ECE 370
Introduction to Biomedical Engineering

Principles of Biomechanics
Introduction

• What is Biomechanics?
  • The study of internal and external forces acting on the body segments, and the effects produced by these forces.
  • The principles of engineering, specifically mechanics, applied to human movement.
  • Kinesiology
    • Study of movement
    • Tends to focus on neuro musculoskeletal systems

• Problems studied by biomechanists
  1. How can human performance be enhanced?
  2. How can injuries be prevented?
  3. How can rehabilitation from injury be expedited?

• Areas of Biomechanics
  • Sports Biomechanics
  • Occupational Biomechanics
  • Clinical Biomechanics
Sports Biomechanics

• Understanding and applying mechanical concepts to
  • Assess the most optimal way to move the body
  • Achieve maximal performance
  • Minimize risk of injury
Occupational Biomechanics

- Design machines and the workplace to
  - Reduce repetitive stress on workers’ joints
  - Minimize injuries and long term problems
Clinical Biomechanics

• Analyze the mechanics of injured patients and provide feedback (biofeedback)
  • Restore normal function.
Isaac Newton’s “3 Laws of Motion”

• **The Law of Inertia**
  • An object at rest tends to stay at rest and an object in motion tends to stay in motion (unless an external force is applied eg. friction or gravity).

• **The Law of Acceleration**
  • A force applied to a body causes an acceleration proportional to the force, in the direction of the force, and inversely proportional to the body’s mass.
  • \( F=ma \)

• **The Law of Reaction**
  • For every action there is an equal and opposite reaction.
Types of Motion

• It is important to distinguish between two types of motion:

• Linear (or Translational) Motion
  • Movement in particular direction. Example: a sprinter accelerating down the track.

• Rotational Motion
  • Movement about an axis. The force does not act through the centre of mass, but rather is “off-centre,” and this results in rotation. Example: ice-skater’s spin.
  • Most human movements are rotational i.e. they take place around an axis
Centre of Mass (Gravity)

- The point on an object where its mass is balanced
  - The point where that body would balance on a very small base
  - A force applied through the CoM → Linear motion
  - A force applied at a distance to the CoM → Rotation or Angular motion

- Important concept when stability is important
Biomechanical Analysis

• Seven Principles of Biomechanical Analysis

• Grouped into 4 broad categories:
  1. stability,
  2. maximum effort,
  3. linear motion, and
  4. angular motion.
Biomechanical Analysis

• STABILITY

• Principle 1:
  • The stability increases
    • Lower center of mass
    • Larger base of support
    • Closer the center of mass to the base of support
    • Greater mass
  • Examples:
    • Sumo wrestling
    • Wrestling
    • Gymnastics
      • Is this position stable? Why?
Unstable Balance

• Sometimes athletes need to be balanced but ready to move quickly i.e. unstable

• Examples
  • Sprint start
  • Receiving serve in tennis
  • Swim start
    • What makes this unstable?
Biomechanical Analysis

• MAXIMUM EFFORT

• Principle 2:
  • The production of maximum force requires the use of all possible joint movements that contribute to the task’s objective.
  • Examples:
    • Bench press
    • Sprint start
Biomechanical Analysis

- **MAXIMUM EFFORT**

- **Principle 3:**
  - The production of *maximum velocity* requires the use of joints in order
    - From largest to smallest.
  - Examples:
    - Pitch a baseball
    - Hitting a golf ball
Biomechanical Analysis

• LINEAR MOTION

• Principle 4:
  • The greater the applied impulse, the greater the increase in velocity.
    • $a = \frac{F}{m}$
    • Range of Motion (ROM) important
  • Example:
    • Spiking a volleyball
Biomechanical Analysis

• LINEAR MOTION

• Principle 5:
  • Movement usually occurs in the direction opposite that of the applied force.
    • Affected by gravity and other forces
  • Examples:
    • Basketball
    • Kicking
• **ANGULAR MOTION**

• **Principle 6:**
  
  • Angular motion is produced by the application of a force acting at some distance from an axis, that is, by torque.
  
  • Torque (or moment)
    
    • \( \tau = r \times F = |r||F|\sin(\theta) \)
  
  • Example:
    
    • Diving
# Levers

<table>
<thead>
<tr>
<th>Class</th>
<th>Illustration</th>
<th>Examples</th>
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</thead>
<tbody>
<tr>
<td>First</td>
<td>The fulcrum lies between the effort and the resistance</td>
<td>Less force</td>
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<tr>
<td></td>
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<td>See saw</td>
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<td>Crowbar</td>
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<td>Hammer pulling out a nail</td>
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<td><img src="image1.png" alt="Class 1 Lever" /></td>
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<tr>
<td>Second</td>
<td>The resistance lies between the fulcrum and the point of effort</td>
<td>Less force</td>
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<td>Wheelbarrow</td>
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<td>Opening a door by the handle</td>
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<td>Rowing a boat</td>
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<td></td>
<td><img src="image2.png" alt="Class 2 Lever" /></td>
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<tr>
<td>Third</td>
<td>The effort lies between the resistance and the fulcrum</td>
<td>More force, more speed</td>
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<td></td>
<td>Biceps curl</td>
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<td>Most limbs of the body</td>
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<td><img src="image3.png" alt="Class 3 Lever" /></td>
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Biomechanical Analysis

• **ANGULAR MOTION**

  • ** Principle 7:**
    • The principle of conservation of angular momentum
      • Angular momentum is constant when an athlete or object is free in the air
      • Once an athlete is airborne, he or she will travel with constant angular momentum.

• **Linear motion**
  • Force moves a body
  • \( F = ma \)
  • If no force is applied, momentum is conserved
  • \( p = m v \)

• **Angular motion**
  • Torque causes a body to spin
  • \( \tau = F \times r = I \alpha \)
    • \( \alpha \): rotational acceleration \((\Delta \omega/\Delta t)\)
    • \( I \): rotational inertia, or moment of inertia
    • \( I \propto m r^2 \)
  • If no torque is applied, angular momentum is conserved
  • \( L = I \omega \propto mr^2 \omega \)
Examples of Conservation of Momentum

• Ice-Skating
  • The ice-skater begins to spin with arms spread apart then suddenly brings them closer to the body.
  • The skater’s spin (angular velocity) increases.
  • Explanation
    • When a figure skater draws her arms and a leg inward, she reduces the distance between the axis of rotation and some of her mass → reduces her moment of inertia
    • Angular momentum is conserved → rotational velocity must increase to compensate.
Examples of Conservation of Momentum

• Diving
  • After leaving the high diving board, the diver curls tightly and then opens up just before entering the water.
  • By opening up before entry, the diver increases the moment of inertia \(\rightarrow\) slows down the angular velocity.
Examples of Conservation of Momentum

• Gymnastics
  • By opening up, the gymnast increases the moment of inertia (radius of rotation), thereby resulting in a decrease in angular velocity.
Conservation of Energy

• The conservation of energy principle
  • Energy can never be created or destroyed, but can only be converted from one form to another
Elements of Kinesiology

• Five Phases of a Sport Skill
  1. Preliminary Movements
  2. Backswing/Recovery
  3. Force Producing Movements
  4. Critical Instant
  5. Follow-Through

• Used to bring a skill down into smaller parts
  • Helps coaches to detect and correct errors
  • Key Points are “look fors” that coaches use to produce ideal mechanics / performance
Five Phases of a Sport Skill

Preliminary Movements

• **Key Points**
  • Pick a Target
  • Open stance
  • Hold Ball with Opposite Hand
  • Hold the Ball at Waist Height
  • Eye on the Ball
Five Phases of a Sport Skill

Backswing/Recovery

• Key Points
  • Eye on the ball
  • Maintain good posture
  • Large last step
  • Ankle locked
Five Phases of a Sport Skill

Force Producing Movements

- **Key Points**
  - Eye on the ball
  - Maintain good posture
  - Largest muscles to the smallest
  - Use arm for balance
  - Open the hips up
Five Phases of a Sport Skill

Critical Instant

• Key Points
  • Eye on the ball
  • Contact with hardest part of the foot
  • Lock your kicking foot upwards
  • Let ball fall below knee height
  • Lock your leg
Five Phases of a Sport Skill

Follow-Through

• **Key Points**
  • Be smooth and fluid
  • Foot carries on towards target
  • Eyes follow ball to target
Elements of Kinesiology

• Why aren’t there more robots walking on two legs?
  • Because it’s REALLY difficult!!!

• Dynamic Walking
  • Hundreds of specific and well coordinated movements
  • Almost all joints involved from head to toes
  • Every step involves not only pushing the body forward but also keeping balance
    • When we walk, is like loosing our balance and falling forward
    • Just before loosing our balance, we put one leg forward to support our body

• Running
  • It’s even more difficult since there are moments when both legs are airborne!
Honda Asimo

• The best biped robot