ATHLETICS OMNIBUS – ENHANCE PERFORMANCE AND REDUCE INJURY RISK

From the Athletics Omnibus of Richard Stander, South Africa

1. INTRODUCTION

Bio-mechanics is a branch of physics which deals with the inner-relations of moving the body by means of the push or pull of muscles. Knowledge of the mechanics of athletics is important to the prevention and treatment of injury, as well as the improvement of human movement and performance.

Bio-mechanics study the functions of the more than 300 muscles in the body that move and/or support the body's more than 200 bones with a high degree of precision and control.

The effectiveness of an athlete's technique is normally determined by the strengths, weaknesses, fitness level and flexibility level of the athlete. By applying bio-mechanical principles, it is possible to analyse the technique of the athlete (human movement), and create more effective techniques.

Many factors influence performance. The relationship between bio-mechanics and performance is far from straightforward e.g. the running speed of an athlete can be improved by increasing both the frequency of leg movement and stride length; however over-striding will lead to decreased running speed and an increased injury risk.

The value of bio-mechanics is much more useful in the prevention of injuries than in improving performance e.g. running on hard surfaces will allow the athlete to run faster. However, injuries are less likely if running takes place on soft surfaces.

Generally, athletes that apply bio-mechanical principles will perform better than their counterparts that do not apply bio-mechanical principles. Athletes applying bio-mechanical principles have much less disruption in their training programs because they have the advantage of more injury free training time.

All athletes have the same time to prepare for a major event. The athlete with the least amount of injuries or disruptions during the period of preparation will have the most quality time to prepare and improve on their level of excellence.

2. TERMINOLOGY

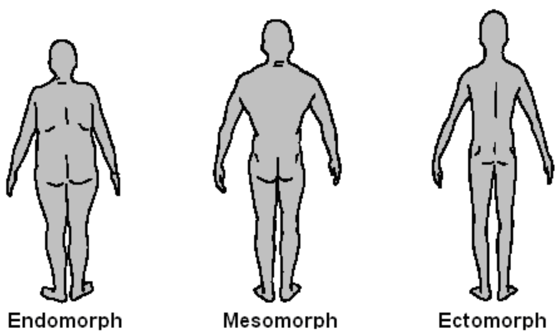
The following terms are frequently used in bio-mechanics:

2.1. LOAD

In bio-mechanics, the body mass is referred to as load.

If an object is picked up, the load will be that of the body plus the object been picked up. The body weight place a load on the bone and muscle structures. If no load is applied, the body will stand still (inertia).

To move the body load, force needs to be applied. A lighter body load requires less applied force to be moved and a stronger body will be able to move the body load faster.



THE THREE BASIC PHYSIQUE TYPES

The secret of success is for the body to become stronger without the body gaining weight.

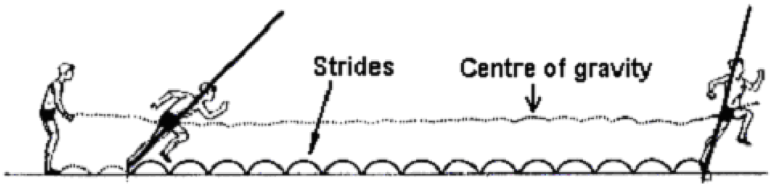
2.2. FORCE (MOTIVE FORCE)

Force = Mass x Acceleration. Force is the strength of the muscle push or pull required to move the body mass (load). As long as the force applied on the muscle is equal to the load of the body, the body will not move and will be in equilibrium (state of rest).

The force applied by the muscles must be bigger than the body mass (load) for the body to move. Strengthening the muscles will enable the body to apply a larger force on the bones.

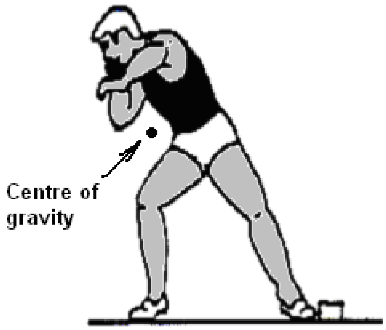
The more force muscles apply on the bones, the faster the movement of the limbs will be.

The long jump run-up clearly demonstrates how the body angle change in accordance with the force applied. The body angle will change to accommodate the force applied.



The key factor is how much strength training can be applied on the muscle in an attempt to develop force before an injury will occur in the form of a torn muscle or a broken bone.

2.2.1. Static force is a force that does not produce motion (The 'set' position in the 100m start).
2.2.2. Centrifugal force is the force pulling outwards during rotation (The discus pulling in the hand during rotation).
2.2.3. Centripetal force is the force pulling inwards during rotation. (The force pulling in the shoulder while delivering a discus).
2.2.4. Eccentric force is an off-centre force. The centre of gravity in the human body is more or less situated at the navel. Delivering a shot needs an eccentric force to deliver the shot, as the shot is held next to the shoulder while delivering the shot. Eccentric force requires more muscle strength than force executed in line with the centre of gravity. In the sketch it can be seen that the shot is not in line (above) with the centre of gravity. The key-factor is to reduce movement away from the centre of gravity by either bringing the source that requires the applied force e.g. the shot, closer to the body to avoid muscle injury.



2.2.5. Internal forces will be the force that is applied by the muscles on the bones in the limbs.
2.2.6. External forces will be the force acting outside the body such as the gravity of the earth and friction between bodies such as the feet and the ground.

2.3. INERTIA

Inertia is the body's resistance to change position (Newton's 1st law – Law of inertia). If no force is applied on the body, the body will not move.

2.3.1. **Moment of inertia = mass x radius squared**. Moment of inertia, normally a very short period of time, is the moment the body is standing still or in a state of rest e.g. in pole vault, the trajectory of the body will follow an upwards and downwards motion. At the point where upwards motion change to downwards motion, a moment of inertia will exist.

2.4. WORK

Work is force x distance in the direction of force e.g. the amount of time the push or pull of the muscles is required to move the body over a 1500m x the 1500m = work required.

The key factor is to develop the capacity of the body to operate at a work rate of e.g. 110% during training. The athlete will then be able to operate at 91% (100% ÷ 110%) during competition to achieve success, with less injury risk to the body.

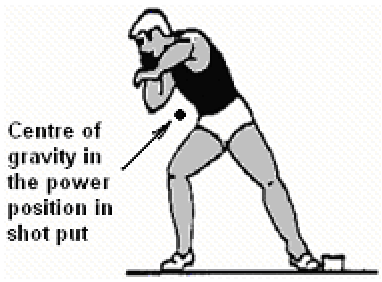
If an 800m athlete wants to run 60 seconds per 400m lap in competition, the training repetitions should be at 54.6 seconds. Training at repletion times of 54.6 seconds will enable the athlete run at 91% capacity and run a time of 60 seconds in per 400m lap.

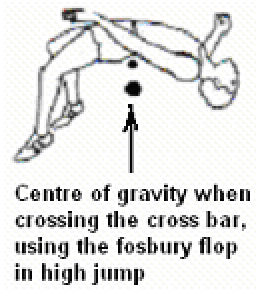
Mechanical work = product of weight lifted x distance lifted

2.5. GRAVITY

Gravity is a force that is always present. It is the magnetic force of the earth which pulls objects vertically downwards to the centre of the earth.

2.5.1. Centre of gravity is the point in a body where force acts through. A solid body like the shot or discus will have a fixed centre of gravity but in the human body the centre of gravity will be determined by the position of the body.





2.6. TORQUE

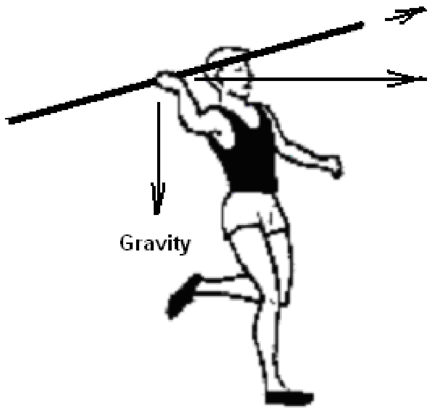
Torque is the force causing an object to rotate x length of lever arm e.g. a longer arm requires more force to deliver a javelin than a shorter arm.

Key factor – If sufficient force can be exerted on a longer arm, the longer arm is likely to generate more torque e.g. a longer arm will throw a javelin further than a short arm because more torque can be applied on the javelin during the process of delivery.

2.6.1. External unbalanced torque must be applied to create angular velocity.

Newton's 1st law – A body will remain at rest, or motion will be in a uniform straight line, until an external force is applied to change its direction is relevant.

To deliver a javelin, an upward and forward movement of the arm is required. The arm holding the javelin will have to exceed the force required to move the javelin forward as well as to overcome the downward force of gravity, before a javelin will be able to travel in a temporary upwards trajectory after delivery.



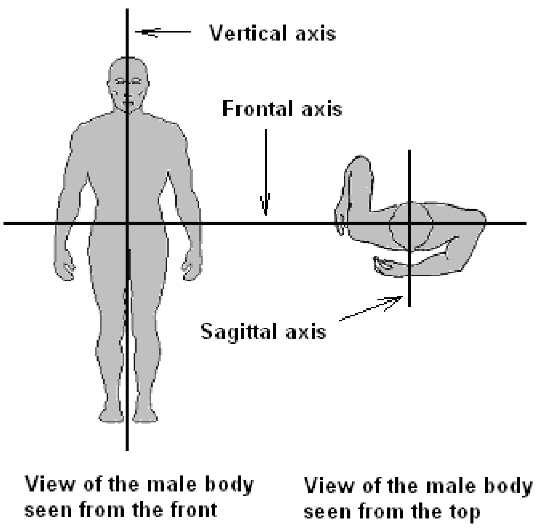
2.7. AXIS

An axis is a straight line about which a body rotates.

2.7.1. Vertical axis of the body passes through body from top to bottom when standing in the upright position.

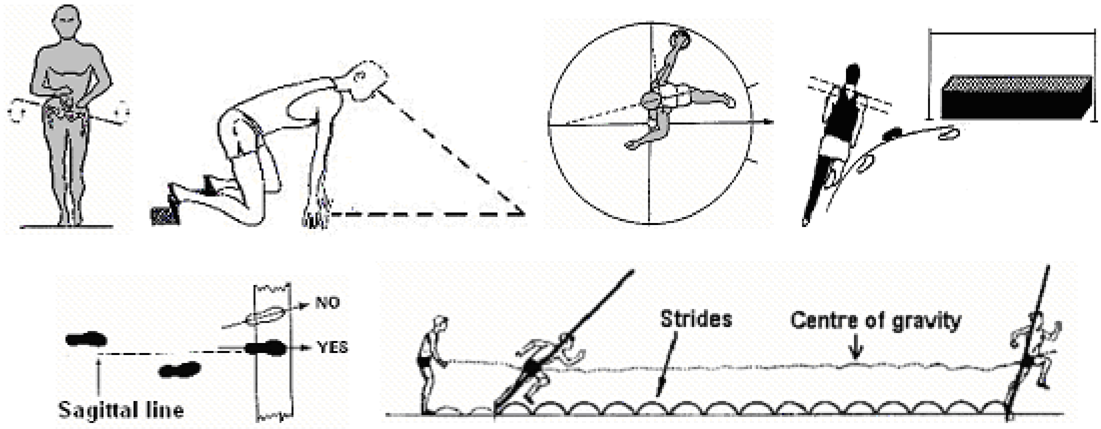
2.7.2. Sagittal (also called anteroposterior) axis of the body is an axis parallel to the ground which passes through the body from front to back. Key factor – The sprinter will move from start to finish as fast as possible without changing the distance of the sagittal axis from the ground (Moving up and down).

2.7.3. Frontal axis of the body is the axis parallel to the ground passing through the body from side to side e.g. the shortest distance between 2 points is a straight line. Key factor – The sprinter will move from start to finish as fast as possible without changing the distance of the frontal axis from the sagittal axis (Moving side to side).



2.7.4. Horizontal (also called transverse) axis is an axis which is parallel to the ground and can be sagittal or frontal.

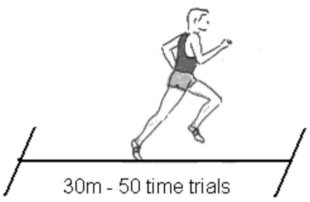
The sketches below show how the 3 axis's is applied in bio-mechanics:



2.8. ACCELERATION

When the body is moving, the speed that it is moving, and the time it takes to move from one point to the next point defines acceleration. Acceleration is the rate of change of velocity.

Acceleration of the body is in proportion with the force applied by the muscles in the body. More force will ensure greater acceleration.



2.8.1. Angular acceleration is the rate of change of angular velocity e.g the angular acceleration of a high jumper crossing the cross bar.

2.8.2. Positive acceleration means the velocity increases faster and faster e.g. a sprinter running the 1st 100m of a 400m sprint.

2.8.3. Negative acceleration is velocity decelerating (slowing down) e.g. a sprinter running the last 100m of a 400m sprint and exhaustion is resulting in a reduced muscle force.

2.8.4. An object free falling downwards accelerates at 9.8m/sec. e.g. to deliver a javelin, the force applied must be more than the body mass, the mass of the javelin and gravity force.

After delivery of the javelin in an upwards direction, gravity will continuously pull the javelin back to earth at a rate of 9.8m/sec. The point of return will be when the combined force of the body the javelin and gravity are reduced to a force less than the force of gravity (9.8m/sec).

The trajectory of the javelin will consist of positive acceleration (going up), a moment of inertia (changing direction) and negative acceleration (going down).

Key factor – The bigger the eccentric force applied during the delivery of the javelin, the longer negative acceleration will be delayed. (The javelin will travel further before returning to the ground).

2.9. SPEED

Speed is the rate of change of a position. For a sprinter speed will mean the stride length x stride frequency. For a jumper speed will mean the speed during take-off. For a thrower the speed will mean the speed during delivery of the implement.

2.10. VELOCITY

Once the force applied on the body (muscle contraction), is bigger than the load (body mass), the body will start moving (positive acceleration). The speed per second that the body change position in a given direction = velocity. If a sprinter covers 100m in 10 seconds the velocity of the athlete will be 100 ÷ 10 = 10m/s.

2.10.1. Optimal velocity is sometimes called maximum velocity
2.10.2. Angular velocity is the angle through which the body turns per second e.g. during the period of time that the jumper travels through air after take off.

2.11. MOTION

Motion is the continuous change of position. As long as force is applied, motion will take place e.g. as long as the athlete is running motion takes place.

2.11.1. Linear motion is movement in a straight line from one point to another e.g. a sprinter from start to finish.
2.11.2. Rotational motion is movement around an axis of rotation e.g. the arms and legs of a sprinter is moving in circular movements while moving forward.
2.11.3. General motion is a combination of linear motion and rotational motion e.g. In the 100m, the body of the sprinter is moving forward in a straight line but the arms and legs is moving in a circular motion. In discus the thrower moves from the back of the circle to the front of the circle while the body is turning around in circles in an attempt to gain maximum speed of the discus prior to delivery.
2.11.4. Uniform motion is steady, constant motion with unchanged speed e.g a 10000m athlete will try to run economically in an attempt to maintain the pace of running (uniform motion) as long as possible.

2.12. MOMENTUM

Momentum is the quantity of motion of a moving body. Momentum = mass x velocity

2.12.1. Angular momentum is the moment of inertia x angular velocity

2.13. FRICTION

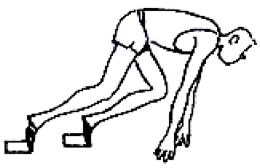
The level of smoothness of two surfaces making contact will determine the level of friction. The smoother the surfaces, the more likely a gliding (slip) motion will appear when force is applied at an angle.

A sprinter has to accelerate as fast as possible. To do this force has to be applied through the feet onto the ground in a running action to ensure forward movement. Fast acceleration may cause the feet to slip on the ground. To avoid slipping the friction between the feet and ground is increased. This is done by wearing spikes in the running shoes to create as much friction as possible between the surfaces of the track and the running shoes.

2.14. EQUILIBRIUM

Equilibrium is another word for balance. When the resultant of all forces acting on a body are zero (neutralizing each other), the body is in equilibrium.

A body at rest is in equilibrium. The sprinter in the set position is in equilibrium. When you lie still on a bed, the body is in equilibrium. The force of the body pressing against the bed and the force of the bed pushing back are equal, resulting in the body lying still. (Newton's 3rd law: Law of reaction - For every action there is an equal and opposite reaction).



2.15. ENERGY

Energy is the capacity to do work. There are 2 types of energy:

2.15.1. Potential energy – When the body is standing still (equilibrium) no energy is used, but the potential for it to move is always there.
2.15.2. Kinetic energy is created when the forces applied on the body causes the body to move. The force applied to stop the body will equal the energy used to move. The more force is applied, the faster the body will move and the more kinetic energy the body will have.

Injuries occur when kinetic energy is transferred to potential energy to quickly e.g. when the body come to a standstill due to external forces such as in a car accident, or the pull on the muscle is to big for the muscle to handle and the muscle will tear. It is important that once kinetic energy is created and the result is a fast moving object, the slowing down process must be within the capacity of the muscles that causes the deceleration process towards potential energy.

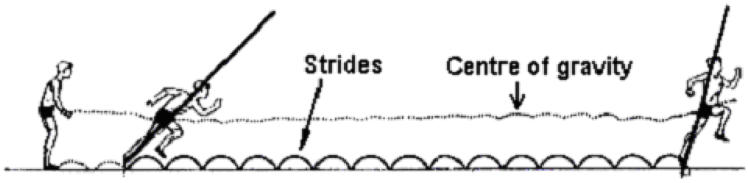
2.16. NEWTON'S 1ST LAW - (Law of inertia)

All bodies continue in a state of rest or uniform motion in a straight line unless acted upon by some external force. We know that the natural tendency of the body is to remain in a state of rest. We need to increase the driving force of the body to overcome this state of rest.

We also know that the motion of the body will be in a straight line only. If speed must be applied in sprinting events that is not in a straight line e.g. 200m, throwing or jumping events, the development of the driving force of an athlete must be done in such a way that the muscles can change the direction of motion in the desired direction.

The sketch below illustrates the run-up for long jump. It can be clearly seen that the body is first in a state of inertia.

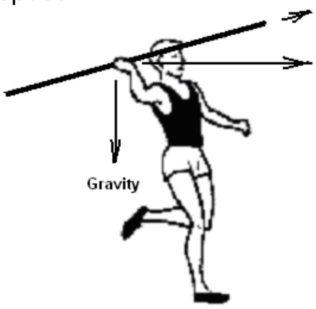
When force is applied to accelerate, the body angle will change. During the run-up the centre of gravity will vary



2.17. NEWTON'S 2ND LAW - (Law of acceleration)

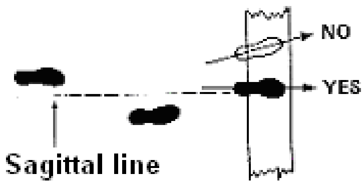
The acceleration of a body is proportional to the force causing it and takes place in the direction the force acts.

We know that acceleration is proportional to the driving force applied. It is therefore important to limit weight gain and increase speed.



We also know that acceleration takes only place in the direction the driving force is applied.

It is therefore important that the muscles utilized to accelerate in a specific direction must enjoy more attention than other muscles of the body.

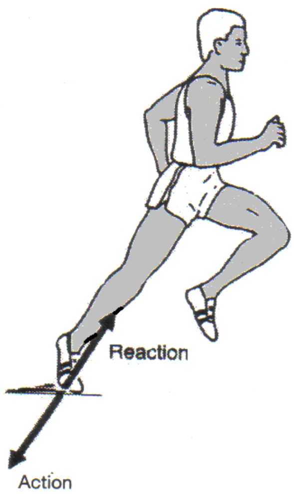


2.18. NEWTON'S 3RD LAW - (Law of reaction)

To every action there is an equal and opposite reaction. We know that if the athlete wants to apply speed in a forward direction, the driving force must be diagonally backwards.

The most visible where Newton's 3rd law is applied is the end of the body (head, hands and feet). The direction of movement of the entire body is reflected in the movement of the end of the body (head, hands and feet).

If the intention is to run forward e.g. in a 100m race the head, hands and feet must move as close as possible, parallel to the ground, and in a straight line in the direction of the finish line. Remember, the shortest distance between 2 points e.g. start and finish, is a straight line.



2.19. LEVER

A lever is a rigid rod which can rotate around a fixed point. A lever is used effectively when a fulcrum, resistance and force is used.

- FULCRUM (F) is the fixed point that the lever rotates around – The joints in the skeleton acts as fulcrums (pivot point)
- RESISTANCE (R) is the term used for the reluctance of an objective to move – The smoothness of the running surface, the weight of the implement to be picked up and the earth's inertia are some of the factors that have an influence on the reluctance of the body to move.
- MOTIVE FORCE (MF) is the term used for the strength of the push or pull on the lever. The muscles in the body provide the push or pull force.

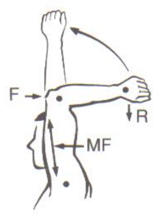
There are 3 types of levers.

2.19.1. 1ST CLASS LEVER

In this type of lever the fulcrum is placed between the resistance and the motive force.

These are the most versatile of the levers but the weakest.

The bending and straightening of the arm at the elbow is a classic example of a first class lever in use.

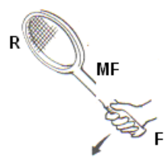


The diagram below demonstrates how a 1st class lever operates:

Motive Force Upper Arm muscle contracts		**Resistance** The fore arm straightens when the bicep muscle in the upper arm contracts
	^ Elbow **Fulcrum**	

2.19.2. 2ND CLASS LEVER

In this type of lever the motive force is applied between the resistance and the fulcrum. The flexing of the wrist when hitting the tennis ball with a tennis racquet is an example.



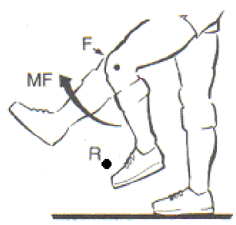
The 2nd type of lever is not used in athletics.

The diagram below demonstrates how a 2nd class lever operates:

	Motive Force Tennis racquet	**Resistance** Tennis ball
^ Wrist **Fulcrum**		

2.19.3. 3RD CLASS LEVER

The 3rd class levers are the most common in the human body. The bending of the leg at the knee is a classic example of a 3rd class lever in action. The motive force arm is the distance of the motive force from the fulcrum (distance between hip and knee).



The resistance arm is the distance from the hip to the foot.

The resistance arm is always longer than the motive force arm. For the leg to move the motive force (upper leg) must be bigger than the resistance (upper and lower leg).

Due to the length of the resistance arm, the third class lever is not good in producing force but is good in producing speed.

The diagram below demonstrates how a 3rd class lever operates:

	Motive Force Upper leg (Distance from hip to knee)		**Resistance** Lower leg and foot (Distance from hip to foot)
^ Hip **Fulcrum**		■ Knee	

3. APPLYING THE PRINCIPLES OF BIO-MECHANICS

Explaining the terminology and principles used in bio-mechanics separately was an attempt to make the terminology and principles easier to understand.

In bio-mechanics we try to understand the internal and external forces acting on the human body and the effects produced by these bodies. Movement is needed to participate in athletics. The bio-mechanical principles often operate together to ensure movement.

3.1. MOTION

A sprinter will apply both linear and rotational motion. While the 100m sprinter is moving in a straight line from the starting line to the finish line, the body will move in a straight line while the arms and legs will move in a circular motion.

3.2. VELOCITY

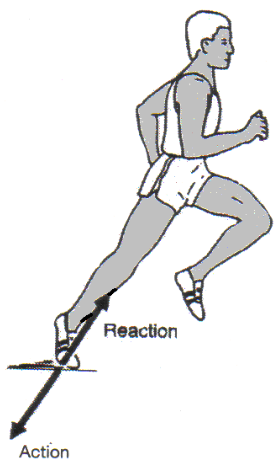
While the 100m sprinter attempt to travel from the starting to finish to the finish line as fast as possible, the velocity of the athlete will tell us how fast the athlete moved and in what direction. However the velocity was not constant from start to finish.

At the starting line the velocity of the athlete was zero m/s. After the start, the athlete will accelerate by attempting to overcome the affect of gravity, friction and body mass (Load) by applying internal forces through the muscles on the bones, and external forces by the feet using friction on the ground. Positive acceleration will take place up to the point maximum velocity is reached.

For a brief period of time after reaching optimal (maximum) velocity, motion will be uniform (steady) until the body will start to feel the affects of exhaustion as a result of the external forces such as gravity, friction and body mass applied on the human body. As exhaustion takes affect a period of deceleration will take place until the athlete cross the finish line, come to a standstill as a result of exhaustion or an injury.

3.3. MOMENTUM

Momentum is the quantity of motion a body has, and is a product of weight and velocity. While the 100m sprinter is in motion the general momentum of all body parts will be forward.

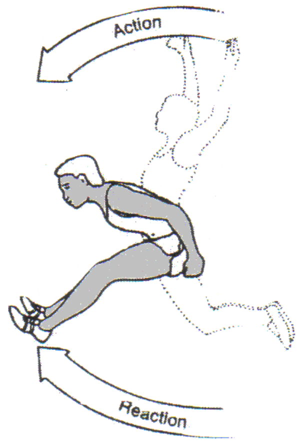


Independently, the body parts will work against its other in an attempt to apply Newton's 3rd law (Law of reaction) - To every action there is an equal and opposite reaction.

The arms create equal and opposite forces for the alternating feet touching the ground creating friction between the 2 surfaces (feet and ground) in an attempt to move forward.

While the left arm of the sprinter moves forward, the right arm is moving backwards in an attempt to reduce the moment of inertia. As the moment of inertia in the arms becomes less, the body will accelerate.

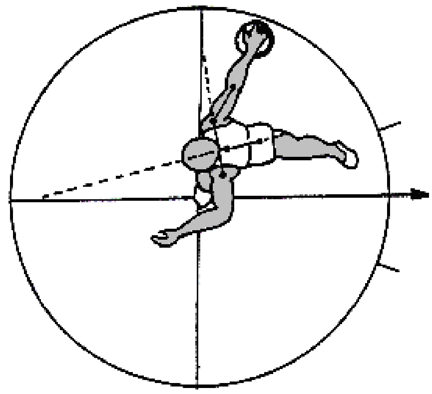
In long jump for example, an attempt will be made to lengthen the moment of inertia. The increase of the moment of inertia will slow down the forward rotation of the upper body.



This is achieved when Newton's 3rd law (Law of reaction) is applied in mid flight during the flight phase prior to landing.

The arms will be forced down while the feet will lift up to allow for a landing flight period. Once the downward motion of the arms and the upwards movement of the legs is completed, the feet will reach a state of inertia, and is waiting for the landing to take place.

Angular momentum can be transferred from one body part to another

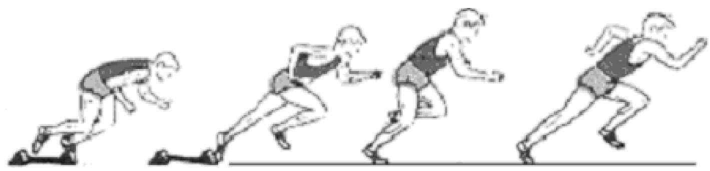


In throwing, Newton's 3rd law (Law of reaction) is applied to transfer angular movement from one body part to another.

A right hand thrower will "block the left side of the body immediately before delivery in an attempt to transfer angular momentum of the body to linear movement of the discus.

While the left side of the body is "blocked" (state of inertia), the right hand arm will accelerate to prepare for the final delivery of the discus.

Keeping in mind that every body part acts as a 3rd class lever, it is important to:



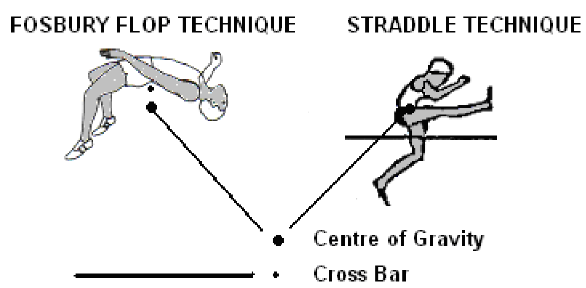
3.3.1. Use all joints that can be used in the body to produce maximum effect and speed e.g. when an athlete run, it is important that the driving leg is fully flexed before the foot start to drive to ensure a longer stride length.

3.3.2. To use every joint in the correct order to avoid the limbs to operate in conflict with each other. Movement should begin with the big muscle groups, followed by the smaller muscles to produce optimal force and continuous movement e.g. the muscles in the driving leg must first flex the muscles in the upper leg and lower leg before the ankle muscles is flexed with the toe muscles completing the final flexing.

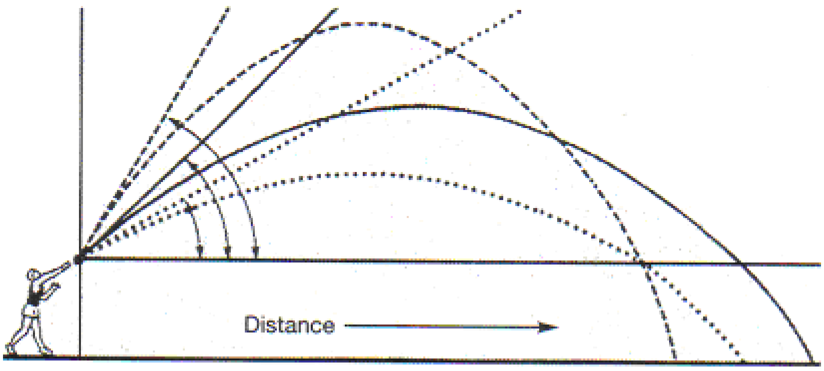
3.4. CENTRE OF GRAVITY

When standing in the upright position the centre of gravity in the body will be around the navel area. Depending on the position of the body, the centre of gravity can also be outside the body e.g. when the high jumper clears the bar. In the sketch below, the fosbury flop technique and the straddle technique is demonstrated.

The position of the cross bar and the centre of gravity is indicated. From the sketch, it can be clearly established that the athlete clears the bar much higher using the fosbury flop. With the centre of gravity outside the body at the point when the athlete crosses the bar enables the athlete to cross the bar at a much higher height using the fosbury flop technique.



The velocity of the body when running, and the force used when jumping or delivering an implement, will also determine the position of the centre of gravity. In javelin for instance, the centre of gravity will follow a parabolic flight path when delivered at an angle at a specific speed. The delivery angle and the speed of delivery will have a direct impact on the parabolic flight path of the javelin.



The parabolic flight path for various release angles

The parabolic flight path of the centre of gravity of the body or implement will depend on the following 3 factors:

3.4.1. The speed of take off of a jumper or the release of the implement
3.4.2. The angle of take off of a jumper or the release of the implement
3.4.3. The height of the athlete's centre of gravity at take off or the implement at release.

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