Exercise & Sports Biomechanics

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Week 06
Lecture 29

Fundamentals of Mechanics

[We will be discussing Newton's laws of motion].

Newton's laws of motion:

Sir Isaac Newton formulated three fundamental laws of motion, and since then, the world has had a different perspective on mechanical analysis. These laws describe the relationship between a body and the forces acting upon it. They are the foundation of classical mechanics, and they were first published in the book Philosophiæ Naturalis Principia Mathematica in the year 1687.

As we all know, there are three main laws given by Newton: the first law of motion, the second law of motion, and the third law of motion.

The first law is also called the **law of inertia**. The second law is known as the **law of acceleration**, and the third law is well known as the **law of action and reaction** or the law of counter force.

Before starting with Newton's first law, have you ever thought about why a jumper, a long jumper, or a triple jumper runs before taking off? Why does a shot putter, a discus thrower, or a hammer thrower turn before throwing their object? Why does a javelin thrower run before throwing the javelin? Obviously, momentum is there. But apart from that, one more basic thing is there.

Have you ever thought about why court games or ball games usually have a warm-up before they start the game?

We already studied inertia in the previous section as the characteristic of a body to remain at rest or in uniform motion. And in that section, we also discussed that inertia depends on mass. So, whatever the object, it could be the player themselves or the object that they are playing with. They basically have inertia, and in order to break the inertia, they need to apply the external force. And they are doing that thing only.

Newton's first law of motion:

The first law of motion or the law of inertia, states that everybody continues to be in a state of rest or uniform motion unless disturbed by an external force. Newton's law of motion explains the impact of forces on the state of motion of an object. Newton's first law is also known as the law of inertia.

This law shows that all objects have a tendency to maintain their original state of motion, and external force is necessary for causing a change in speed, direction, or state of motion.

The resistance to this external force is called inertia. And we know that as that inertia depends on the mass. The heavier the mass of an object, the heavier the inertia or the lighter the mass, the less inertia the object has, or the less force is needed to disturb the inertia of the particular object.

Let us explore some of the examples. So, the first example here, which I will be explaining, is basically the passengers swinging in the turning bus. Whenever a bus turns sharply, we can feel ourselves moving in the opposite direction. This is in accordance with Newton's first law, which states that a body moving in a straight line continues to move in a straight line unless acted upon by an external force. So, your body is trying to move in the original direction, but the force of the bus is moving you in the other direction. This is called the **inertia of direction**.

In the second example, you see a rock at rest. So, a rock that is lying on the ground will continue to do so for thousands of years unless it is pushed by nature or by some force. It will not be floating around in different places. An astronaut moving continuously in space. So, in outer space, there is no force of gravity. So, an object in motion continues to be in motion because there is no external force to stop its motion. Astronauts are able to fly due to this reason, which is in accordance with Newton's first law.

In another example, you can see the skidding of roads while taking a turn. So, while taking a turn, we are deviating from a straight-line path. This causes the inertia of direction. Our body continues to move in a straight line, but the vehicle tries to turn. This causes the vehicle to be caught in a situation in which the vehicle skids.

The centripetal force is very vital for turning. A centripetal force is an example of an external force that, according to Newton's first law of motion, causes a change in direction. The centripetal force can be provided by the banking of the road or increasing the frictional force.

In another example, you can see the sudden application of brakes in the vehicle. So, when we apply brakes to the vehicle or the sudden application of brakes, it brings the passenger a bit forward. It is just because, in accordance with Newton's first law. A marathon runner is unable to stop after the finish line. A marathon is a competition in which the runner runs for a very long distance.

When they approach the finish line, they do not stop immediately. They continue to run for a short distance to continue with the inertia of motion. Since their body was in motion, it was very difficult to bring them to rest for a moment. A cycle moves even after pedalling stops. So, a cycle is able to move only when we pedal using the muscular force of our legs. But when you stop pedaling, while we are in motion, the cycle moves on its own without any application of force.

This is an example of inertia of motion. According to Newton's first law, a body in motion continues to move unless stopped by an external force. After some time, the motion of the cycle stops. When we see a game of cricket, we can observe that if the ball is hit by a bat, the muscular force is transferred to the ball via the bat, which changes the direction and speed of the ball's motion. Before we start to walk or take a step, we are ideally in a state of rest, so an external force is required for our motion. According to Newton's first law, the external forces that act here are our muscular forces and the frictional forces. While we walk, we push the ground with the help of friction and get a motion in the forward direction. A rolling ball coming to a stop. So, a rolling ball should roll forever according to Newton's first law of motion, but the external force here, which is the force of rolling friction, stops it from rolling forever. In the second example, you see jumping on a trampoline.

So, when we jump on the trampoline, we are thrown skywards, but eventually, we do come down. This is due to the force of gravity, which acts as an external force to bring us back. In this example of Newton's first law, the gravitational force acts as an external force. The rocket has to escape the gravitational force of the Earth in order to enter outer space.

So, in outer space, there is no force acting on the rocket, so it can move unhindered, but to escape the Earth's gravitational pull, it moves at a very high speed called the escape velocity. These are a few examples of Newton's first law. I hope it is clear to everyone now. Let us move to Newton's second law of motion.

[But before moving to the second law, we need to do some revision or recap].

From the previous section, you now know what mass is, and mass is measured in kilograms. Velocity is nothing but displacement divided by time (velocity = displacement/time), and the unit is meters per second (m/s). Force is definitely the push-and-pull effect. Acceleration is the rate of change of velocity, where the final velocity minus initial velocity is divided by time, and we express that in meters per second squared.

$a = v_f – v_i / t$

Impulse is nothing but force multiplied by time, and the unit for impulse is Newton seconds. Impulse = F * T (force x time), unit = Ns

So, this was the thing that we would be using to describe Newton's second law of motion in a simpler way.

Newton's second law of motion:

The law says that the rate of change of momentum of a body is directly proportional to the force applied, and the change takes place in the direction in which the force is being applied. So, you can see there are two parts of the law:

The first statement says that the rate of change of momentum of a body is proportional to the force applied. So, whenever we talk about the change of momentum, we are talking about the two momentums: the final momentum and the initial momentum. Momentum is directly proportional to the force being applied. And we all know that momentum is nothing but mass times velocity. And if we are talking about the rate of change of momentum, it means we are talking in terms of time. So, we can write this expression as

force $\propto$ change of momentum/time.

And the change of momentum means we are talking about the final momentum minus the initial momentum. So, we can definitely write this expression as $F= mv_f – mv_i/t$. The term states that the rate of change of momentum of a body is proportional to the force applied, and the changes take place in the direction in which the force is being applied. You can see there are two parts of the statement. The first part says that the rate of change of momentum of a body is proportional to the force being applied. So, I can write this expression as this: the rate of change of momentum of a body is proportional to the force applied, and the changes take place in the direction in which the force is being applied.

So, you can see there are two parts to the statement. The first part says that the rate of change of momentum of a body is proportional to the force applied. You can see something like this. And we all know that momentum is nothing but mass times velocity. Now we are talking about the rate of change of momentum.

So, it means we are talking in terms of time. The change of momentum with respect to time. And we all know that if you are talking about the change of momentum, it means there are two momenta. One is the final momentum, and definitely, the other one is the initial momentum. So, we can write this expression as $F = mv_f – mv_i/t$

where MV_f is nothing but the final momentum, and MV_i is the initial momentum.

So, this is the first part of the equation, and this equation says that the change in momentum is directly proportional to the force being applied. It can simply be expressed with this particular picture. You can see that the momentum of this particular box is being changed towards the direction where the force is being applied. Or we can understand this with this particular illustration, in which the force of the bat is being applied to a particular ball.

The direction in which the force is applied will cause the ball to move in that particular direction. If the force applied is more, the ball is low, then the change of momentum or the ball travels a lesser distance. If the application of force is going in the right direction, the ball will definitely travel in the right direction. If it is in the left direction, the ball will definitely travel in the left direction. So, again, coming to the statement that we got the change of momentum of a body, or the rate of change of momentum of a body, is proportional to the force applied.

The second aspect is the change of momentum, which is expressed in the direction in which the force is being applied. So, we all know this equation now, which is nothing but

$F = mv_f – mv_i/t.$

Where MV_f is nothing but the final momentum, MV_i is nothing but the initial momentum, and T is the time. So, in this particular situation, we can take out M as a common factor because M is constant, whether it is final or initial. And we can take Vf minus Vi divided by T as a separate thing. And we know that V_f minus V_i is nothing but the rate of change of velocity. And we know that this is nothing but the acceleration. And we can denote the whole value as A. So, if I replace V_f minus V_i divided by T with A, the equation will come here as F equals MA,

$F = mv_f – mv_i/t.$

$F= m\ (v_f – v_i)/t \qquad \therefore v_f – v_i\ /t = a$

$\therefore F = ma$

and that is the exact equation of Newton's second law, which says that force equals mass times acceleration. And we can state that, for a constant mass, the force applied to the body is directly proportional to the acceleration of the object. In order to increase the acceleration, a sprinter or swimmer must increase their force because the mass is constant.

You can see this illustration in order to get it more clear. Let us look at some of the examples. So, when we press the accelerator in our car, we definitely apply more force. So, the speed increases. The accelerator controls the flow of fuel to the combustion chamber in the engine.

So, when we press the accelerator, more fuel goes into the engine, which gives more power. Hence, the acceleration is higher. On the other hand, when we have a truck and bicycles, together, and if they are moving at the same acceleration force of the bicycle. So, if an object were to come in the way of a bicycle, it may not be damaged much in comparison to a collision with the truck because the truck has a heavier mass.

It has directions. So, if a cricketer or a baseball player strikes a ball in a particular direction, then the ball moves in the specific direction with the force provided. It is very easy to lift an empty bag compared to a heavy bag. The mass increases the force required to lift up the bag. The weight of the aircraft is a very crucial factor.

It is designed to carry only a specific load. So, above the limit, it cannot generate the lift or the takeoff. That is why we are very particular about the weight that we carry on the aircraft. The tension in the rope is also a type of force. So, all types of force follow Newton's second law of motion.

In an elevator, a strong cable is used to lift the elevator cabin. The person limit and the speed of the elevators are calculated based on Newton's second law. Newton's second law only. Which we encounter every day. So, every object on planet Earth experiences a force of gravity pulling it towards the center of the Earth.

This force is equal to the mass of the object multiplied by the acceleration due to gravity. But we feel weightless in outer space due to the lack of gravity. For the simulation during the design of prosthetic limbs and arms. When the rocket is launched into outer space, it has to overcome the gravitational pull of the Earth. For this, it has to have a force that can help it escape the gravitational force.

The thrust provided by the combustion gives the rocket a velocity greater than the escape velocity. So, the force required to reach this velocity is adjusted to achieve this velocity. So, these are a few examples. Now coming to one more mechanism. That mechanism is called the mechanism of injury prevention.

Newton's second law also plays a crucial role. So, if you look at the equation. So, if you look at the equation. It says that the force equals m times (vf minus vi) divided by t. If we increase the time t. So, if we increase this particular time t, which is the denominator, the whole value will basically decrease, right? That is simple mathematics. So, if the time t increases, the rate of change of momentum definitely decreases, and this is directly proportional to the force applied. This force here is nothing but the impact force, meaning it results in less injury. For example, you can see a fielder moving his hand backward in cricket to avoid injuries to his hand using the following mechanism. Nothing but a denominator. So, the rate of change of momentum decreases, and ultimately, the force of impact decreases; therefore, there will be fewer injuries to the hand or to the body. The same mechanism applies when a jumper, a pole vaulter, or a high jumper lands on the mat. So, by landing on the mat, they are basically increasing the time of that landing.

So, if the time increases, they increase the time of the change of momentum. So, if the time increases, the change in momentum decreases. If the change in momentum decreases, it is directly proportional to the force applied. And this way, they reduce the impact force. So they feel less jerked.

Momentum should not be reduced to zero suddenly; otherwise, there will be an injury. And this is the reason a karate player breaks the pile of tiles because the larger momentum of his hand is suddenly reduced to zero. And the injury happens to the pile. Definitely the weaker zone. One more concept that needs to be understood here is called the impulse-momentum relationship.

So, we know this equation now, which is F equals M Vi minus Vi by T. So, if I bring this T to the F, the equation becomes something like this. This is simple mathematics. So, F times T equals M Vf minus Vi, or if I want to open the equation, the equation will open up something like this. Now, I know that F times T, which is force times time, is nothing but impulse, and MVf minus MVi is nothing but the change of momentum. So, I can write this expression as impulse equals the change of momentum.

$F = m\,(v_{f} - v_{i})/t$

$F{*}t = m\,(v_{f} - v_{i})$

$F{*}t = mv_{f} - mv_{i}$

The change of momentum depends on the impulse. I can explain this to you with one more example. Every one of us watches the match of cricket, right? And we know that when the bowler bowls a ball, it reaches the batsman in a fraction of a second. In this fraction of a second itself, the batsman has to decide in which direction he or she has to hit the ball. So, the ball comes up with momentum, and the batsman applies force to the bat. So, along with the application of force, it is also important to consider the timing of the application of force. So, he applies the force at a certain time, at the right time. Otherwise, it is of no use.

So, the force, when multiplied by time, becomes the impulse. So, if the impulse is good, the change in momentum of the ball will be good. And if he misses the impulse, the result will definitely not be in his favour. Just look at the last illustration to explain how force equals mass times acceleration or how the change in momentum takes place with respect to force.

[Let us move to Newton's third law, also known as the law of action and reaction or the law of counterforce].

Newton's third law of motion:

It states that every action has an equal and opposite reaction, or the action and reaction are equal and opposite. This law explains how forces are balanced in nature by an equal and opposite force. This law gives us the magnitude and direction of the reaction forces, which is useful in the numerical computation of forces. It sets up examples like pressing the trigger of a gun as the action, while the recoiling of the gun is the reaction. We cannot jump vertically because the muscular action of our legs cannot overcome the inertia of the Earth.

We jump because of the thrust provided by the earth. Let us simplify this. So, when you jump, your legs push down on the ground. So, that is the action force. And the ground pushes back upon you with an equal and opposite force, propelling you into the air.

That is nothing but a reaction force. When a projectile like a javelin or discus applies force on the air, the air also applies an equal and opposite force on the projectile. A swimmer is able to move forward because of the counterforce of the water. So, examples of Newton's third law are more visible to us in nature and in our daily lives. So, we encounter such examples every moment in our lives.

The very reason we are able to sit, stand, and walk is due to the reaction forces from the ground. Let us discuss each of the examples in detail and see how they are consistent with Newton's third law of motion. A body in motion should remain in motion unless acted upon by an external force. You can see the red line of the force, which is nothing but the ground reaction forces. So, the ground reaction forces are equal and opposite to the force that a person is applying on the ground.

And in this way, the person will be in the position to be stable and in the position to be upright. You have to push the water backward in order to move forward. The force generated in the backward direction gives us an opposite reaction in the forward direction. The more you push back, the more you move forward. While we walk,

We apply a force in the backward direction, and in response, the friction provides an equal and opposite force that helps us to move forward. But there is actually a reaction force from the ground which counters the weight of our body. The action here is our body weight, and the reaction force is the force from the ground to support us. When we pull a slingshot, the energy gets stored in the elastic material, and when we release the slingshot, we get an equivalent opposite force that is able to propel the object. Here, the direction in which we pull is also important, as that will determine the direction in which the object will travel.

When we punch an object or kick something, the object may break due to our force, which is an action. But we also get the force onto our hand and legs as the reaction force. This is why you feel pain after slapping someone or punching the wall. Even when we rest against a tree or a wall, we get the reaction force from the tree or the wall in order to support us.

You can understand this example by imagining someone resting on you, some force supporting another person. This example of Newton's third law is also an example of balanced force. A rocket is able to escape the gravitational force of the Earth because of its high velocity. This velocity is calculated to exceed the escape velocity, but how is such a high velocity possible? This is based on external reaction forces. The exhaust from the rocket creates a downward force, which creates an equal and opposite thrust in the upward direction, and this is how the rocket moves away. A ball is able to bounce because of the reaction from the ground. If there was no reaction, then the ball would not bounce but rather stick to the ground. We are able to jump on the trampoline due to the reaction force from the elastic material. When a basketball hits the board, it comes back with almost an equal force at which it was thrown.

The throwing action resulted in an equal and opposite force from the board. When someone is diving from a diving board, you can clearly see the reaction force in the board in the way it vibrates after the jump. The action force is the muscular force by the leg of the diver, and the reaction is the jump by the diver and also the vibration of the board. So, these were some examples to explain Newton's third law. Coming to the fourth law, and that is also called Newton's law of gravitation.

So, Newton also explains and states that every particle of matter in the universe attracts each other with a force that is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them. So, if you look at this particular equation, the force between the two objects, the two objects have masses m1 and m2, and the product of these masses is directly proportional to the force between them, and the square of the distance between these two objects is inversely proportional to the force between them. Or, I can explain this equation as F equals k times m1 m2 divided by s squared, where k is nothing but a constant value.

$F \propto \frac{m_1 m_2}{s^2}$

Or $F = K \frac{m_1 m_2}{s^2}$

So, the force which attracts each other is so small that it is not of any significance, except when one of these bodies is the Earth.

So, in this case. We are considering one object as a simple object with a certain mass, and the other object we are considering as the Earth. So, the force we are talking about is between the object and the Earth. So, the equation can be written as F equals G times, where we have replaced the constant k by G because that is nothing but the gravitational constant, and it has a constant value of $6.67 *10^{-11}$.

So, the equation will be F equals G m m_e divided by s squared. So, in this equation, that is F equals G times m, which is the mass of one person or one object, and m_e, which is the mass of the Earth, divided by s squared, which is the distance between these two. We know that F is the force, the weight, and weight is nothing but mass times gravity, mg. Then, if we replace this F by mg, So, we will get the final equation as g equals capital G times m_e divided by s squared, because this m cancels with this particular m, or we can get the value as g, the small g, is inversely proportional to the distance between the two objects.

$F = G \frac{m m_e}{s^2}$

g= G $\frac{m_e}{s^2}$

Or, g $\propto \frac{\mathbf{1}}{s^2}$

So, it says that the acceleration due to gravity is inversely proportional to the square of the distance from the center of the Earth.

You can simply understand that the object which is nearer to the center of the earth will feel more gravitational force, and the object which is at a higher height or the distance between the center of the mass and the object is greater, you can feel less gravitational field. So, we know that the earth looks something like this, but if we actually look at it, the earth is something like this, which basically has a pole and the equator. The poles are the portion of the earth which has the lesser radius from the center of the earth. On the other hand, the equator is the one which is away. So, that is the reason we feel more gravity when we are towards the pole and we feel less gravity if we are towards the equator.

[**Let us discuss the concept of work, energy, and power**].

The **terms work**, energy, and power are frequently used in everyday language. A farmer plowing the field, a construction worker carrying bricks, a student studying for a competitive examination, an artist painting a beautiful landscape, all are said to be working. In physics, however, the **word work** covers a definite and precise meaning.

Somebody who has the capacity to work for 14 to 16 hours a day is said to have great stamina or energy. We admire a long-distance runner for her stamina or energy. **Energy is** thus our capacity to do work. In physics, the term energy is related to work in this sense.

But as said above, the term work itself is defined much more precisely. The **word power** is used in everyday life with different shades of meaning. In karate or boxing, we talk of powerful punches. These are delivered at great speed. These shades of meaning are close to the meaning of the word power used in physics.

We shall find that there is at best a loose correlation between the physical definition and the physiological picture these terms generate in our minds.

The aim of this section is to develop an understanding of these three physical quantities. For work to be done, a force must be exerted, and there must be motion or displacement in the direction of the force. Consider a constant force F acting on an object of mass m. The object undergoes a displacement d in the positive x direction. The work done by a force acting on an object is equal to the magnitude of the force multiplied by the distance moved in the direction of the force.

Mathematically, it can be expressed as,

W = f * d * cosθ

where force F is the applied force and is measured in Newtons. Displacement d is the distance moved in the direction of the force, measured in meters, and theta is the angle between the force and the displacement. We understand from the work equation that if there is no displacement, there is no work done, irrespective of how large the force is. To summarize, we can say that no work is done if the displacement is zero, the force is zero, or the force and the displacement are mutually perpendicular to each other. The unit of work is the joule, denoted by a capital letter J. For example, if a force of 5 Newtons is applied to an object and it moves 2 meters, the work done will be 10 Newton meters or 10 joules. It should be noted that,

1J =Nm

Or, $1J = 1\ kg.m^2/\ s^2$

For example, an object is horizontally dragged across the surface by a hundred Newton force acting parallel to the surface. Find out. For example, an object is horizontally dragged across the surface by a 100 N force acting parallel to the surface.

Find out the amount of work done by the force in moving the object through a distance of 8 m. To solve this problem, we know that the given values are F = 100 N and d, the displacement, d = 8 m. Since F and D are in the same direction. So, $\theta = 0$. Therefore, the equation becomes,

$W = F * d * \cos\theta$

$W = 100 * 8 * \cos 0$

W = 800 J (since cos 0 = 1)

So, the answer will be work done equals 800 Joules. The key points about work and force are: if there is no displacement, no work is done. For example, holding a heavy weight in a static position. Work is only done in the direction of movement. If force is applied perpendicular to the movement, no work is done.

The amount of work depends on the force magnitude, the distance moved, and the angle of application. There are three types of work in physics that we usually discuss. The positive work, the negative work, and the zero work. The positive work is when the force applied and the displacement are in the same direction. Like pushing off the ground in sprinting or in the jumping tip.

On the other hand, the negative work is when the force applied is in the opposite direction of the displacement. Examples include landing from a jump and braking in running. The third type is the zero work, where the force is applied but there is no displacement, or the movement is perpendicular to the force. The example of positive work is when a weightlifter lifts a barbell upward, work is done against gravity.

When a player jumps for a dunk, they apply force against the ground, propelling their body upward. In cycling, the force exerted on the pedals moves the bike forward and uphill, resulting in positive work. The examples of negative work include when gymnasts land from a vault; their legs apply force against the ground to slow down motion. The hands move backward while catching to reduce the impact and perform negative work. The muscles work eccentrically to control descent in downhill running, performing negative work against gravity.

In the case of zero work, it means that there is no displacement. So, the examples include holding a plank position. Even though the muscles exert force to maintain the position, no movement occurs. So, no work is done. Carrying a weight horizontally.

So, if the athlete carries a weight forward without lifting or lowering it, no vertical work is done against gravity. These are a few examples where we explain work in terms of sporting movements. In cases like basketball, volleyball, or high jumps, positive work occurs when pushing off the ground, and negative work occurs when landing and absorbing impact forces. In the case of running and sprinting, positive work occurs when the runner pushes off the ground to propel forward. And negative work occurs when decelerating or stopping.

In the case of cycling, positive work occurs when pedaling uphill or accelerating. Negative work occurs when braking or slowing down. These are a few practical applications of work. Work is a fundamental concept in sports biomechanics, influencing movement efficiency, performance, and injury prevention.

Whether in lifting, running, jumping, or braking, athletes constantly perform positive and negative work to generate force, control movement, and optimize performance. Understanding how work interacts with force and displacement allows coaches and athletes to improve training, technique, and movement mechanics. The practical allocation of work includes optimizing performance, understanding work helps in improving movement efficiency, like reducing unnecessary energy expenditure in running. In injury prevention, like by controlling negative work, it helps in reducing injuries, such as landing properly and all, and obviously in equipment design, where especially the sports gear, like the running shoes and the tennis racket, is designed to maximize positive work and minimize energy loss.

[Coming to the topic of energy].

So, in sports biomechanics, **energy is** the capacity to do work, and it plays a vital role in athlete performance.

Every movement in sports, from sprinting to swimming, involves energy transfers, conversion, and conservation. Understanding energy helps in optimizing movement efficiency, reducing fatigue, and enhancing performance. Energy is the ability to perform work. Energy can neither be created nor destroyed, and it can only be transferred from one form to another. The unit of energy is the same as that of work, which is the joule, and energy is found in many things, and thus there are different types of energy. All the forms of energy are either kinetic or potential energy.

The energy in motion is known as **kinetic energy**, whereas **potential energy** is the energy stored in an object and is measured by the amount of work done. Let us discuss a few of them. So, kinetic energy, denoted by the alphabets KE, is the energy in motion. So, kinetic energy is the energy an object possesses due to its motion. It depends on mass and velocity and is given by

$$KE = \frac{1}{2} mv^2$$

where m is the mass and v is the velocity of the particular moment.

For example, a sprinter at top speed has high kinetic energy. In a tennis serve, the racket and ball have kinetic energy when swung and hit. In a football kick, a fast-moving ball has more kinetic energy than a slow-moving one. The key insight here is that kinetic energy increases with velocity, meaning a faster-moving athlete or object has more energy to transfer.

The **potential energy**, denoted by the letters PE, is the energy due to its position. So, potential energy is stored energy due to an object's position, commonly seen in gravitational potential energy. It is given by PE = mgh, where M is the mass of an object, G is gravity with a value of $9.81 m/s^2$, and H is the height in meters. Examples of potential energy include the high jump and pole vault. The athletes store potential energy as they rise.

In diving, a diver on a high platform has maximum potential energy before jumping. In the case of weightlifting, a barbell raised above the ground has potential energy that turns into kinetic energy when dropped. So, the key insight here is that the higher the object, the greater the potential energy, which is later converted into kinetic energy during motion.

Elastic energy is stored in objects that can stretch or compress and return to their original shape.

It follows **Hooke's law of elasticity**, which states that the deformation of an object is proportional to the force applied to it, as long as the deformation is within the object's elastic limit. For example, pole vaulting. The pole bends and stores elastic energy, which is released to propel the athlete. The tennis racket strings stretch when hitting the ball and release energy to propel it forward. The tendons in the muscle while running, the Achilles tendon stores and releases elastic energy, improving running efficiency.

The key insight here is that elastic energy improves performance by reducing muscular effort. The body uses chemical energy stored in the muscle from ATP, carbohydrates, and fats to generate force for movement. For example, in marathon running, the body breaks down glucose and fat for long-term energy. In weightlifting, ATP provides a quick burst of energy for lifting heavy weights. And in cycling, the muscle converts stored chemical energy into mechanical work for a long duration.

The key insight here is that proper nutrition and training improve energy ability for performance. So, we are talking about the transfer of energy. In sports, if we talk about it, we take some examples like in jumping events such as basketball, volleyball, and high jump. Before the jump, the chemical energy in the muscle is converted into mechanical energy. During the takeoff, work is done against gravity, converting kinetic energy into potential energy.

At the peak of the jump, the maximal potential energy and the minimal kinetic energy occur, and at the landing, the potential energy turns into kinetic energy and dissipates upon landing. In the case of sprinting, at the start, the chemical energy converts into kinetic energy. As the athlete accelerates, more kinetic energy is generated, and in the deceleration phase of the sprint, the kinetic energy decreases due to friction and air resistance. In rowing, the chemical energy converts to kinetic energy in the oar and the boat during the pulling phase. The water resistance causes some energy to be lost due to friction.

The key principle here is the law of conservation of energy, which states that energy cannot be created or destroyed, only transformed from one form to another. These are a few strategies to improve energy efficiency. Optimizing movement mechanics. Proper technique reduces wasted energy. For example, minimizing unnecessary movement in swimming.

Using elastic energy, runners benefit from tendon elasticity to reduce energy cost. Reducing air resistance and friction. Cyclists use an aerodynamic posture to conserve kinetic energy. Efficient energy storage and release.

Strengthening muscles and tendons improves energy return in jumping and sprinting. So, energy is a crucial factor in sports biomechanics, influencing performance, efficiency, and endurance. Whether it is kinetic energy in sprinting, potential energy in jumping, elastic energy in pole vaulting, or chemical energy during movement or chemical energy fueling the movement. Understanding these concepts allows athletes to optimize performance and reduce injury risk.

[Coming to power]

In sports biomechanics, **power is** the rate at which work is done or energy is transferred. It is a crucial factor in athletic performance, especially in explosive movements like sprinting, jumping, and weightlifting. High power output allows athletes to generate force quickly, improving speed, strength, and efficiency. So, power is a physical concept with several different meanings depending on the context and the available information. We can define power as the rate of doing work, and it is the amount of energy consumed per unit of time. It can be calculated by dividing work done by time. The formula for power is,

$$\text{power} = \frac{\text{work}}{\text{time}}$$

Since work is defined as force multiplied by displacement. So, power can also be expressed as,

power = force x velocity

Where power P is measured in watts.

The work is measured in joules. Time is measured in seconds. The force can be measured in newtons, and the velocity is measured in meters per second. So, the key insight here is that power is directly related to both force, production, and speed of movement, meaning stronger and faster athletes tend to have higher power outputs.

The SI unit of power is joules per second, which is termed as watts. A watt can be defined as the power needed to do 1 joule of work in 1 second. There are three types of power we discuss in sports. The first is explosive power, also known as anaerobic power. The second is sustained power, known as aerobic power.

And the third is reactive power, known as elastic power. Talking about explosive power, that is anaerobic power, so the power generated in short, high-intensity bursts. It is essential for activities requiring quick force application, and it depends on fast-twitch muscle fibers and the ATP-PC energy system. For example, in a 100-meter dash, high power output is needed to accelerate quickly.

In weightlifting, the snatch and clean and jerk require maximum power output in a short time. In jumping events like basketball, volleyball, and high jump, rapid force production is required to propel the body upward. The second type of power we are discussing here is sustained power, or aerobic power. So, the power maintained over a longer duration depends on endurance capacity and efficient energy utilization. For example, events like two-day runs need sustained power for a long time.

In events like rowing, the athlete maintains a high power output for a prolonged period. Events like long-distance running, such as marathons, require a balance between speed and endurance power. The third type of power we are discussing here is reactive power, or elastic power. It is the power derived from stored elastic energy and the stretch-shortening cycle. It utilizes the tendons and muscle elasticity to enhance efficiency.

For example, in pole vaulting, elastic energy increases the power output. In plyometric jumps, bouncing drills enhance explosive reactive power. In the tennis serve, rapid phase-shortening motion generates power. Let us discuss the power output in different sporting movements. So, if you are talking about sprinting, force is applied to the ground rapidly to achieve acceleration.

Higher stride frequency and force production lead to greater power. And more power allows a sprinter to maintain speed longer. Power is critical in Olympic weightlifting movements like the snatch and clean and jerk. A heavier bar moved quickly requires more power than a lighter bar lifted slowly. In the case of cycling, it is measured in watts per kilogram, with higher power output improving sprinting abilities.

Track cyclists generate maximum power in short bursts, while road cyclists focus on sustained power. In the case of events like boxing and martial arts, power is key to striking effectiveness. The power of punches depends on speed and strength. Ultimately, it depends on power. These are the factors that affect power in sports, like muscle strength and power production.

Stronger muscles generate more force, leading to higher power output. For example, a weightlifter with strong leg muscles can lift heavier weights explosively. Speed and the rate of force development are other factors that affect power. The faster an athlete can generate force, the more power they produce. For example, a sprinter with rapid acceleration has a higher power-to-weight ratio.

The stress-shortening cycle and elastic energy. Utilizing stored energy. Utilizing stored elastic energy improves power efficiency. For example, a volleyball player uses a quick dip before jumping to maximize power output. And the last factor I am discussing here is neuromuscular efficiency.

Faster nervous system responses lead to better muscle activation and power. For example, a boxer with quick reflexes can deliver powerful punches more efficiently. These are some training methods to improve power, including plyometric training that enhances explosive power by utilizing the stretch-shortening cycle, like box jumps, depth jumps, bounding drills, and more. Olympic weightlifting develops maximal power output through rapid force application. Resistance training exercises like speed, strength drills, and others build muscle force to increase power output, such as squats, deadlifts, and bench presses. Sprint training improves speed and power in running-based sports, like hill sprints, leg pushes, and resistance sprints. And the last one I am discussing here is the medicine ball throw.

It develops upper body power for cutting and throwing sports. Examples include overhead slams, rotational throws, and chest passes. So, power is a critical component of sports biomechanics, influencing speed, strength, and overall athletic performance. By optimizing sports production, velocity, and efficiency, athletes can enhance their explosiveness, movements, endurance, and reactive abilities. Through specific training methods and biomechanical analysis, power can be developed and maximized for superior athletic success.

There is one more concept which needs to be discussed, and which is important, is the work-energy theorem. So, this concept in physics relates to the dynamic motion of an object. It states that the work done on an object is equal to the change in its kinetic energy. This means if you apply force to an object, you either speed it up or slow it down, depending on the direction of the forces. For example, when you apply the brake in a car, the braking force slows the car down, reducing its kinetic energy. In sports biomechanics, the work-energy theorem helps explain how athletes generate and dissipate energy during movements. It is particularly useful in understanding performance, injury prevention, and equipment design.

This theorem simplifies the understanding of how forces affect motion. eliminating the need for complex equations in many cases. Instead of analyzing the force of friction, air resistance, or other forces in detail, we can calculate how much work is done by all these forces combined and find out how the object's speed changes. To understand the work-energy theorem better, imagine you are pushing a box across the floor. When you push, you apply a force to the box, and it starts to move. The force you apply is transferred to the box in the form of work, and this work causes the box to gain kinetic energy, meaning its speed increases. The more force you apply or the further you push the box, the more work is done, and the faster the box moves.

Another example is throwing a ball. When you throw a ball, you apply a force to it with your hand. The force you use to throw the ball is transferred into work, and this work increases the ball's kinetic energy. The faster you throw the ball, the more work you have done, and the more kinetic energy is gained. As the ball moves through the air, it is still carrying that kinetic energy, and this is what keeps it moving until something slows it down, like gravity or air resistance.

The work-energy theorem states that the net work done on an object is equal to the change in its kinetic energy. Mathematically, the work-energy theorem can be expressed as

$W_{net} = \Delta KE$. Where W_net is the total work done on an object. ΔKE is the change in the kinetic energy of the object. We know that the kinetic energy is given by the formula,

$KE = \frac{1}{2}mv^2$.

The net work refers to the total work done by all forces acting on an object. If multiple forces act on an object, we must consider the overall effect of all these forces to determine how the kinetic energy changes. The sprinter converts chemical energy into kinetic energy. It is as simple as that fuel is turning into motion. The net work done by the ground reaction forces increases their velocity.

If friction or air resistance does more negative work, energy dissipates and slows the runners down. The sprinter uses an optimized technique to maximize ground reaction forces and minimize the effect of friction. High jumpers and basketball players use their legs to perform work against gravity. The energy from the leg muscles is transferred into kinetic energy and then into gravitational potential energy. The proper technique maximizes work output and increases jump height.

When the boxer punches, work is done on the opponent's body, transferring the energy. In rugby, when the player tackles another, negative work is applied, reducing the tackled player's kinetic energy. In the pole vault, the athlete converts kinetic energy into potential energy by bending the pole. These stored energies then release, converting back into kinetic energy and gravitational potential energy for lift-off. The efficient energy transfer reduces wasted effort and maximizes the world height.

In swimming, the swimmer supplies force against the water to perform positive work, increasing the speed. The water resistance, which is the drag force, does the negative work, slowing them down. And the optimized stroke technique reduces wasted energy and improves performance. The key takeaway point here is energy efficiency. Training technique, injury prevention, and equipment design.

Energy efficiency improves athletic performance, like running economy and all. Training technique optimizes the work done by muscles for maximizing speed, height, or force. Injury prevention strategies consider how forces and energy affect joints and tissue. And equipment design, like shoes, helmets, and rackets, helps athletes maximize energy use while minimizing injury risk.

[Thank you. See you in the next video].