Physical Education (HKDSE)

Part III: Movement Analysis

Physical Education Section
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Learning Objectives

This part covers the basic principles of human movement and is linked to the discipline of physics. It guides students to understand the scientific basis of body movement and to apply this knowledge, together with the acquired psychological skills in Part VII, to enhancing performance or interest in participation in (Part X) PE, sport and recreation. It also helps students understand more about the causes of some common sports injuries (Part VI).

Expected Learning outcomes: Students will be able to

1. explain, using practical examples, the contents and meanings behind Newton's three Laws of Motion;
2. apply the principles of leverage to improve movement performance;
3. when analysing movement performance, identify the different types of movements regarding the musculoskeletal system, and understand the execution of the three movement planes of the body; and
4. explore some basic principles of sports biomechanics by using simple measurements.

Glossary

	Term	Description
1.	Acceleration 加速度	The rate of change in velocity of an object over time.
2.	Biomechanics 生物力學 / 生物機械學	An area of study wherein the knowledge and methods of mechanics are applied to the structure and function of the living human system.
3.	Centre of gravity 重心	The centre of gravity (CG) of an object is the point at which weight is evenly dispersed and all sides are in balance.
4.	Displacement 位移	The net distance an object changes in position.
5.	Distance 距離	The total length of the route travelled.
6.	Force 力	The "push" or "pull" exerted upon an object which may cause either a motion of a stationary object or a speeding up, a slowing down or even a change of direction of a moving object. To alter the state of motion of an object, causing a change in its velocity, including changes in both speed and direction of motion.
7.	Gravity 重力	This is the force of attraction between any two masses in the universe; especially for the attraction force exerted by the earth on the objects in its vicinity.
8.	Inertia 慣性 / 慣量	The tendency of an object to remain at rest or in motion at the same speed and in the same direction unless acted upon by a force.
9.	Lateral rotation 外旋	The rotation of the axis of a joint away from the midline of the body.
10.	Magnitude 量值	The greatness or the relative size.

Glossary

	Term	Description
11.	Medial rotation 內旋	The rotation towards the midline of the body; opposite of the lateral rotation.
12.	Moment of force / Torque 力矩 / 轉矩	A measure of the turning effect of a force around an axis. The moment of a force is also known as torque.
13.	Newton 牛頓	A Newton is a unit of force. It is defined as the amount of force needed to make an object of one kilogram to accelerate by one meter per second squared ($1\ N = 1\ kg/ms^2$).
14.	Scalar 標量	Physical quantity with magnitude but no direction such as mass, volume or time.
15.	Speed 速率	The distance travelled at a given time.
16.	Vector 矢量 / 向量	A physical quantity with both magnitude and direction such as force, displacement and velocity.
17.	Velocity 速度	The rate of change of displacement of an object over time.

Essential Concepts and Theories

A. Forces and movement

i) Newton's Law of Motion

Please refer to paragraph (v) of this section.

ii) Motion

In mechanics, "motion" refers to a change in position. It is described in terms of velocity, acceleration, displacement and time.

iii) Velocity

It is the rate of change of displacement of an object. Speed is a scalar, with magnitude but no direction. Velocity is a vector, possessing both magnitude and direction. It can be calculated as follows:

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time taken}}$$

iv) Acceleration

Acceleration represents the rate of change of velocity during a given time. It is a vector, possessing both magnitude and direction. It can be calculated as follows:

$$\text{Acceleration} = \frac{\text{Change in Velocity}}{\text{Time taken}}$$

OR

$$\text{Acceleration} = \frac{\text{Final Velocity - Initial Velocity}}{\text{Time taken}}$$

v) Force

Force is the "push" or "pull" exerted upon an object which may cause either a motion of a stationary object or a speeding up, a slowing down or even a change of direction of a moving object.

1st Law: The Law of Inertia
Every object at rest, or moving in a constant velocity in a straight line, will continue in that state unless it is compelled to change by an external force exerted upon it.
Example 1: Before the penalty kick of a football player, the ball is at rest; to perform a kick, the football player has to apply a force (kicking) to the football to overcome its inertia. This makes the football move forward. Example 2: When a sprinter reaches the finishing line, he/she cannot stop immediately because of the influence of forward inertia.

Force is a vector, possessing both magnitude and direction. The unit of force is Newton (N). One Newton (N) represents the force required to give a one kilogram mass an acceleration of one meter per second squared.

2nd Law: The Law of Acceleration
The acceleration of an object is proportional to the force causing it and inversely proportional to the mass of the object; the acceleration takes place in the direction in which that force acts.
Example 1: In a volleyball match, a more powerful spike cause a greater acceleration of the ball making it more difficult for the defenders to receive the spike. Example 2: We can feel the force and acceleration when we ride in a car. When the car is started, we feel the push from the back of the seat. This force accelerates our bodies forward. If we ride on a roller coaster, the push will be stronger and the acceleration will be greater.

In order to generate a greater acceleration, a stronger force must be exerted. If the mass of the object and the acceleration are known, the force required for that acceleration can be calculated by using the following formula:

Force = Mass of the object x Acceleration

3rd Law: The Action and Reaction Law

When an object exerts a force on a second object, there is a force equal in magnitude but opposite in direction exerted by the second object on the first.

Example 1: A high jumper exerts a force on the ground during a take-off. The ground generates a reaction force in the upward direction, acting upon the jumper to propel him / her over the bar.

Example 2: The foot strike and plantarflexion motion of a runner exert a downward and backward force on the ground, and the ground exerts a force on the runner with an upward and forward reaction force. This enables the runner to leap upwards into the air and propel themselves forwards.

vi) **Resultant force**

A resultant force is the vector produced when two or more forces act upon a single object. Its magnitude and direction can be calculated by constructing a parallelogram of forces *(See Fig. 3.1)*.

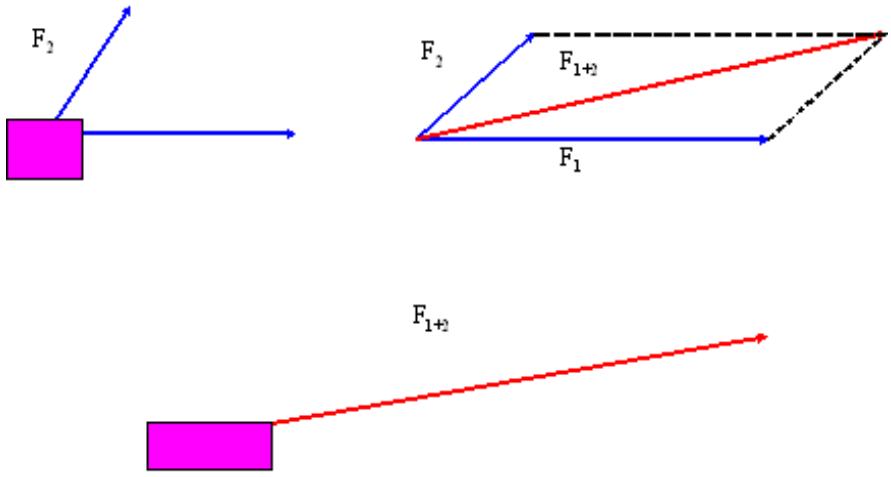


Fig. 3.1 A resultant force

vii) **Centre of gravity**

Gravity is a force that occurs naturally and pulls an object towards the centre of the earth at a rate of 9.81 meters per second squared. A gravitational pull always occurs through the centre of mass of an object. The location of the centre of gravity depends on the arrangement of mass within the object. In humans, this location is changing constantly during movement. When standing in an anatomical position, a person's centre of gravity is about 53% to 57% of his / her body height. In high jump, an athlete can move his / her centre of gravity outside his / her body by arching the back, so that the centre of gravity is close to or passes under the bar while he / she is passing over the bar *(See Fig. 3.2)*.

Fig. 3.2 A high jumper performing a Fosbury Flop

viii) **Lever**

The application of leverage principles enhances the effectiveness and efficiency of movement. There are many examples in our daily life such as loosening and tightening screws with spanners, inserting and removing nails with hammers or hitting the ball with a baseball bat etc. There are three types of levers *(See Fig. 3.3)*:

First Class Lever - The fulcrum lies between the effort and the load.

Second Class Lever - The load lies between the fulcrum and the effort.

Third Class Lever - The effort lies between the fulcrum and the load.

(F: Fulcrum, E: Effort, L: Load)

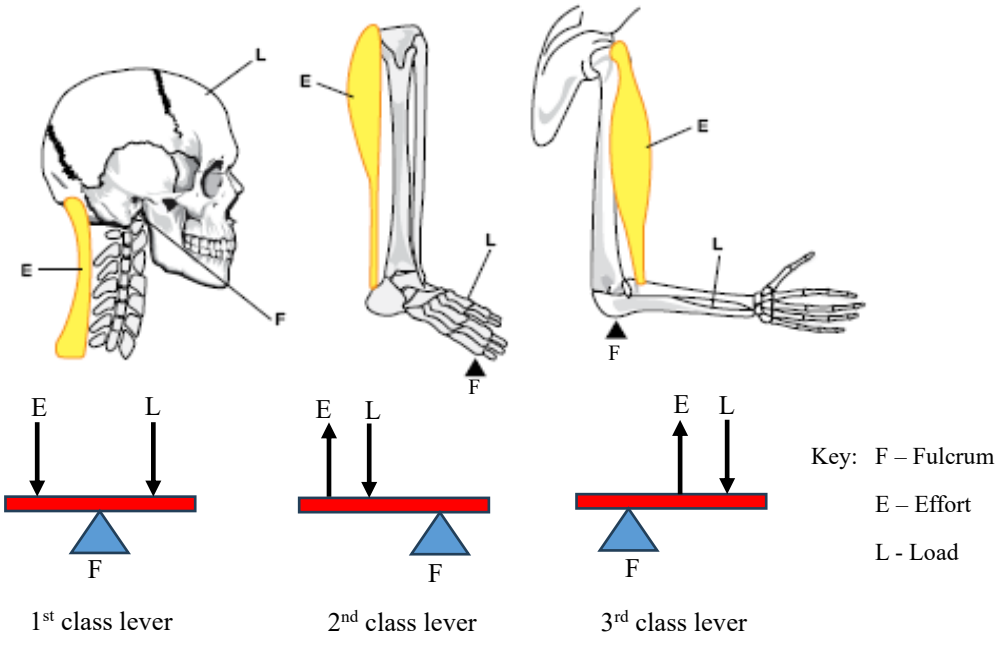
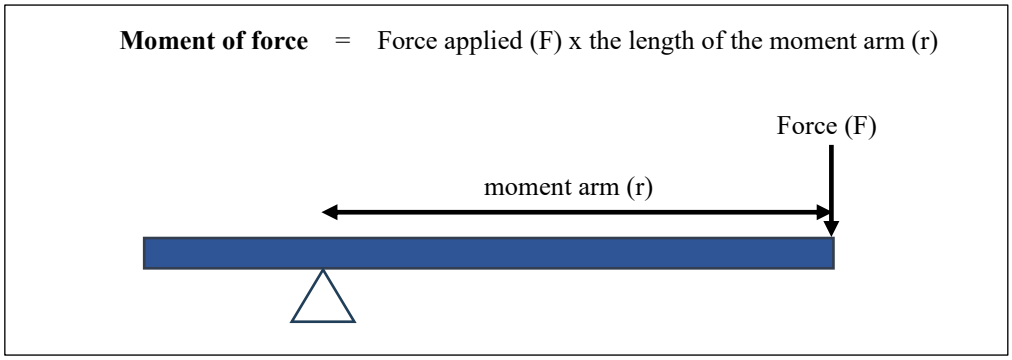


Fig. 3.3 Examples of 1st, 2nd and 3rd class levers

If the effort remains unchanged, we can lift a heavier object or increase the speed of the object by using leverage principles. The effectiveness is determined by the length of the load arm and the effort arm.

The levers of the human body are capable of rotational movement only, and this turning effect is known as the "moment of force", which is directly related to the distance between the point of muscle insertion and the joint. The moment of force is equal to the force applied multiplied by the length of the moment arm (the perpendicular distance from the fulcrum to the line of action of the force).



There are a number of examples of applying the leverage principles in sports activities. For instance, the length of a golf club affects the travel distance of the ball hit. If the angular velocity remains the same, a golfer can hit the ball over a longer distance by using a longer club. The travel distance of the ball is shorter if a shorter club is used. (The driving force would be different)

ix) **Angular motion**

- **Angular Displacement -** It is measured in degrees travelled by an object rotating around a central axis. One full rotation is 360 degrees *(See Fig. 3.4)*.
- **Angular Velocity -** It is the rate of change of angular displacement with respect to time of an object. The unit of measurement is degrees per second($^{\circ}$/s) or radians per second (rad/s).
- **Angular Acceleration -** It is the rate of change of angular velocity with respect to time. The unit of measurement is degrees per second squared ($^{\circ}/s^2$) or radians per second squared (rad/s^2).

- **Moment of Inertia -** It is a measure of a body's resistance to changes in its rotational rate. This is determined by the distribution of the mass around the axis of rotation. The further its mass is away from the axis, the greater its moment of inertia is. When the body's mass is concentrated about the axis, the moment of inertia is lower. The moment of inertia can be calculated as follows:

Moment of Inertia = Mass of body part x (the perpendicular distance between the mass and the axis of rotation)^2

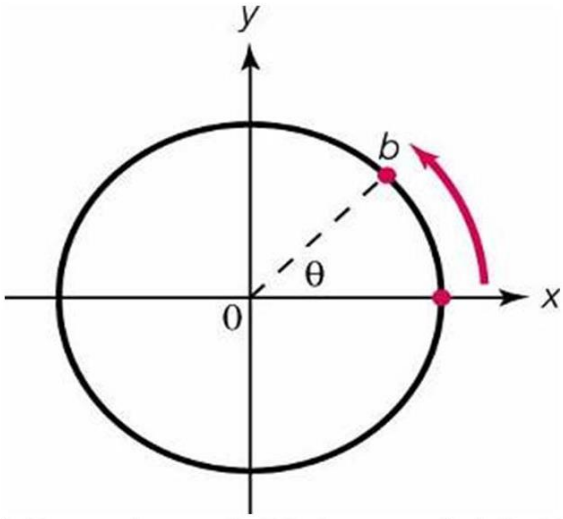


Fig. 3.4 The ɵ marks an angle of displacement as body b orbits. Angular velocity is the rate of change of ɵ with respect to time.

- **Newton's Laws of Angular Motion**

The angular form of Newton's first law - A rotating body will continue to turn about its axis of rotation with constant angular momentum unless an external force is exerted upon it. For example, after rotating the body during the flying spin, the ice skater will keep the spin going before landing.

The angular form of Newton's second law - The angular acceleration of a body is proportional to the torque acting on the body, and the direction of the angular acceleration is the same as the direction of the torque. For example, a force is applied to a bicycle tire in the direction of rotation as shown in *Fig. 3.5*. The larger the force applied, the greater the torque, and the greater the angular acceleration of the bicycle tire.

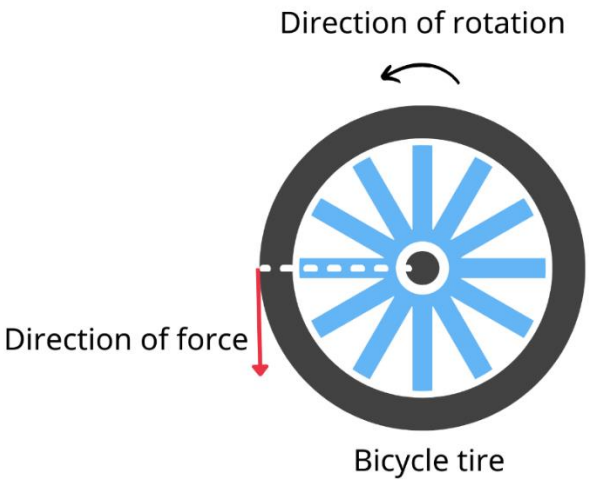


Fig. 3.5 The direction of rotation when a force is applied to the bicycle tire

The angular form of Newton's third law - For every torque that is exerted by one body on another, there is an equal in magnitude and opposite torque produced by the second body on the first. For example, a gymnast feels that she is about to topple off a balance beam. As soon as she feels she starts to overbalance, she tries to swing her arms (and perhaps her non-supporting leg) in the direction she is about to fall in order to maintain her balance. (*Fig. 3.6*)

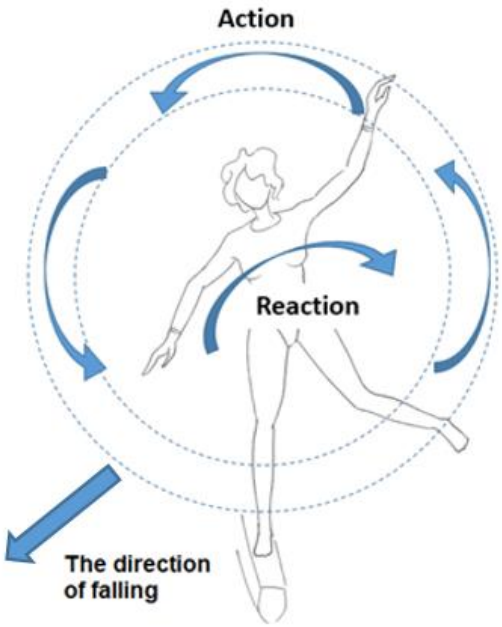


Fig. 3.6 The direction of the action and reaction force when the gymnast on the balance beam feels that she is about to topple off

B. Types of movements

i) Anatomical position

The body is upright and facing forward, eyes are looking forward, feet together and pointing forward, arms by the sides of the body and palms facing forward. (*Fig. 3.7*)

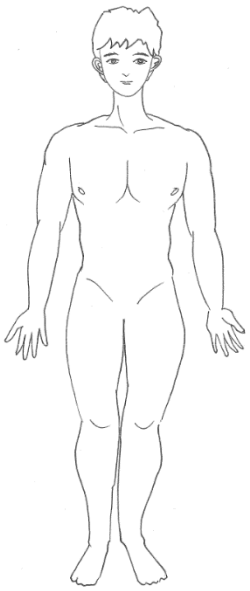


Fig. 3.7 Anatomical position

ii) Flexion / extension

Flexion – It occurs when the angle between the articulating bones is decreased *(See Fig. 3.8)*. An example of this is when the lower arm is raised to touch the shoulder. A muscle that causes flexion is known as a "flexor". In this instance, the biceps brachii is the flexor.

Fig. 3.8 Raising the hand towards the shoulder causes flexion

Extension – It occurs when the angle between the articulating bones is increased. An example of this is when someone stands up from a seated position, the angle between the femur and the tibia increases, causing extension of the knee joints. A muscle that causes extension is called an "extensor". In this case, the quadriceps muscle group is the extensor.

iii) **Abduction / adduction**

Abduction – It refers to the movement of a body part away from the midline of the body. An example of this is when the arms are placed by the sides of the body and then raised laterally *(See Fig. 3.9a)*.

Adduction – It refers to the movement of a body part towards the midline of the body. An example of this is when the arms are straight above the head and lowered laterally down to the sides of the body *(See Fig. 3.9b)*.

Fig. 3.9a Abduction

Fig. 3.9b Adduction

iv) **Pronation / supination**

Pronation – The pronation of the forearm takes place at the elbow and involves medial rotation between the radius and the ulna. It occurs when the palm of the hand is moved from facing upwards to facing downwards *(See Fig 3.10a)*. For example, pronation is commonly seen in playing forehand attack or drive in table tennis.

Supination – The supination of the forearm takes place at the elbow and involves lateral rotation between the radius and the ulna. It occurs when the palm of the hand is turned so that it faces upwards *(See Fig. 3.10b)*. Can you name one drive in table tennis using supination?

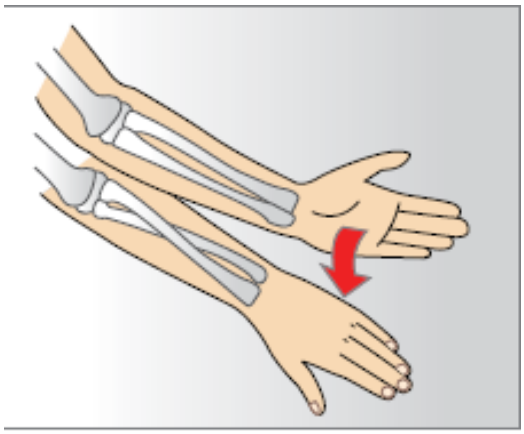


Fig. 3.10a Pronation

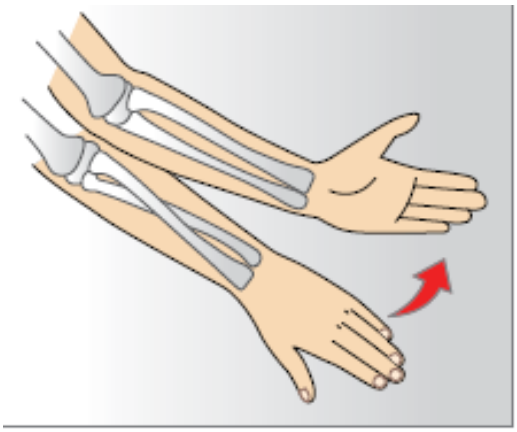


Fig. 3.10b Supination

v) **Planes of motion**

There are three body planes *(See Fig. 3.11)*:

- **The sagittal plane -** It divides the body vertically into left and right sides.
- **The transverse plane -** It divides the body into superior (upper) and inferior (lower) sections.
- **The frontal plane -** It divides the body into anterior (front) and posterior (back) sections.

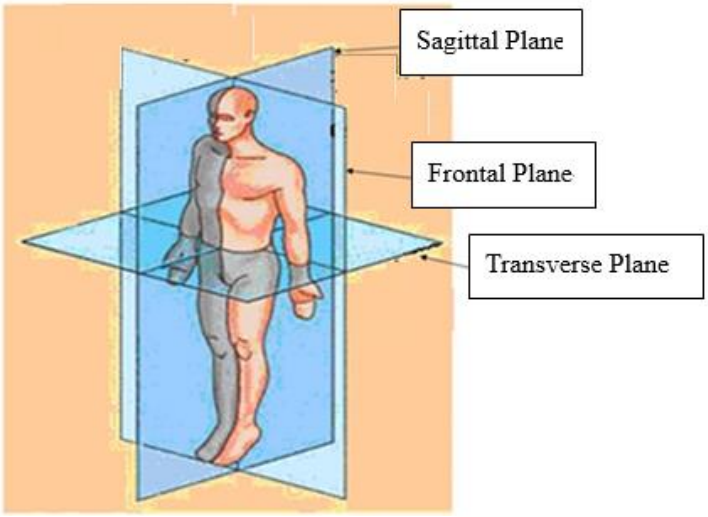


Fig. 3.11 Planes of motion

vi) **Circumduction**

The human body has three basic axes that are perpendicular to the related planes.

Anteroposterior Axis - A line, parallel to the ground, runs from the front to the back of the body. The rotation movements in the frontal plane are around this axis, for example, abduction, adduction, cartwheels, etc.

Mediolateral Axis - A line, parallel to the ground, runs from the medial to the lateral side of the body. The rotation movements in the sagittal plane are around this axis, for example flexion, extension, forward rolls, front somersaults and forward handsprings etc.

Longitudinal Axis - A line, perpendicular to the ground, runs along the length of a body or segment. The rotation movements in the transverse plane are about this axis, for example, pronation, supination, twisting, etc.

The shoulder and hip joints can perform circumduction across different planes.

C. Steps and guidelines for performance analysis

i) Scientific method[1]

Scientific attitude – Scientific inquiry is driven by a spirit of truth-seeking, grounded in evidence, and based on empirical experience as the criterion. It also encourages innovation and scepticism.

Scientific thinking - Scientific knowledge is built on creative thinking. The scientists use deductive and inductive reasoning, to propose new scientific theories, which are then tested for verification. Although scientific knowledge has a long history, it is not eternal and unchanging.

Scientific practice – Scientists use precise research designs and appropriate instruments to explore phenomena or verify theories. They handle the quantitative and qualitative data carefully and report the findings honestly.

[1] Morris, et al. (1995). Biomechanical analysis of the men's javelin throw at the 1995 world championships in athletics. (Source: www.athleticscoaching.ca)

ii) **Movement and performance analysis**

The movement and performance analysis is one of the topics in biomechanics. We can explore some basic principles of biomechanics by using simple measurements

- **Review the movement**

- Sequential description of the movement *(See the part of "key learning points" in Fig. 3.12)*
- Joints and muscles involved (*See Fig. 3.13*)
- Types of muscle contraction (i.e. concentric contraction, eccentric contraction and isometric contraction) (*See Fig. 3.14*)
- Range and speed of joint movements (See the part of "different angles of the joint in throwing a javelin" in Table 3.1)

World Athletic Championship 1995 – Javelin	**Different angles of the joint during the delivery phase in throwing a javelin**		
	Hip joint	**Elbow joint**	**Shoulder joint**
Gold medallist	59°	170°	55°
Silver medallist	59°	147°	45°
Bronze medallist	70°	154°	59°

Table 3.1 A comparison of joint angles in javelin throw[1]

- **Quantify the performance**

- Quantify the process as well as the result (*See Table 3.2*)
- Use a rating scale for a systematic observation (*See Fig. 3.13*)
- Use technology to collect precise data such as velocity, angle, tension, etc (*See Fig. 3.15, Table 3.1 and 3.2)*

Runner	**Velocity (km/hr)**	**Stride frequency (times/min)**	**Velocity (km/hr)**	**Stride frequency (times/min)**	**Velocity (km/hr)**	**Stride frequency (times/min)**
A	12	171	14	177	16	183
B	12	174	14	178	16	182
C	12	182	14	188	16	194
D	12	176	14	181	16	187
E	12	177	14	180	16	186

Table 3.2 A comparison of the velocity and stride frequency of five distance runners

- **Movement comparison**

- Simulation - explore the effects of different ways of executing the skill
- Imitation - make adjustments with reference to high-level performance (See Table 3.1)

World Athletic Championship 1995 – Javelin	Different angles of the joint during the delivery phase in throwing a javelin		
	Hip joint	Elbow joint	Shoulder joint
Gold medallist	59°	170°	55°
Silver medallist	59°	147°	45°
Bronze medallist	70°	154°	59°

Table 3.1 A comparison of joint angles in javelin throw[1]

Assessment Form - Spiking (with the right hand)

Name: LEE Siu Fu (15) Class: Secondary 4B

Date 25/1

Pictures	Key Learning Points	Assessment (only of items marked with*)		
		Self assessment (understanding teaching demonstration)	Peer assessment (overall technical performance)	
	1. The number of approach strides depends on the distance of the ball from spiker.			
	2. Last two approaching strides: right leg steps out followed by left leg. 3. Pull arms back to increase the range of the swing.	2	2	*
	4. Jump: extend both legs and jump up with two arms swinging vigorously backwards and upwards.	2	1	*
	5. Swing the arm after jumping to get ready to hit the ball.			
	6. Arm swinging movement: - lift right arm with the hand above shoulder height	3	3	*
	- swing upwards to the front until the arm is cocked	2	2	*
	- hit the ball slightly in front at the highest point	2	2	*
	7. Hit the upper back of the ball with the whole palm and all fingers. Follow through by flicking the wrist.			
	8. Landing: bend knees, land on the balls of the feet, transfer weight to the full soles.			
Effect of hitting the ball	9. The ball lands within the opponent's court after crossing the net.	2	2	*

3 – Fully understood/achieved 2 – Not fully understood/achieved 1 – Not understood/achieved

Fig. 3.12 An example of a rating scale for skill assessment

Kicking takes place in the sagittal plane. It involves the hip, knee and ankle joints and comprises two phases:

The Preparatory Phase

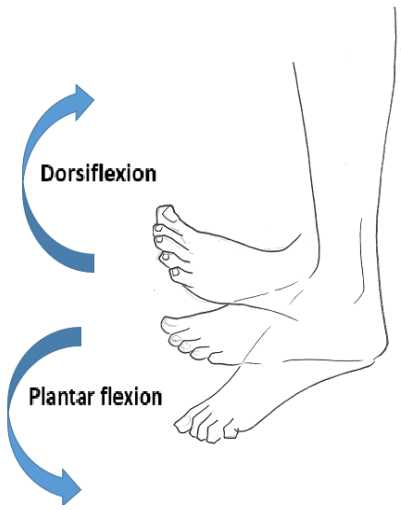
Joints involved	Action	Agonist (Major muscles)
Hip	Extension	Gluteal muscles (gluteus maximus and gluteus minimus)
Knee	Flexion	Hamstrings
Ankle	Plantar flexion*	Triceps Surae (Gastrocnemius and Soleus muscle)

The Kicking phase

Joints involved	Action	Agonist (Major muscles)
Hip	Flexion	Iliopsoas
Knee	Extension	Quadriceps group of muscles
Ankle	Plantar flexion*	Triceps Surae (Gastrocnemius and Soleus muscle)

Fig. 3.13 The joints and agonist muscles involved in kicking

* **Plantar flexion** describes the extension of the ankle so that the toes point down and away from the leg; **dorsiflexion** describes the flexion of the ankle so that the toes are brought closer to the shin.



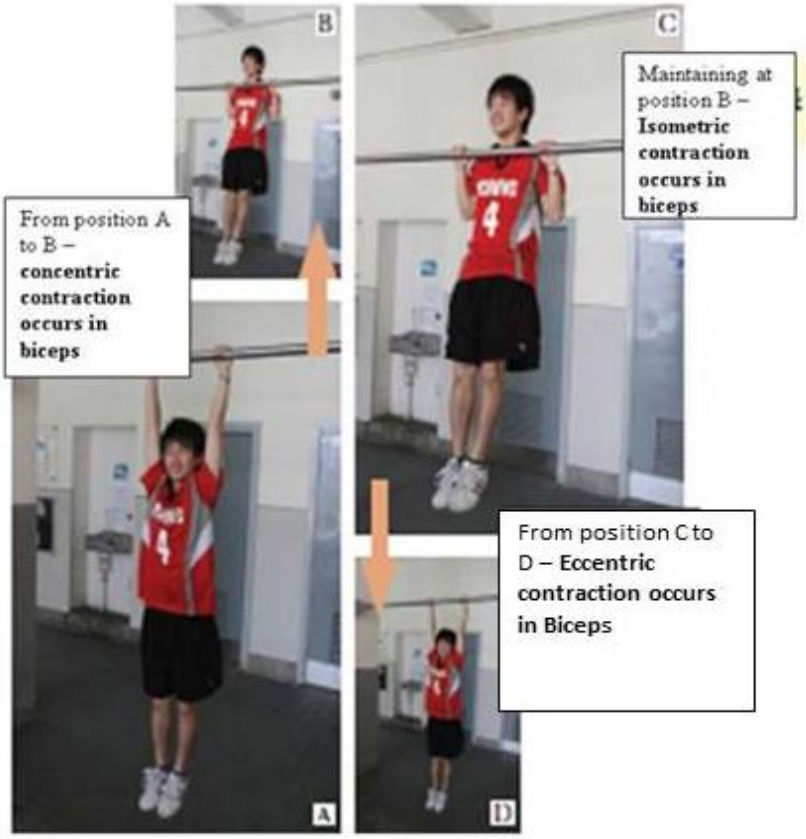


Fig. 3.14 Types of muscle contraction

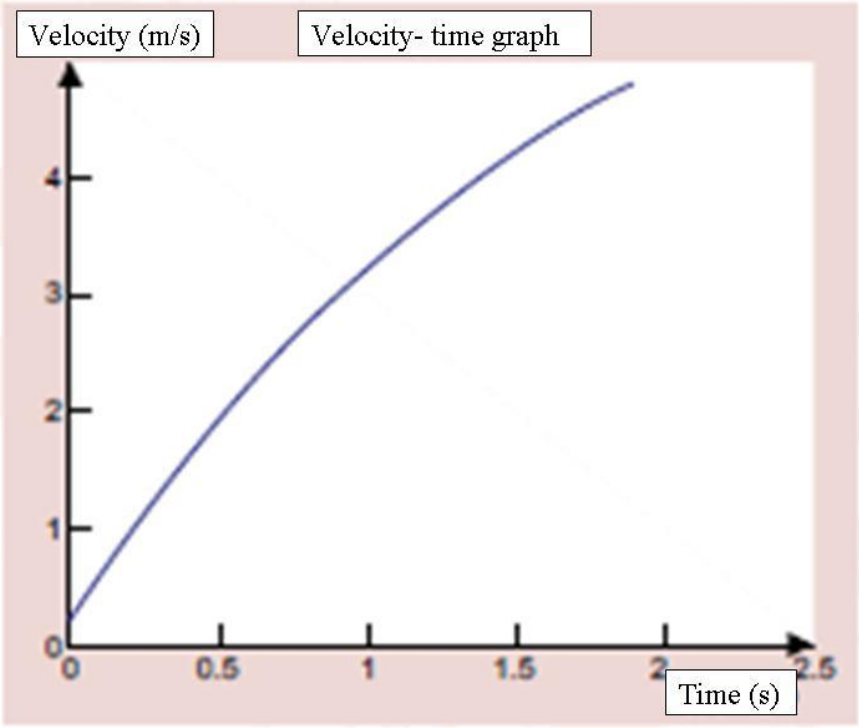


Fig. 3.15 Using computer software "Motion Video Analysis" to analyze the change of velocity

Hot Research Topics and forward-looking issues in Sports Biomechanics

With the continuous development of new advanced technology, the research in sports biomechanics continues to progress. Recent hot topics in sports biomechanics can be divided into:

Topics related to

1. motion analysis;
2. sports performance enhancement;
3. motion control related science;
4. rehabilitation;
5. instrumentation methods.

The forward-looking issues include special needs for people (aging, elite athletes, strength training); application practice (functional apparel, sports industry) and innovative technology (wearable technology), etc.

Examples of Enquiry Activities

Theme		Activities
1.	Forces and Movement	• Newton's Laws of Motion *(See additional information (1))* • Principles of Leverage (See additional information (2))
2.	Types of Movements	• Types of motion (See additional information (3)) • Weight Training (See additional information (4))
3.	Performance Analysis	• Centre of gravity (See additional information (5)) • Vertical jump (See additional information (6)) • Throwing (See additional information (7))

Examples of enquiry activities (Additional information) (1): Newton's Laws of Motion

Objective: To enable students to understand how the theories of Newton's Laws of Motion can be applied to movement analysis.

Implementation:

- In a classroom setting, students are divided into 15-20 groups and each group is assigned a specific sports skill for analysis.
- Members use Newton's Laws of Motion to analyse the assigned skill, and suggest some key points for improving performance.
- The teacher can assist and provide feedback whenever necessary to enhance students' analytical power.

The following examples are relevant:

Sports skill	Newton's law of motion	Explanation
Start or finish in sprinting	1st Law: The Law of Inertia	During the start or finish, the runner needs to overcome inertia. Therefore, he / she can only accelerate / decelerate gradually
Acceleration during running	2nd Law: The Law of Acceleration	If the mass and acceleration of the runner are known, we can find out the force required to produce the acceleration by using the formula F=ma.
Take-off in high jump	3rd Law: The Action and Reaction Law	A high-jumper exerts a force on the ground during a take-off. The ground then exerts an upward force upon the jumper to propel him / her over the bar.

Examples of enquiry activities (Additional information) (2): Leverage principles

Objective: To enable students to have a deeper understanding of the concept of leverage principles and to be able to put the theory into practice.

Implementation:

- Students are divided into groups of 5. Apparatus includes a baseball bat, 5 small balls (10cm in diameter; not fully inflated), a batting tee (1 meter in height) and a measuring tape.
- The first round of batting – Each student makes 5 consecutive hits with the middle part of the bat (the hitting form and force applied should be kept consistent across the 5 hits); and record the average distance that the ball travels.
- The second round of batting – It is the same as the first round, but the far end of the bat is used to hit the ball.

Examples of questions to be raised:

- Which type of lever does “baseball batting” demonstrate? Draw a diagram to show the “effort arm”, “fulcrum” and “load arm” of the movement.
- [Ask individual student] What are the average distances that the ball travelled when it was hit by the middle part and the far end of the bat respectively?
- Collect data of the whole group and compare the results of batting with the middle part and that of batting with the far end of a bat.
- What conclusions can be drawn from this experiment?

Examples of enquiry activities (Additional information) (3): Types of motion

Objective: To enable students to apply appropriate terms to illustrate the motion types and mechanical principles of sports skills.

Implementation:

- Ask students to collect some photos of various kinds of sports skills from the internet.
- The students develop presentation materials using the photos collected and discuss the motion types and mechanical principles involved in the skills.
- They present their findings in class.

Students may refer to the following format to describe the photos:

Event	Skill	Types of motion	Mechanical principles
Gymnastics	Swing on high bar	Angular motion	Moment of inertia

Examples of enquiry activities (Additional information) (4): Weight training

Objective: To deepen students' knowledge of muscle movements.

Implementation:

- Students are taught the correct techniques for lifting weights.
- They perform the muscle movements by lifting dumbbells with both the upper and lower limbs. Movements include flexion, extension, abduction, adduction, pronation, supination, etc.
- In pairs, students take turns to perform and observe. The observer will provide feedback to help the partner develop the correct techniques.
- The teacher should explain clearly to the students their roles and responsibilities in the learning process.
- The teacher should observe and provide timely feedback and guidance when necessary.
- The teacher should use more open-ended questions to encourage students to think.

Examples of enquiry activities (Additional information) (5): Centre of gravity

Objective: To help students gain a deeper understanding of centre of the gravity and master the skill of charting the changes.

Implementation:

- Students watch videos of 100-meter sprint, high jump, triple jump, dismount from a balance beam, “clean and jerk” weightlifting, 110-meter hurdle, etc.
- The teacher demonstrates the technique of using serial pictures (for example, by capturing pictures from a video clip) to show the changes in the centre of gravity.

Examples of enquiry activities (Additional information) (6): Vertical jump

Objective: To help students understand the relationship between biomechanical principles and sports performance.

Implementation:

- The teacher explains and demonstrates the proper technique for a vertical jump.
- Each student performs 2 vertical jumps, one with an arm swing and the other without (i.e. hands placed on the hips or the thighs throughout the jump).
- Students then evaluate their own performance and use biomechanical principles to explain the differences in outcomes. Results should be recorded.

Analysis of performance in vertical jumps

Procedure:

1. Perform a vertical jump with an arm swing and the other without an arm swing. What are the differences in your feelings?

_____

_____

2. Which technique produces a better performance (i.e. jump higher)? Can you explain why?

_____

3. Perform and evaluate the two jumps again. Try to find out the most efficient vertical jump technique by using the hints in the table:

Body parts	Key points (position and actions)		Discussion (using biomechanical principles)
	First jump (with arm swing)	Second jump (without arm swing)	
Arms			
Hips			
Knees			
Ankles			
Other			

Examples of enquiry activities (Additional information) (7): Throwing

Objective: To help students understand the relationship between actions and sports performance.

Implementation:

- In groups of three, a student throws a bean bag, another student measures the distance and the last one observes the movement of the thrower.
- Students compare and contrast the following five methods of throwing a bean bag:

1. Sitting with their back against a wall. Throwing with an arm only.
2. Sitting on the ground. Throwing with an arm and rotating the shoulders.
3. Standing. Throwing with an arm, turning the hips and rotating the shoulders. The feet must stay in contact with the ground and must not twist.
4. Standing. Throwing with an arm, turning the hips and rotating the shoulders. Throwing with one foot placed forward.
5. Standing. Throwing with an arm, turning the hips and rotating the shoulders. Throwing by taking a run-up and using a side-on position.

- Results should be recorded in the chart below. Ask the students why there are differences between the results.

	Method 1	**Method 2**	**Method 3**	**Method 4**	**Method 5**
Distance					
How does the body feel					
Discussion					

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