HAB718 Spor Biyomekaniğinde Hareket Analizi

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#7

- Energy, Work, and Power

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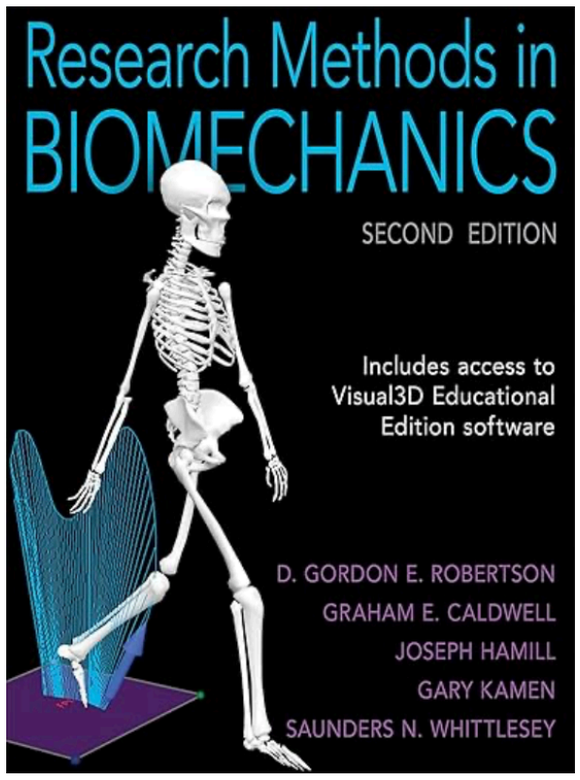

Energy, Work, and Power

Chapter 6

Energy, Work, and Power

D. Gordon E. Robertson

Energy is a well-known physical quantity that, despite its notoriety, is not well understood. For instance, physicists have yet to identify any atomic or subatomic particle that corresponds to a basic unit, or quantum, of energy. One of the difficulties with understanding energy is that it takes many forms. Matter itself is one form of energy, which Einstein was able to quantify with his most famous equation, $E = mc^2$, but this energy is only manifest when the matter itself is torn apart. Other forms of energy include nuclear, electrical, thermal (heat), solar, light, chemical, and, the one of greatest interest to biomechanists, mechanical.

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Energy other words, the ability to affect the state of matter. In a sense, energy is the motion of particles or the potential to create motion.

Thermodynamics is the field of study concerned with energy and its quantification, transmission and transduction (change) from one form to another.

According to the first law of thermodynamics, also called the law of conservation of energy, the quantity of energy in the universe is a constant.

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The second law of thermodynamics, first elucidated by Rudolf Clausius in 1865, states that when energy is transformed from one form to another—for example, when electricity produces light, water power produces electricity, or biochemical energy produces a muscle contraction—some of the energy is wasted and can no longer be transformed into another usable form of energy. Clausius named this unusable energy **entropy**, to sound like energy. **Entropy** can be considered energy that can no longer perform useful work.

Work can be defined as the changing of energy to another useful form of energy, also called *transduction*.

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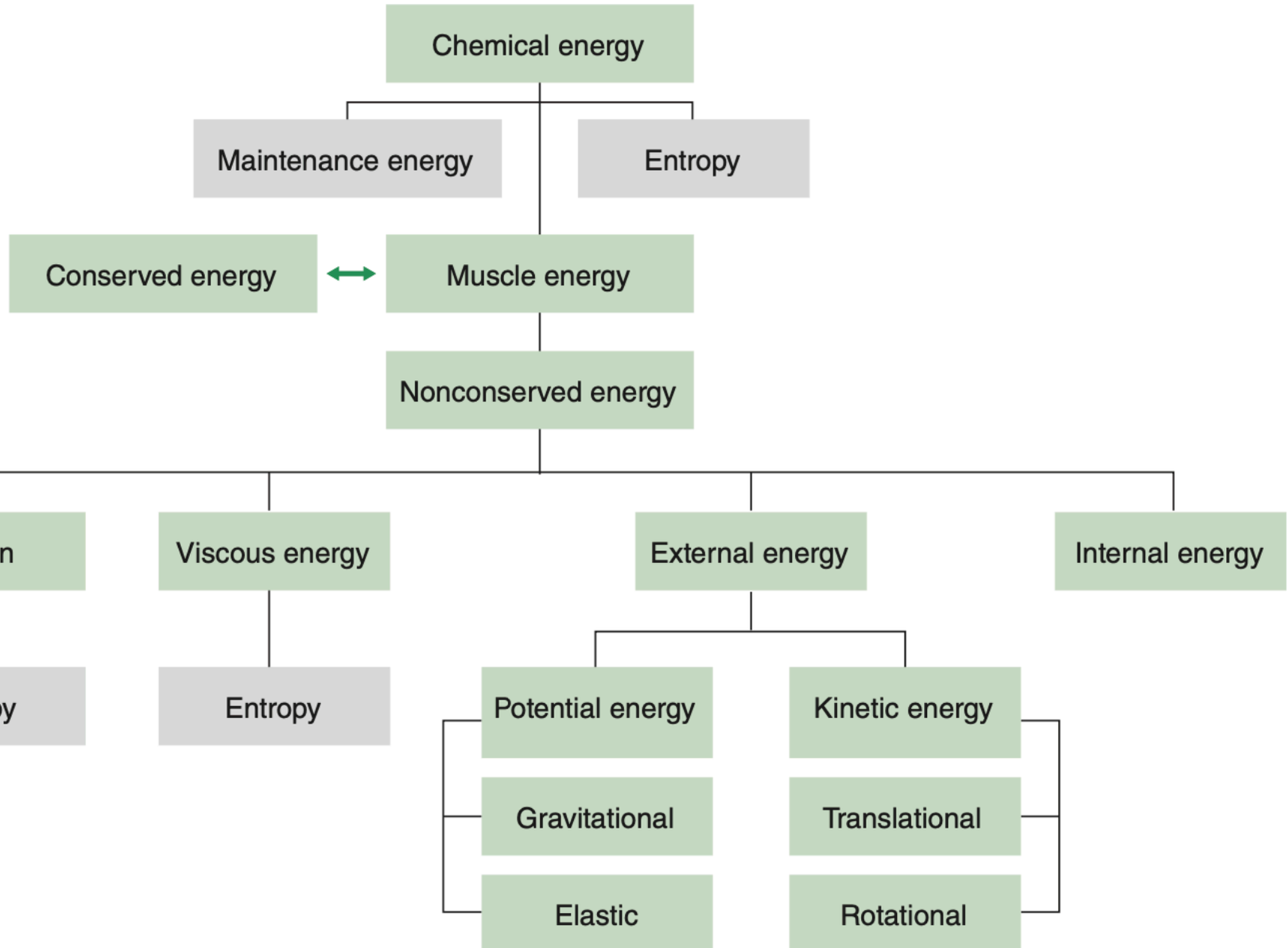

▲ **Figure 6.1** Energy flow through the human body to the environment. Maintenance energy includes energy to all tissues, excluding the skeletal muscles. Entropy includes all energy that can no longer be recovered to perform useful work as a result of heating the environment or creating turbulence in fluids in the environment (air or water). Conservative energy is the energy that recycles by changing form within segments or exchanges between and among segments or other bodies.

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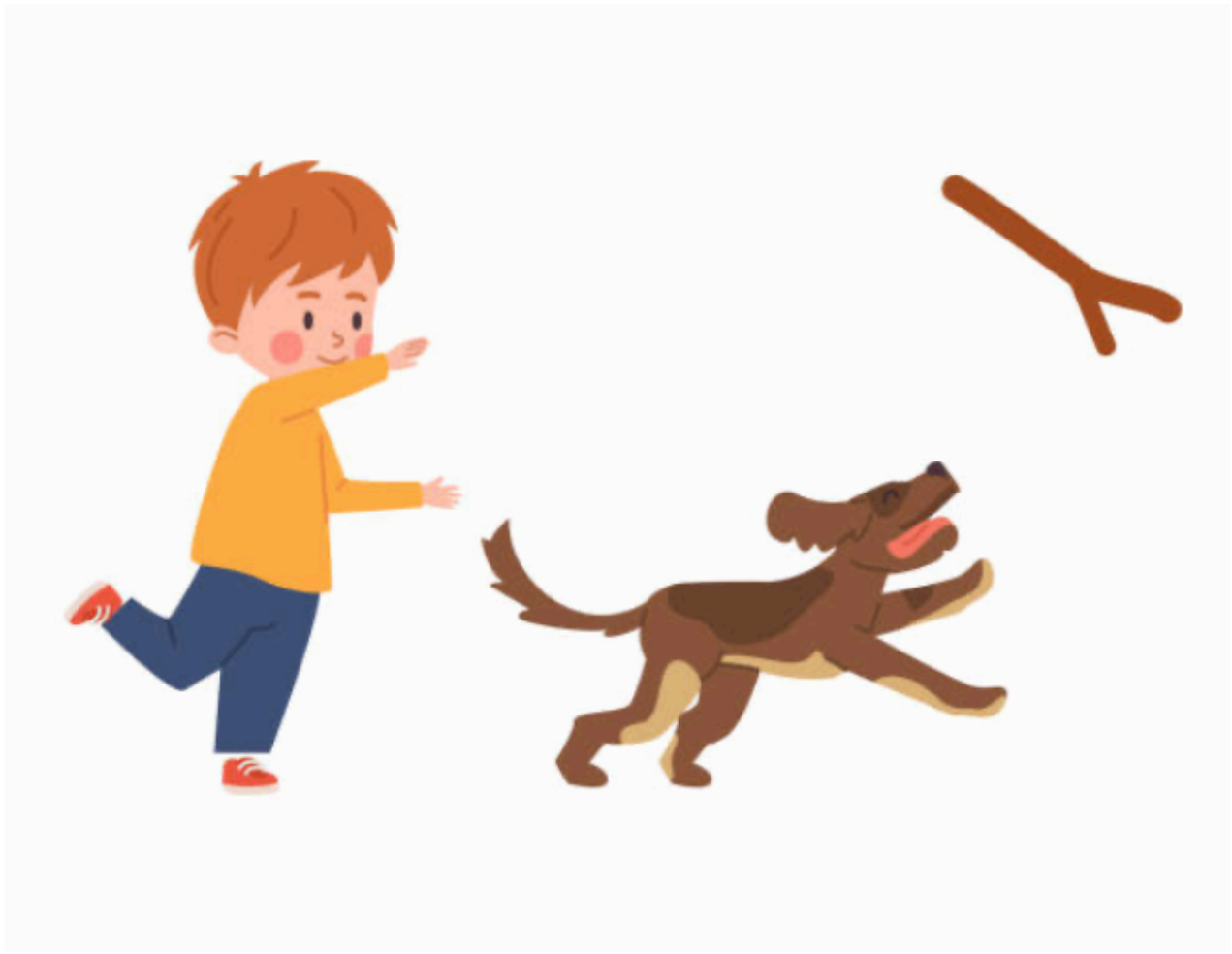
Mechanical work is the work done when the total mechanical energy of a body changes. This principle, called the work-energy relationship, is based on Newton's second law.



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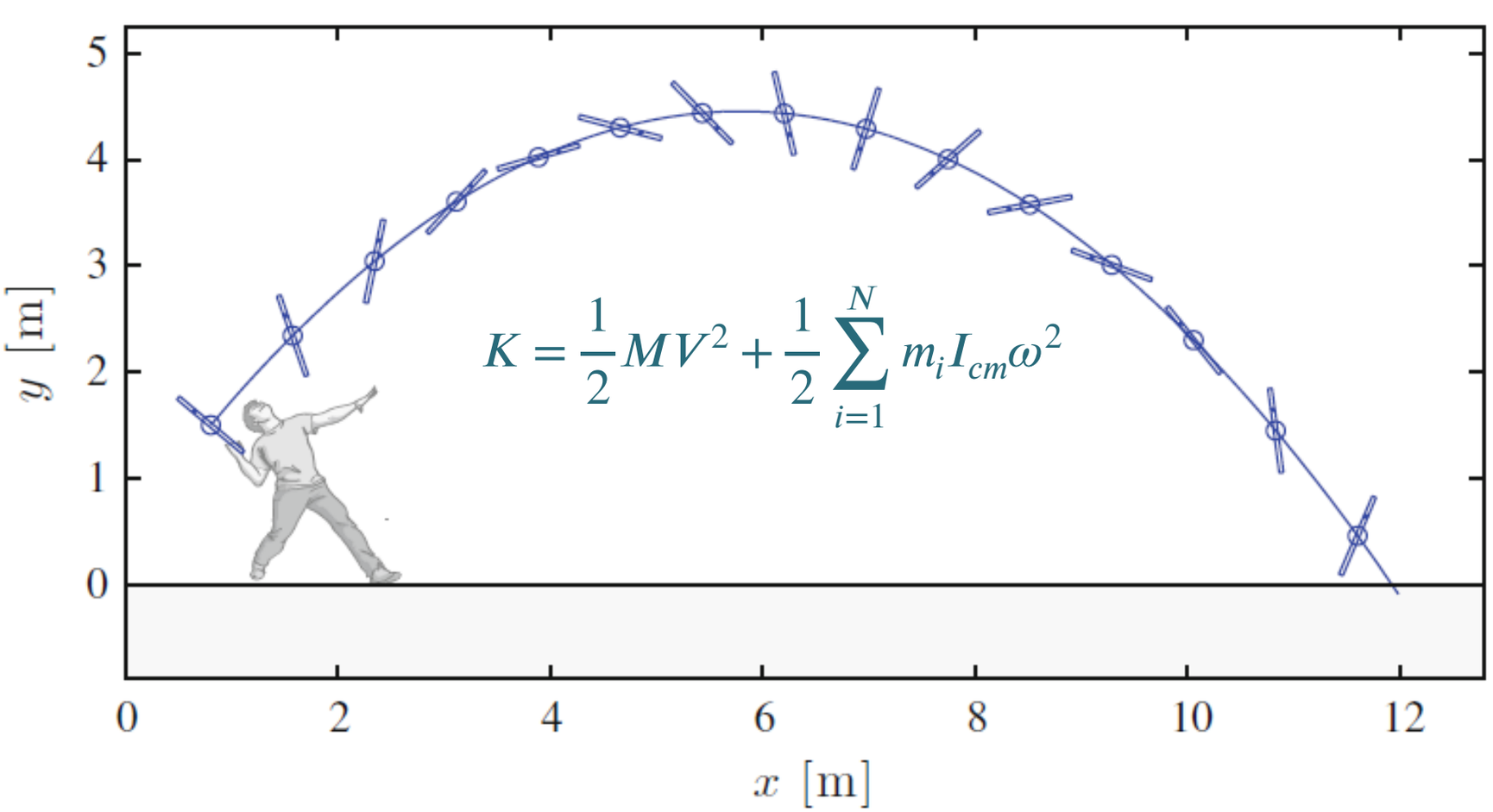
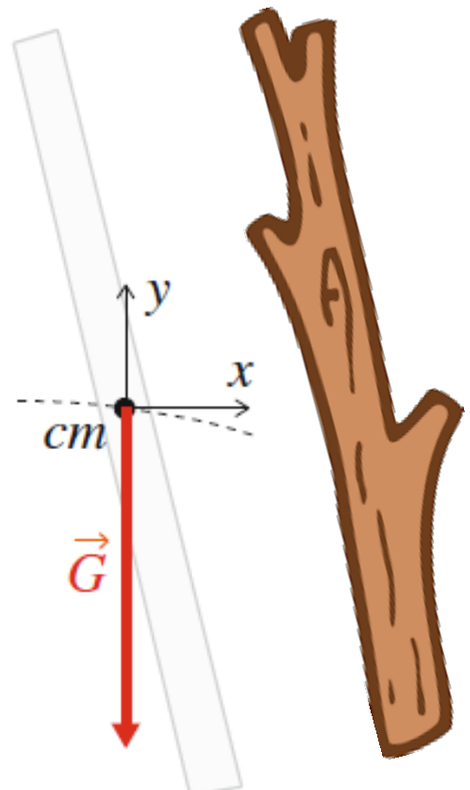
Conservation of mechanical energy occurs when all the forces and moments of force acting on a body or a single segment are conservative, that is, the resultant force acting on the body is a conservative force.





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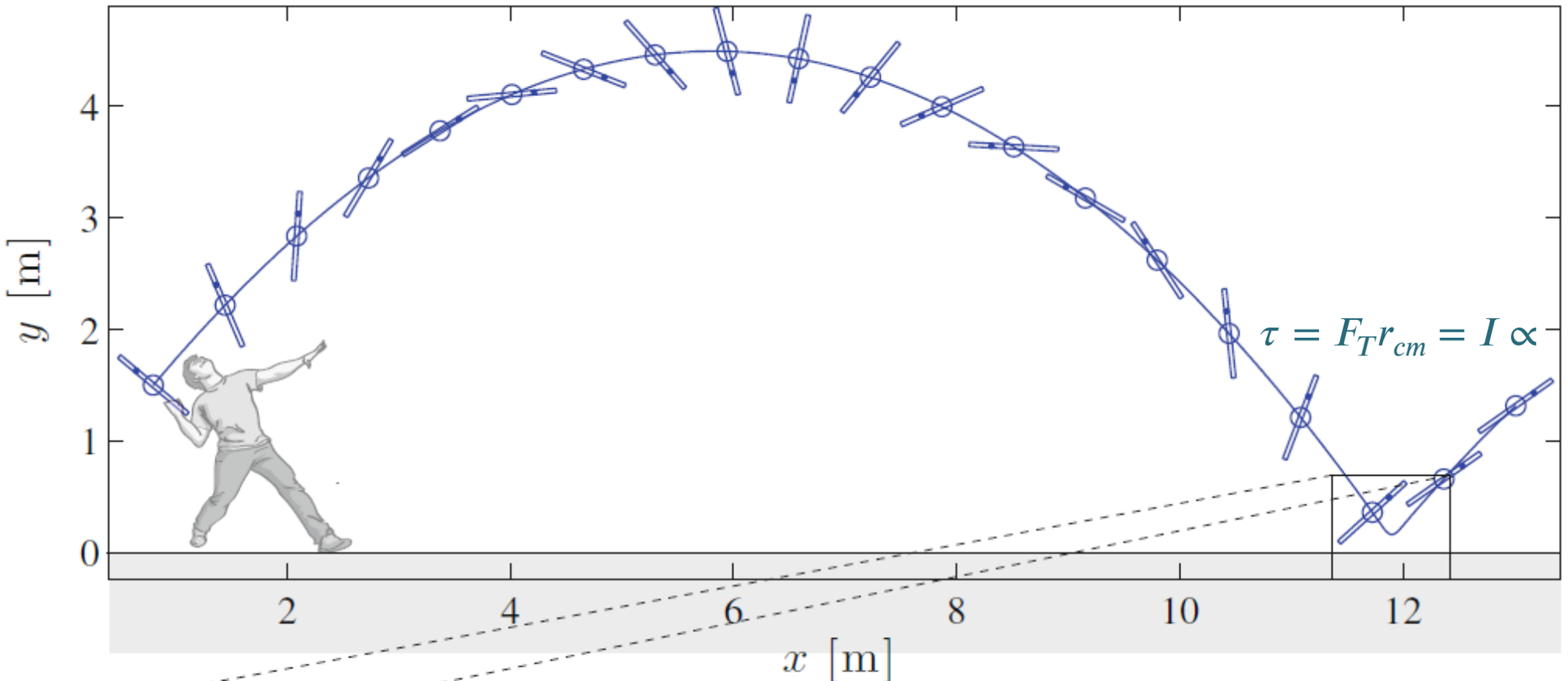
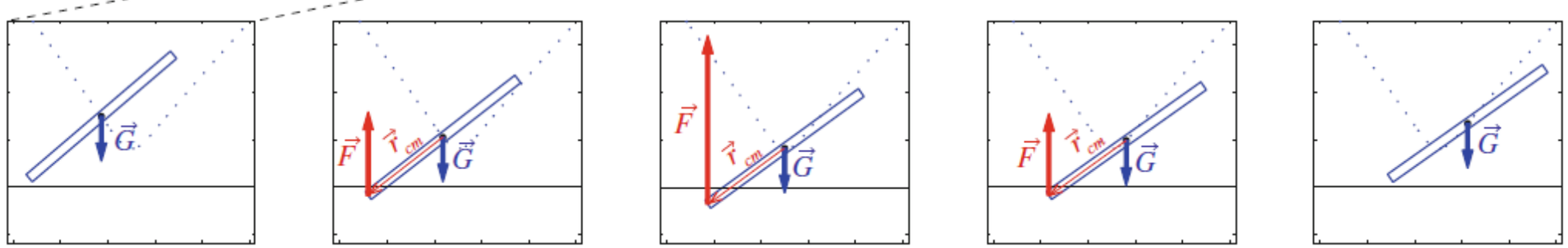
Conservative forces include gravitational forces, the force of an ideal **spring**, elastic collisions, the tensile force of an ideal pendulum, and the normal force of a frictionless surface.





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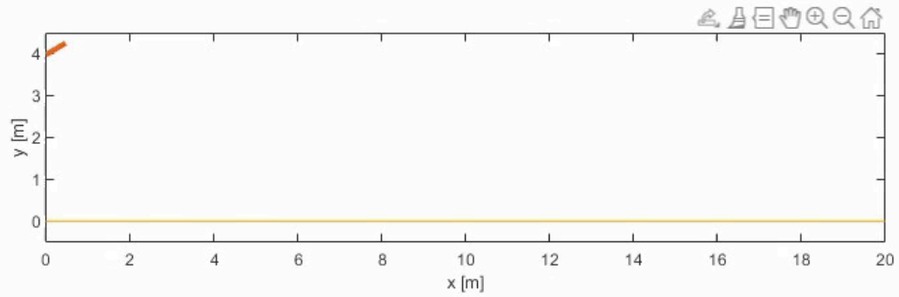

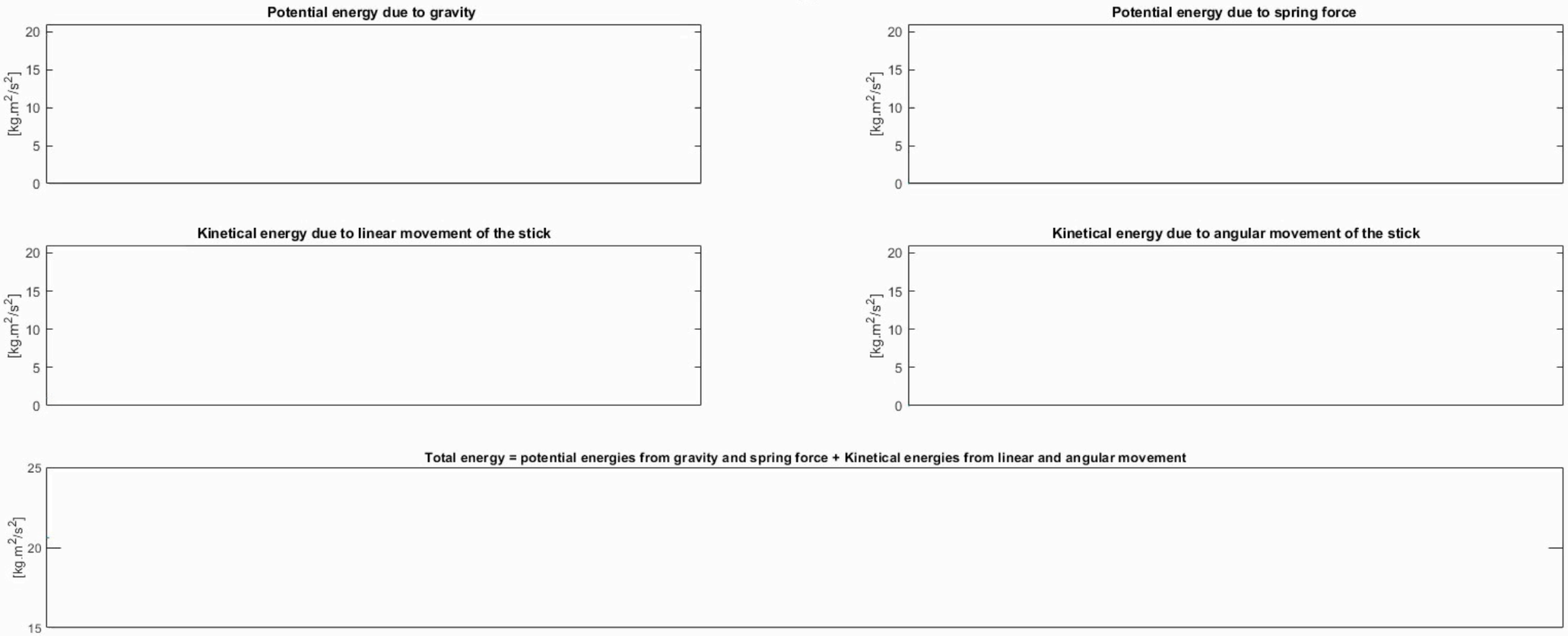

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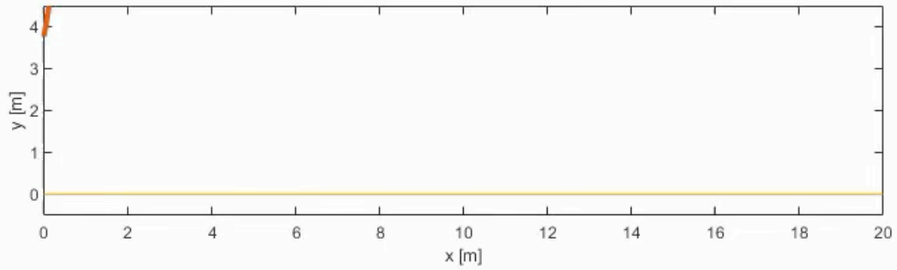

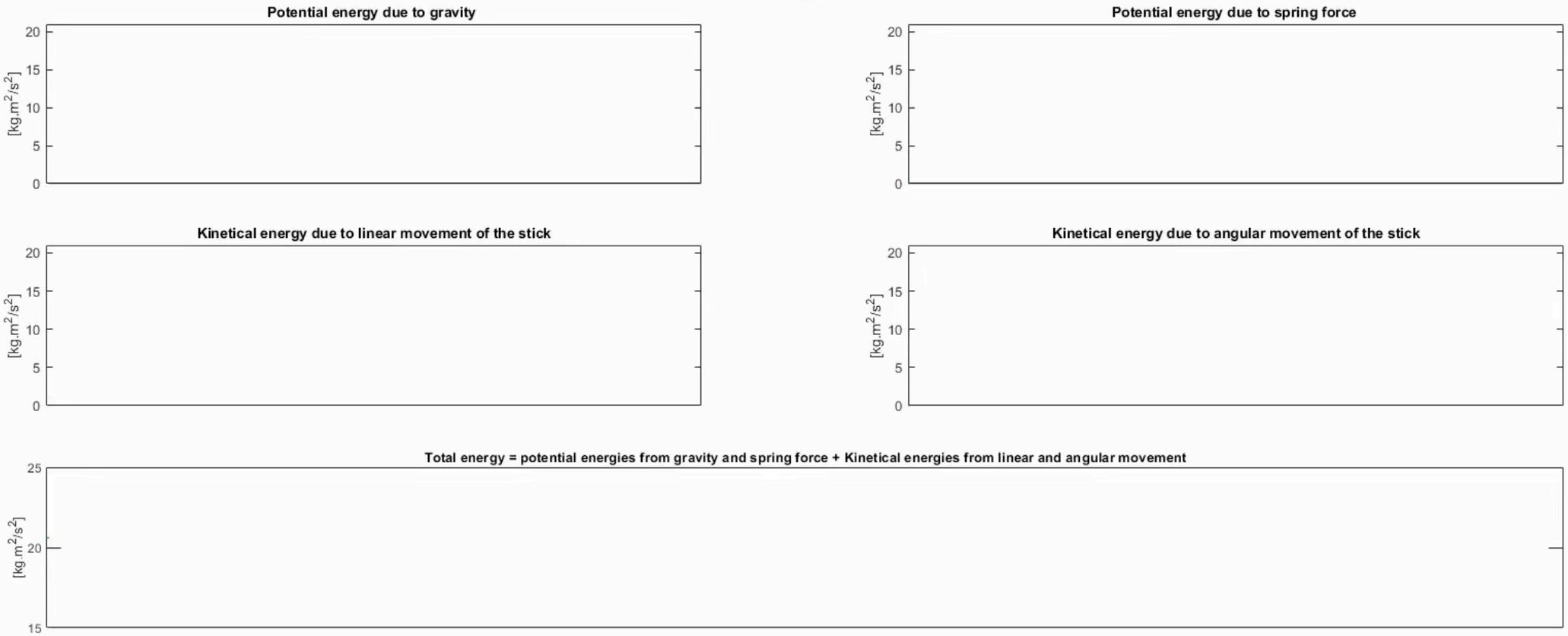

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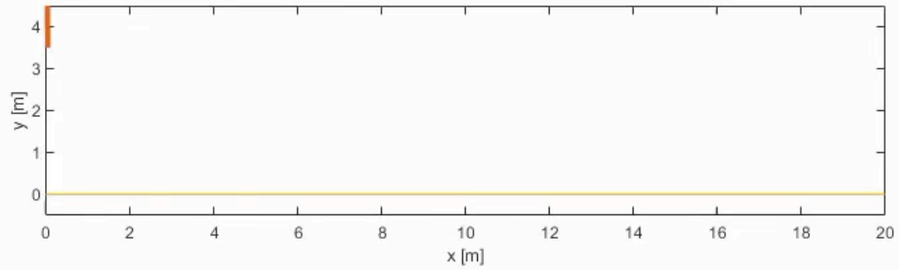

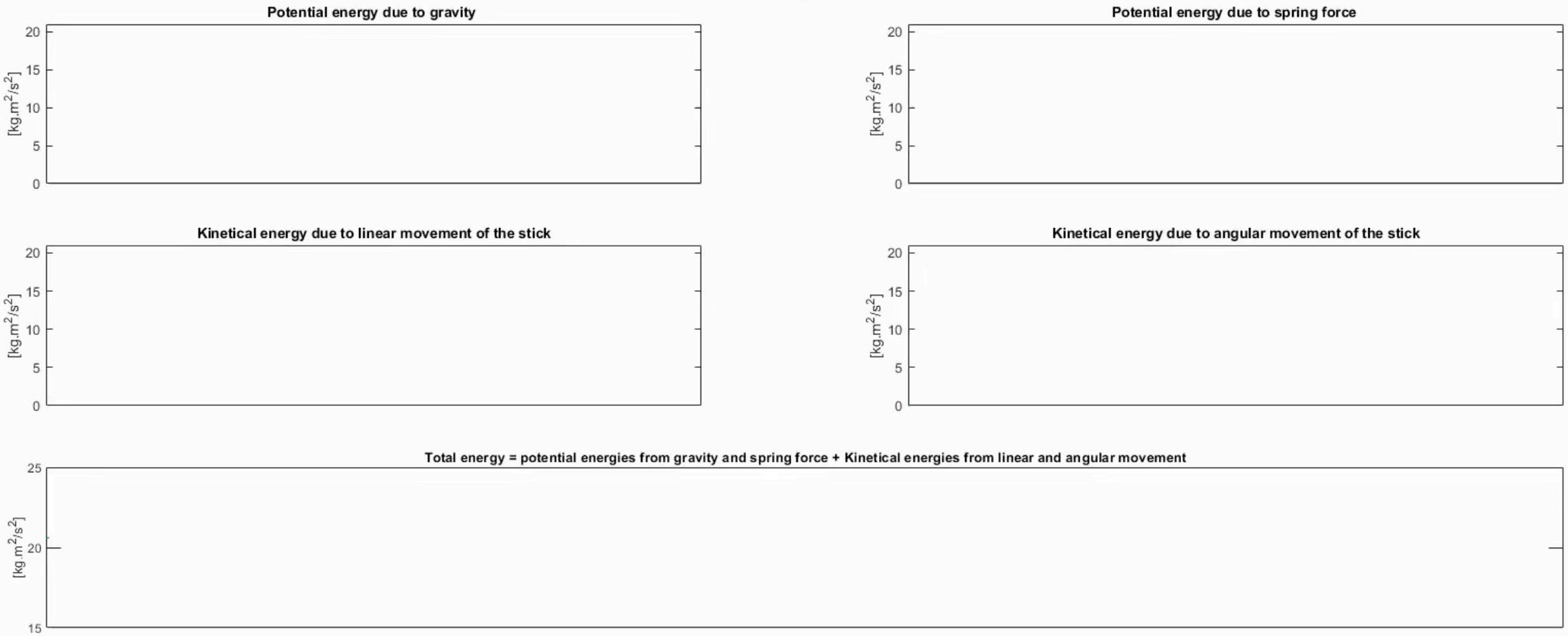

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Segmental energy analysis requires only knowledge of segmental kinematics and inertial properties. Using inverse dynamics methods to obtain the work done by the moments of force at each joint requires additional information and a more complex analysis.

The additional information includes the history of any external force that is in direct contact with the segment of interest. For example, to compute the work done at the ankle during stance, the GRF acting against the foot must be measured so force platforms are necessary in gait laboratories. During the swing phase, however, a force platform is not needed because no external force (excluding gravity) acts on the foot.

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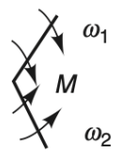
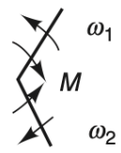
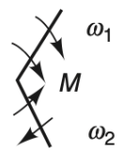
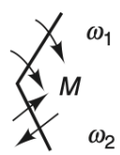
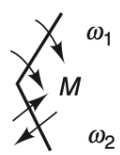
Description of movement	Type of contraction	Directions of segmental original velocities	Muscle function	Amount, type, and direction of power
TWO SEGMENTS ROTATING IN OPPOSITE DIRECTIONS				
a. Joint angle decreasing	Concentric		Mechanical energy generation	$M\omega_1$ generated to segment 1. $M\omega_2$ generated to segment 2.
b. Joint angle increasing	Eccentric		Mechanical energy absorption	$M\omega_1$ absorbed from segment 1. $M\omega_2$ absorbed from segment 2.
BOTH SEGMENTS ROTATING IN SAME DIRECTION				
a. Joint angle decreasing (e.g., $\omega_1 > \omega_2$)	Concentric		Mechanical energy generation and transfer	$M(\omega_1 - \omega_2)$ generated to segment 1. $M\omega_2$ transferred to segment 1 from 2.
b. Joint angle increasing (e.g., $\omega_2 > \omega_1$)	Eccentric		Mechanical energy absorption and transfer	$M(\omega_2 - \omega_1)$ absorbed from segment 2. $M\omega_1$ transferred to segment 1 from 2.
c. Joint angle constant ($\omega_1 = \omega_2$)	Isometric (dynamic)		Mechanical energy transfer	$M\omega_2$ transferred from segment 2 to 1.
ONE SEGMENT FIXED (e.g., SEGMENT 1)				
a. Joint angle decreasing ($\omega_1 = 0, \omega_2 > 0$)	Concentric		Mechanical energy generation	$M\omega_2$ generated to segment 2.
b. Joint angle increasing ($\omega_1 = 0, \omega_2 < 0$)	Eccentric		Mechanical energy absorption	$M\omega_2$ absorbed from segment 2.
c. Joint angle constant ($\omega_1 = \omega_2 = 0$)	Isometric (static)		No mechanical energy function	Zero

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Segment and Total Powers of a Four-Segment Model of the Body

Joint	Ankle	Knee	Hip	Total
Foot	$+F_{ankle} \cdot v_{ankle} + M_{ankle}\,\omega_{foot}$			$= \dfrac{\Delta E_{foot}}{\Delta t}$
Leg	$-F_{ankle} \cdot v_{ankle} - M_{ankle}\,\omega_{leg}$	$+F_{knee} \cdot v_{knee} + M_{knee}\,\omega_{leg}$		$= \dfrac{\Delta E_{leg}}{\Delta t}$
Thigh		$-F_{knee} \cdot v_{knee} - M_{knee}\,\omega_{thigh}$	$+F_{hip} \cdot v_{hip} + M_{hip}\,\omega_{thigh}$	$= \dfrac{\Delta E_{thigh}}{\Delta t}$
Trunk			$-F_{hip} \cdot v_{hip} - M_{hip}\,\omega_{trunk}$	$= \dfrac{\Delta E_{trunk}}{\Delta t}$
Total	$M_{ankle}\,(\omega_{foot} - \omega_{leg})$ or $M_{ankle}\,\omega_{ankle}$	$M_{knee}\,(\omega_{leg} - \omega_{thigh})$ or $+ M_{knee}\,\omega_{knee}$	$M_{hip}\,(\omega_{thigh} - \omega_{trunk})$ or $+ M_{hip}\,\omega_{hip}$	$= \dfrac{\Delta E_{Total}}{\Delta t}$

F_{ankle} = net ankle force as applied to foot; F_{knee} = net knee force as applied to leg; F_{hip} = net hip force as applied to thigh; v_{ankle} = velocity of ankle; v_{knee} = velocity of knee; v_{hip} = velocity of hip; M_{ankle} = net ankle moment as applied to foot; M_{knee} = net knee moment as applied to leg; M_{hip} = net hip moment as applied to thigh; ω_{foot} = angular velocity of foot; ω_{leg} = angular velocity of leg; ω_{thigh} = angular velocity of thigh; ω_{trunk} = angular velocity of trunk; ΔE_{foot} = change in total mechanical energy of foot; ΔE_{leg} = change in total mechanical energy of leg; ΔE_{thigh} = change in total mechanical energy of thigh; ΔE_{trunk} = change in total mechanical energy of trunk; ΔE_{Total} = change in total mechanical energy of total body; Δt = duration of motion; ω_{ankle} = angular velocity of ankle; ω_{knee} = angular velocity of knee; and ω_{hip} = angular velocity of hip.

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MECHANICAL ENERGY GENERATION, ABSORPTION AND TRANSFER AMONGST SEGMENTS DURING WALKING*

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SURVEY ARTICLE

POWER EQUATIONS IN ENDURANCE SPORTS

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