and the spring force have potential energy associated with them.

According to the conservation of mechanical energy principle, the total mechanical energy of an object is the sum of its kinetic energy and potential energy:

$$E_M = E_K + E_p$$

Conservation of mechanical energy only applies when all forces are conservative [7]. This is important to be considered when it is required to calculate the energy of an object falling from certain height, for example.

3.4 Work

Work: A force is doing work if, when acting, there is a movement of the point of application in the direction of the force (same direction or the force has a component in the direction of the motion). The work done by a constant force acting on the body is the product of the component of the force, the distance/displacement and the cosine of the angle between them [8]:

$$Work = F\Delta d cos\emptyset$$

$F = Force$

$\Delta d = displacement$

$\cos\emptyset =$ cosine of the angle formed by the $force$ and the direc$tion\ of\ the\ displacement$.

The international system (SI) units for work are $Joules = Newton * m$.

Work is a scalar quantity.

Example (Figure 3): A person use a rope to pull on this box. The point is that the horizontal component is the only component of the applied force that is doing work on the box since the box is being displaced horizontally [9].

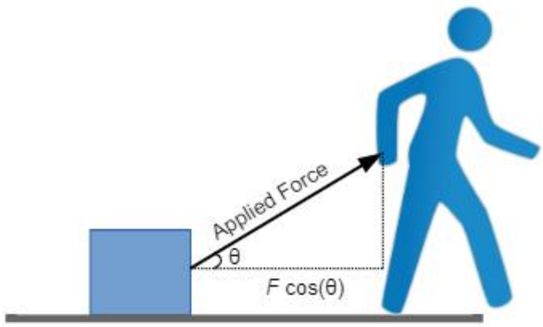

Figure 3: Example of work performed by a force. Extracted from [9]

As part of your theoretical training it is recommend watching a video about the relationship between energy and work. You can access to some example videos through the following links: https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/v/work-and-the-work-energy-principle?modal=1

https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/v/work-as-the-transfer-of-energy?modal=1

The material that the hyperlinks lead to, is public and available for viewing online. It has been selected for its adequacy with the subject covered in this teaching unit (Forces and Pressure), after performing a search using the terms "Classical Mechanics" or "Energy and Work", on the web indicated above. Like these, you can find and revise other interesting public didactic videos by using the same searching terms.

3.5 Power

Power is defined as the rate of doing work or the rate of using energy [10]:

$$Power = \frac{Work}{time} = \frac{Force * distance *}{time} = Force * velocity$$

The international system (SI) units for power are $Watts$

Power is a scalar quantity.

*In this case, force and displacement/distance are considered to be parallel, so cosine is not needed in the formula because $cosine(0) = 1$.

As part of your theoretical training it is recommend watching a video about power. You can access to some example videos through the following links: https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/v/power?modal=1

The material that the hyperlinks lead to, is public and available for viewing online. It has been selected for its adequacy with the subject covered in this teaching unit (Forces and Pressure), after performing a search using the terms "Classical Mechanics" or "Power", on the web indicated above. Like these, you can find and revise other interesting public didactic videos by using the same searching terms.

3.6 Torque

Torque is defined by the measurement of the twisting action caused by a force that can cause an object to rotate about an axis [11]:

$$Torque(\tau) = F * r * sin\theta$$

$F = Force$

$r = \ distance\ from\ the\ axis\ of\ rotation\ to\ the\ location\ where\ the\ force\ is\ exerted$

$sin\theta = sine\ of\ the\ angle\ formed\ by\ the\ force\ and\ the\ radius/distance.$

The international system (SI) units for torque are $Newton * metres$.

Torque is a vector quantity.

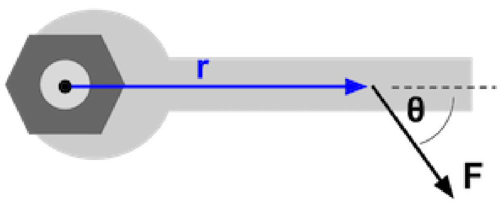

Figure 4: Example of torque application. Extracted from [11]

4. Centre of gravity and centre of pressures [12]

In many studies that quantify human posture and motion, these two variables are very important: Centre of gravity (CG) of the body and the centre of pressure (CP) of the ground reaction forces.

Centre of gravity (CG):

CG is the point at which the total body mass can be assumed to be concentrated without altering the body's translational inertia properties. The position of the CG characterizes whole body position and is subject to body posture control. Quantifying the motion of the CG allows comparative assessment of motion performance.

Centre of pressures (CP):

CP is the projection on the ground plane of the centroid of the vertical force distribution. The CP position can be obtained directly from force plate data during posture or gait trials. Determining whole body centre of gravity position requires knowledge of the position and mass of the body segments.

In the most elementary approach, the vertical projection of the CG into the floor is assumed to coincide with the CP. Practically, this assumption is true only when the body is static (i.e., no movement of any segments), and since the body sways even during stable standing, the assumption is generally incorrect.

5. Key ideas

Please, check the following schemes to review your knowledge about kinetics.

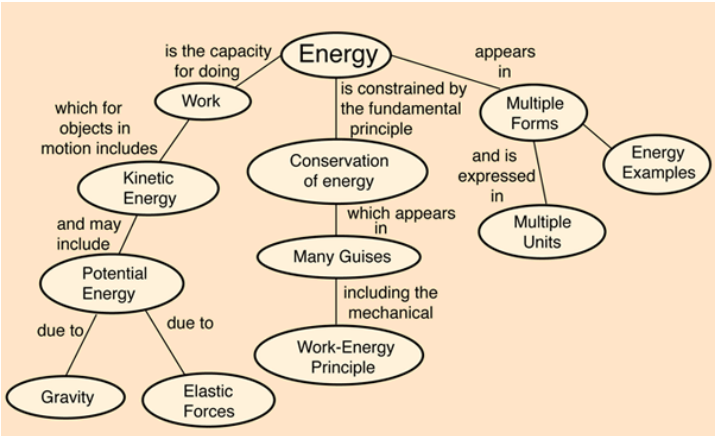

Figure 5: Scheme about Energy [13]

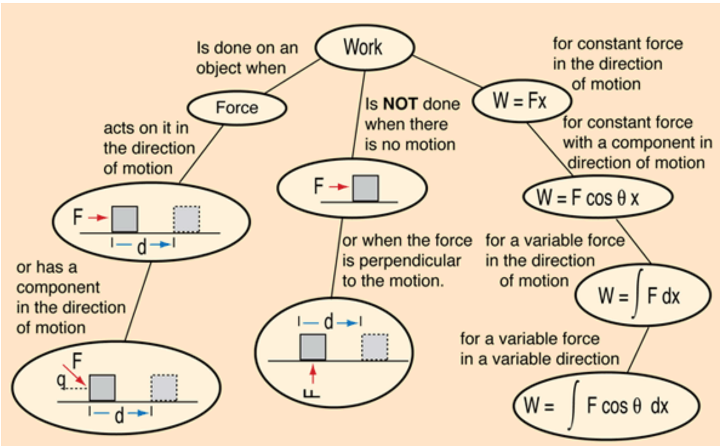

Figure 6: Scheme about work [14]

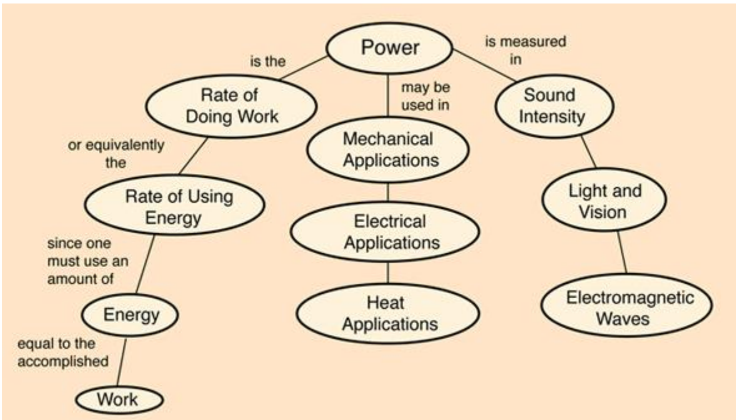

Figure 7: Scheme about power [15]

6. References

[1] Máster de Biomecánica clínica. Título propio de la Universidad Politécnica de Valencia. Impartido y desarrollado por el Instituto de Biomecánica de Valencia (IBV).

[2] http://hyperphysics.phy-astr.gsu.edu/hbase/Newt.html#ntcon

[3] D.Knudson, fundamentals of Biomechanics. Cambrigde, 2007

[4] https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/a/what-is-work?modal=14

[5] https://ocw.mit.edu/courses/physics/8-01sc-classical-mechanics-fall-2016/readings/MIT8_01F16_chapter13.1.pdf

[6] http://hyperphysics.phy-astr.gsu.edu/hbase/ke.html#ke

[7] https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/a/what-is-conservation-of-energy

[8] https://ocw.mit.edu/courses/physics/8-01sc-classical-mechanics-fall-2016/readings/MIT8_01F16_chapter13.4_13.5.pdf

[9] https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/a/what-is-work?modal=1

[10] http://hyperphysics.phy-astr.gsu.edu/hbase/pow.html#pw

[11] https://www.khanacademy.org/science/ap-physics-1/ap-torque-angular-momentum/torque-and-equilibrium-ap/a/torque-and-equilibrium?modal=1

[12] B.J. Benda, P. O. Riley D.E. Krebs. Biomechanical relationship between center of gravity and center of pressure during standing. April 1994. IEEE Transactions on Rehabilitation Engineering 2(1):3 – 10. DOI: 10.1109/86.296348. Source IEEE Xplore.

[13] http://hyperphysics.phy-astr.gsu.edu/hbase/enecon.html

[14] http://hyperphysics.phy-astr.gsu.edu/hbase/wcon.html

[15] http://hyperphysics.phy-astr.gsu.edu/hbase/pow.html#pwc