Biomechanical Principles of Force production and Balance

Unit 1 Physical Education
Biomechanics

Biomechanics involves the study of human motion with the ultimate aim of producing world best performance through perfect technique.

As athletes strives to improve their performance, they look to biomechanics for advice on technique, style, development and refinement of equipment and analysis of performance.
Tiger Woods and biomechanics

Wide stance:
Foundation for speed

Feet firm on ground:
Trunk extension (hips turned):
Arm extended (wide arc)

Extension of shoulders: trunk turns enabling wide arc and therefore speed

Chest and hips open:
Head over ball:
Body power.
Tiger finishes nice and tall with chest and belt buckle pointed left of the target. His left leg is straight and the laces of his right shoe point to the target. His arms are in a relaxed position and his balance is so good he could stay there all day.
Biomechanics can be described as

- the study of how and why the human body moves
- the science of physics applied to human movement
- the study of the structure and function of the human body using the methods of mechanics:
- the investigation of the internal and external forces which act on the human body and the effects produced by these forces.
Why use biomechanics?

1. Optimise performance by developing most efficient and effective technique.

2. Correct technique to avoid injury

3. Modify and develop equipment to widen participation (junior size balls)

4. Transfer skills from training to playing (rowing machines, ball throw machines)
What does biomechanics investigate?

Biomechanics is the study of human movement, including muscle and limb action and the results of human movement (eg the flight path of a javelin or the spin on a baseball pitch).

It also involves environmental or external factors that influence human and projectile motion (eg. Gravity, air resistance, water resistance and friction)
Equipment used in biomechanics

- Video, high speed photography, slow motion analysis
- Computer and digital analysis (gravity of object, speed, the range of motion)
- Force platforms - measure force application, acceleration (activities such as shot put, sprint start, high jump take off), dynamometers
- In-shoe pressure sensors (boxing)
- Electromyography - measurement of electrical activity and muscle force and action in activity
- Electrogoniographers (joint angle measurement eg. Murali)
- Wind tunnels - streamlining body positioning and equipment in cycling, downhill skiing
- Resistance pools - refining swim strokes
- Ergometers
- Head-mounted cameras
- Telemetry systems (eg. Polar HR monitors)
- Accelerometers
Principles of Biomechanics

• Not necessarily only for elite performers and coaches, but also easily applied to improve anyone’s performance

• Four important areas
  – Force production (mass, weight, velocity, inertia, acceleration, momentum, impulse, elasticity, accuracy, friction)
  – Balance and Stability (base of support, CofG)
  – Motion (air resistance, spin)
  – Levers within the body
Forces in physical activity

A force is “any pushing or pulling activity that tends to alter the state of motion (velocity) of a body”:

- human body
- ball
- discus, javelin, hammer, shot
- others?

The forces to these bodies are usually external and they include gravity, friction, air and wind resistance.

Forces can also be internal such as those generated by the actions of muscles and tendons.
Newton’s 1st Law of Motion

- **1st - Inertia**: a body will remain at rest or in uniform motion in a straight line until an external unbalanced force acts on that body to change its state of motion
- Eg. A footballer runs straight towards goal until an unbalanced force (opponent) hits him with hip and shoulder thus changing his state of motion (throws him off-balance)

Questions:
1. What is the unit of measurement for force?
2. When does a force not produce movement? Give an example.
Inertia

- the tendency of an object to maintain its state of motion (velocity) whether it is stationary or moving
- The greater an object’s inertia, the more difficult it is to change its motion
- Inertia is proportional to an object’s mass, so inertia can be measured by weight
- To alter an object’s motion, we must apply an unbalanced force to overcome its inertia
- Consider kicking a dry v wet soccer ball. Which is harder to start moving, stop/trap/save? Which has the greater inertia? Which is easier to kick further? Why?
- Consider who makes the most effective rugby players. Why?
Mass and weight

- Mass - the amount of matter that makes up an object
- Weight - directly proportional to mass. For example, a medicine ball has greater mass (and weighs more) than a basketball.
- We commonly use weight as an indirect measure of mass

Velocity

- Measures the rate (speed) of the positional change of an object.
- Velocity has two important factors (speed and direction).
- Units of measurement = m/s
Momentum

• the measure of the amount of motion possessed by a moving body (mass x velocity), using kg and m/s as units of measurement (kgms⁻¹)
  eg. if two objects moving at same velocity, which has greater momentum?
  eg. if two objects of equal mass are moving at different velocities, which has greater momentum?
• When two bodies collide, the one with greater momentum will be least affected. Give a sporting example of this. How can a smaller player knock over a bigger one?
• If Player 1 weighs 75kg and travels at 2m/sec, what velocity must Player 2 travel at if he weighs 50kg and wishes to equal the impact force if the two were to collide in a head on? What is their momentum measured at?
Impulse

- The amount of change in the momentum of an object is related to the TIME over which a force is applied to that object. This change in momentum is known as *impulse*. Eg. A push pass in hockey in which the stick is in contact with the ball for a prolonged period.

- Impulse is affected by
  - The magnitude of the unbalanced force. Eg. rowing
  - The length of time the force is applied. Eg. the spinning action in a discus throw that serves to increase the speed of release

- Questions
  - Give two examples of how impulse is applied in a sporting situation.
  - Suggest how greater impulse can be applied.
Newton’s 2\textsuperscript{nd} Law of Motion

- **2\textsuperscript{nd} - Acceleration:** the amount of acceleration produced when an unbalanced force acts on a body is proportional to the size of that force.

- Acceleration is the rate of change in velocity, a measure of how quickly an object can change its velocity.

- Units of measurement are metres per second squared (m/sec\(^2\) or ms\(^{-2}\))

- Acceleration is affected by force, but also by the mass of an object. A lighter object will have a larger acceleration than a heavier one if the same force is applied. eg. A lighter v heavier tennis racquet, cricket bat or golf club

- Acceleration is important in sport at the start of events eg. track sprints and cycle sprints. Acceleration cannot last indefinitely eg. 100m sprinter has +ve accel out of the blocks, then zero accel, and finally -ve accel as he slows down near the end of a race
Newton’s 3rd Law of Motion

- **3rd - Action/Reaction:** for every action there is an equal and opposite reaction
- Conservation of Momentum - applies to any collision between two objects eg. stick with ball, ball with ball, foot with ground etc.
- When a collision occurs, the total momentum of two bodies before impact is equal to the total momentum after impact. eg. white ball hitting coloured ball in snooker - the white ball may stop (unless spin is applied), transferring momentum on to the coloured ball. When the white ball applies a force to another ball, the coloured ball also applies an equal force in the opposite direction to the white ball
- In sport, conservation of momentum is important eg. A lighter player contacting a heavier player with great impact due to the higher momentum they are able to produce, giving them an advantage on impact

**Questions:**
1. Explain C of M using ten pin bowling as an example.
2. Explain C of M using skateboarding as an example.
Elasticity

- the ability of surfaces to ‘give’ then return to their original shape
- The size of the forces acting during an impact depend on the speed of each object before collision and the elasticity of the objects involved in the collision. More elastic surfaces result in less energy being lost in the collision because they rebound to their original position more quickly eg. tennis ball rebounding higher from Rebound Ace than from lawn as RA is more elastic.

Questions: 1. A new v old tennis ball - which one is preferred by the server? Why?
   2. How can temperature affect elasticity?
   3. Explain how tennis racquet string tension affects the velocity of the ball on impact.
Co-efficient of Restitution

It is a measure of the elasticity of the collision between two surfaces (eg. ball and racquet). Elasticity is a measure of how much bounce there is. A perfectly elastic collision has a C of R of 1. A score of 0 (zero) eg. two lumps of clay, won’t bounce at all. So, C of R scores will always fall between 0 and 1.

- To find the coefficient of restitution in the case of a falling object bouncing off the floor, or off a racquet on the floor, use the following formula:

\[ c = \sqrt{\frac{h}{H}} \]

- \( c \) = coefficient of restitution (dimensionless)
- \( h \) = bounce height
- \( H \) = drop height
Summation of Momentum

- Consider sports which require an object to be thrown or hit at very high velocities: golf drive, baseball pitch, tennis serve, javelin throw.
- The athlete must maximize the speed of the hand during the throw or hit.
- **Summation of momentum** is the technique by which an athlete does this.
Summation of Momentum

• Body parts involved in performing skill are moved in a sequential way, beginning with the largest and slowest segments and finishing with the smallest and fastest segments.

• Increasingly greater amounts of momentum are transferred from the larger to smaller parts if the **timing** of the movement is such that the next segment begins to move when the previous segment has reached its top speed.

• **Questions**
  – Describe the summation of momentum in a baseball swing, including the order of movement of specific body parts
  
  - How is a skill movement modified if accuracy rather than velocity is required eg. foul shooting in basketball?
Accuracy

- Precise and controlled movements that bring about an exact or desired outcome require accuracy determined by the amount of force applied and the direction in which the force is applied.
- For accuracy, optimise direction eg. putting, foul shooting
- For distance, optimise the amount of force
- Accuracy is increased by ‘flattening the arc’ ie. move body parts in such a way as to cause the motion of the bat or hand to move in a straight line at the point of impact or release, increasing the likelihood of making contact with the ball, or releasing the ball at the correct point. eg. softball pitch
Flattening the arc of the swing in a tennis serve improves accuracy. The correct trajectory is obtained by striking the ball at B.
Friction

- Friction is the force that opposes a motion, caused by the interaction between two surfaces moving against each other. eg. Friction causes a ball to slow down and stop after rolling on ground.

- When a stable base is required to apply force against, we need to increase frictional forces. This can be done by increasing the surface area of two contact points eg. screw in boots, blades in wet weather, spikes for sprinters etc.

Questions.  
1. When might decreasing friction be the aim? Give three examples.
2. Explain why surf boards are waxed.
Fluid Friction

- Includes forces such as air and water that work in opposite direction to a moving object. These forces increase **drag** (the force pulling an object backwards due to a low pressure air pocket). Examples of efforts to minimise these forces include:
  - High-tech swim suits (↓ surface resistance to allow water to flow over the suit surface)
  - Cycling (equipment changes to reduce wind resistance, inc. aerodynamically designed bikes, disc wheels, handlebars, helmets in teardrop shape)
Balance and Stability

• Balance - the ability of a body or object to maintain stability or equilibrium when stationary or moving.

• Balance varies according to body position (gravitational forces), surface you’re standing on (friction) and your state of equilibrium (moving or not).

• Stability - the ability of a body to resist being moved (how hard is it to disturb your balance?)

• Static balance - set position held for a period of time eg. archery, gymnastics handstand, preparing for platform diving

• Dynamic balance - balance can be altered easily eg. dodging in a game of netball
Balance and Stability

- Factors affecting:
  - Size of base of support - the larger, the greater the stability
    eg. Headstand v handstand
  - Position of centre of gravity (C of G) - the point through which all the weight of the object appears to act.
    eg. ruler test, man v woman, arms up, one arm to the right, lean forward, change position til C of G falls outside the body etc. A lower C of G means greater stability eg. wrestling, surfers etc. bend knees. To disrupt balance, apply force above or below C of G eg. rugby tackle
  - Line of gravity - ie. the theoretical line drawn from the C of G to the base of support. If C of G is directly over the middle of the base of support, a body is more stable. Unstable bodies have C of G not over the base of support.
  - Mass of the body - ↑ mass also increases stability. A heavier person is more stable and more difficult to move eg. AFL full forwards, ruckmen
Biomechanical Principles of Motion and Levers

Unit 1 Physical Education
Types of Motion

• Three ways an athlete can move
  – Linear motion or translation (straight line)
  – Angular motion (rotating around a fixed point)
  – General motion (mixture of linear and rotational movement)
Linear Motion

• All parts of an object travel over the same distance at the same time.
  – Straight line motion eg. ice skater gliding down back straight after a race
  – Curvilinear motion ie. path follows a curved line eg. flight path of a projectile (ball, javelin, long jumper)
Angular Motion

• All parts of an object rotate in the same direction at the same time around a fixed point eg. shoulder joint in a throw
• Not all parts move the same distance; the parts further from axis will always move further.
• Axis of rotation can be Internal or External. Eg. (internal) Joints of the body e.g. knee joint for lower leg linear rotation Eg. (external) imaginary such as centre of gravity, or rotation on a high bar where the bar itself is the external axis.
Angular Motion

• Human axes include;
  – Longitudinal (vertical axis) taken from head to toe vertically
    eg.
  – Transverse (horizontal) taken from hip to hip
    eg.
  – Medial (also a horizontal) axis taken from the navel to the small of the back
    eg. cartwheel
The three axes of the human body

- Longitudinal or vertical axis
- Traverse or horizontal axis

Angular motion: an axis of rotation.
Angular Motion

• Angular motion is created by applying an unbalanced force that does not pass through the axis of rotation.
• When the force applied is off-centre, it produces a torque (turning effect) that changes the rotation of the object.
  eg. Forehand topspin of the ball in tennis
  eg. Backspin on volleyball serve

http://65.23.114.181/tennis/Backhand%20Topspin.gif
General Motion

• Whilst angular motion (rotation) is far more common in sports than linear motion, most use a combination of both types of motion.

• General motion - linear motion of the whole body that is achieved by the angular motion of some parts of the body.

eg. running a 100 metre

eg. ________________________________

eg. ________________________________
More about angular motion

- Newton’s three laws also apply to angular motion
  1\textsuperscript{st} - inertia eg. spinning ball from drop punt in football only occurs after ball has been kicked
  2\textsuperscript{nd} - acceleration eg. a diver increases its speed of rotation in a tuck position after a strong push off the diving board
  3\textsuperscript{rd} - a spinning ball hits the ground and its amount of spin is reduced by the opposite action applied by the ground
Torque

- The turning effect created when a force is applied to an object outside its axis of rotation.
- The size of a torque depends on the size of the force being applied and the distance from the axis of rotation to the line of the force. 
  eg. pushing a door open 
  eg. an ice skater spinning

Questions: 
  a) Which position results in the faster spin? 
  b) How does the skater stop spinning?
Eccentric force

• A force that is applied away from the centre of gravity of an object (eccentric) causes rotation
• If one eccentric force is applied, linear and angular motion occurs
• If one end is fixed, rotation only occurs eg. giant swing on a high bar
• Eccentric forces are commonly used in sports to apply spin to a ball

Eg 1. _____________________________
Eg 2. _____________________________
Force Couples

- When two equal but ____________ forces are applied at the same distance from, but on ____________ sides of the ____________ of an object, the object will simply ________ in a fixed position. No ____________ motion will occur. This situation is referred to as a ____________ _________.

  eg 1. ____________________________________________________________
  eg 2. ____________________________________________________________
Activity 9  Laboratory report

Angular motion (rotation)
This laboratory activity explores angular motion (rotation), and in particular, the concepts of moment of force and force couple.

Part A
Equipment
• a ruler (30 cm)
Method
Step 1
• Place the ruler flat on a table.
• Use your finger to apply a force on the side of the ruler through the centre of gravity of the ruler.
• Observe and record what happened.

Questions
What name is given to a force that produces this effect?

Step 2
• Place the ruler flat on a table.
• Use your finger to apply a force on the side of the ruler through a point 2 centimetres along from the centre of gravity of the ruler.
• Repeat the above but applying the force at 5, 10, and 15 centimetres from the centre of gravity of the ruler.
• Observe and record what happens in each case.

Questions
1. What name is given to a force that produces this effect?
2. What effect, if any, did applying the force further from the centre of gravity of the ruler have on the motion produced?
3. Explain the meaning of the following terms — moment arm and moment of force.

Part B
Equipment
• a basketball
Method
Step 1
• Bounce the basketball vertically down onto the floor, so that it rebounds straight back up to you. Make sure your hand is positioned directly on top of the ball as you bounce it.

Questions
4. Did the ball travel with linear and/or rotational motion? Explain your answer.
5. In which direction is the force applied, in relation to the centre of gravity of the ball, in order to produce this effect?

Step 2
• Place the basketball on the floor. With one hand on either side of the ball, apply an equal force with each hand so that the ball rotates (spins) on the spot.

Questions
6. Draw a diagram to indicate the direction of force application required to produce this effect?
7. What name is given to the forces that produce this effect?
Complete Lab Report Activity
Equipment - ruler, basketball
Answer all questions (1-9) in exercise book

Activity 9 continued

Step 3
• You will need to work with a partner to complete this step.
• Stand 3 metres from your partner. Bounce the basketball to your partner giving the ball heavy topspin (i.e. the top of the ball rotating away from you).

Questions
8. Draw a diagram to indicate the direction of force application required to produce this effect.
9. In which direction are the forces applied, in relation to the centre of gravity of the ball, to produce this effect?
Angular Velocity and Moment of Inertia

- measures the rate of angular velocity of an object around its axis of rotation, measured in degrees per second, or revolutions per second eg. cycling rpm
- Moment of Inertia reflects Newton’s First Law: the moment of inertia of a rotating body is its resistance to change, particularly resistance to beginning angular motion or rotation. Ie.it is a measure of how difficult to change an object’s rotary motion. In linear motion, the object’s weight or mass determines its inertia. In angular motion, an object’s moment of inertia has two components: its weight or mass, and the distance that the weight of the object is distributed away from its axis of rotation eg. comparing a long, heavy surfboard to a short board. Which has the higher moment of inertia?

![Diagram](image-url)
Moment of Inertia

- In sport, equipment is modified to reduce the moment of inertia for children eg. lighter bats, shorter handled racquets etc.
- Choking down on the handle achieves the same thing, thereby making the bat easier to swing

Question: How is moment of inertia reduced in the running action?

In diving, is moment of inertia greater in a tucked or pike dive? What is the effect on rotation?
Angular Momentum

• A measure of the amount of angular motion possessed by a rotating body. ie. how hard it is to stop a rotating object.

• The AM of an object is directly related to its ___________ and its ______________. The greater these two things, the harder it is to stop an object’s angular momentum.

• The conservation of angular momentum describes how the total momentum of a body stays constant during a movement. AM will remain constant until an unbalanced torque acts on the object (1st law). eg. divers moving from an open position into a tuck position, easing their _________________ and easing ________________, therefore allowing AM to be conserved.
Projectile Motion

- A number factors affect the movement path of an object or the human body. Sport provides many examples of objects propelled into the air. Athletes must assess, control and manipulate the flight path of the projectile.
  eg. soccer goal keeper, high jumper, shot put
- Factors affecting the path of a projectile include
  - Velocity of release
  - Angle of projection
  - Height of release
  - Air resistance and spin
Factors affecting the path of a projectile

- **Velocity of release**
  - Increasing the velocity at the time of release increases the vertical height, the length of time in the air and the distance it travels (horizontal component)

- **Angle of projection**
  - Without the effects of air resistance there are three alternative flight paths
    - $45^0$ release angle if from ground will maximize horizontal distance
    - $> 45^0$ results in shorter distances, greater heights and longer flight times
    - $< 45^0$ results in shorter distances, low heights and shorter flight times
Projectile Motion

Figure 2.34: The range of trajectories for various sports.

- Pole vault
- Lay-up shot
- High jump
- Front tuck somersault
- Badminton serve
- Hammer throw
- Shot put
- Triple jump
- Lawn bowling
- Throw for distance
Factors affecting the path of a projectile

- Height of release and height of landing surface also affect the most appropriate flight path
  - Ground to ground (use 45°)
  - Projected from above landing area (use < 45°)
  - Projected from below landing area (use > 45°)

In summary, increasing height of projection results in greater flight times and greater distances travelled
Factors affecting the path of a projectile

- Air resistance and spin
  - Increased air resistance decreases the time in the air and the distance a ball will travel if into a head wind, and vice versa for a tailwind
  - Magnus Effect - a lift force that affects the flight path of a ball.
- An object passing through the air causes a disturbance to the air flowing around the object. It is more difficult for air to pass by the side of a ball that is spinning in the same direction as the ball is travelling, causing high pressure on one side of the ball. The ball deviates to the area of lower pressure on the other side of the ball eg. topspin causing the ball to dip
Spin imparted on a projectile

Participate in a game of table tennis. How can you impart topspin, sidespin and backspin on the ball?

What effect do these spin have on the bounce of the ball off the table? Off the opponent’s bat?
Effects of topspin and backspin on the rebound of a ball
Ball of the century
Levers

- Simple machines that change mechanical energy from one place to another
  - e.g. pliers, hammers, crowbars, seesaws, catapults

- We are mostly interested in levers within the human body, and the extended levers we use in sport such as bats, racquets etc.

- Muscles, bones and joints work together as levers; bones as the levers, joints providing the axis of rotation and muscles providing the force to move the resistance

- 3 parts to lever systems
  - Axis (also known as fulcrum - pivot point)
  - Resistance (the load to be moved)
  - Force (the action which causes the load to move)
Classes of levers

First class lever - axis b/n resistance and force eg. seesaw

Second class lever - resistance b/n axis and force eg. wheelbarrow

Third class lever - force b/n axis and resistance eg. most levers in the human body eg. bicep curl, drop punt
Which class of lever does the calf raise depict?

What about the leg press?
Use of levers

- It is important to know these definitions;
  - Force arm of a lever is the distance from the force to the axis ie. the distance from the muscle attachment to the joint
  - Resistance arm ie. the distance from the load to the axis
  - A longer force arm means less effort is required to move a resistance
  - A longer resistance arm maximises the speed and range of motion of a lever
  - Implements such as tennis racquets, cricket bats, golf clubs act as extended levers

Questions: *How can choking down on a bat handle reduce the distance we’re able to hit the ball?*

*If we take a long grip on a bat to increase the speed at the point of impact with a ball, what is the trade off? Why?*