

**Exercise & Sports Biomechanics**  
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**Week 06**  
**Lecture 28**  
**Dynamics of motion**

[Hello! Friends, we are going to discuss what inertia is, the effect it has, and what affects it].

**Inertia:**

It is defined as the characteristic of a body to remain at rest or in uniform motion. Inertia is the resistance to change in motion. So, the object at rest remains at rest, and the object in motion remains in motion at the same velocity unless disturbed by an external force. Inertia is the reason you feel a jerk while applying the brake in a car or bus.

Your body tries to move forward with your seat belt, which is attached to a slowing car, applying the force that also slows you down. So, inertia is the resistance to a change in velocity. We can demonstrate inertia using the following experiment.

“You need a glass of water, a coin, and a piece of cardboard. When the cardboard is pulled, the coin falls into the glass”.

This is because the inertia of the coin maintained its state of rest as long as the friction between the card and the coin is not too high. It falls into the glass due to gravity. It also applies when the plate stays in the same place when the magician pushes the tablecloth away. So, inertia depends on mass. More mass means more inertia. So, the inertia of an object depends on its mass. More mass means more inertia.

A greater resultant force is needed to change the motion of an object with higher inertia. Inertial mass is a measure of how difficult it is to change the velocity of an object, and the larger the inertial mass, the bigger the force needed or the smaller the acceleration produced by a given force.

And we all know that force equals mass times acceleration ( $F = m \cdot a$ ) as per Newton's second law. We know that inertia is the property of an object that resists any change to its state of motion. To illustrate the property of inertia, we are going to use two objects. The first object has a mass of 10 kilograms, and the second object has a mass of 100 kilograms.

So, in both cases, we are going to apply a force of 50 Newtons. So, which object do you think has more inertia? Obviously, it is easier to move the lighter object than the heavier object because the heavier object has more inertia. So, inertia is proportional to mass. Now, based on Newton's second law of motion, **net force** is the product of mass and acceleration. So, acceleration is net force divided by mass.  $a = F_{\text{net}}/m$

So, for the first object, force is 50 divided by mass 10. Which gives us the acceleration of  $5 \text{ m/s}^2$ , and for the second object, 50 divided by 100, which gives us the acceleration of

$0.5\text{m/s}^2$ . So, we can see that the smaller object has a very large acceleration, while the larger object has the smaller acceleration.

So, what this teaches is that the lighter object has less inertia because it was very easy to accelerate the object with the smaller force, and the larger object has more inertia because, even though we applied the same amount of force, the acceleration of the object is smaller. So, whenever you increase the mass of the object, the inertia of the object increases. Let us take one more example. It would require a much larger force to throw a shot put at the same speed as a tennis ball.

This is because a shot put has a larger inertial mass than a tennis ball. So, what did Einstein mean when he said, 'Nothing happens until something moves'? He was talking about inertia. We will be discussing **momentum and impulse**.

### **Momentum:**

Momentum in physics is denoted by a small letter p. Momentum is a measure of how much motion an object has. It is calculated by multiplying an object's mass by its velocity.

$$p = m \cdot v$$

In sports, momentum can refer to the flow of the game or a player's ability to keep moving and make plays.

Momentum is the tendency of an object to continue moving in the same direction and is associated with great mass and speed. In sports, an athlete can increase their momentum by either increasing their mass or velocity. As we all know, momentum is the product of mass and velocity, and it is nothing but mass in motion. Now, we all know that mass is a scalar quantity and velocity is a vector quantity.

### **Coming to the unit:**

The mass can be expressed as kg, and the velocity can be expressed as meters per second. So, the unit of momentum is kg meters per second. And if we want to talk about the change in momentum, it is always final momentum minus initial momentum. Which can be expressed mathematically as  $m_v - m_u$ , where v is the final velocity and u is the initial velocity. So, in sports, whenever we talk about the change of momentum or the rate of change of momentum, we always consider the two momenta.

One is the final momentum, and the other is the initial momentum. So, for example, if a football is coming to an athlete with certain momentum and then he kicks the football, the momentum changes into another direction. So, the previous one is obviously the initial momentum, and the momentum after the kick is the final momentum. Let us have some more examples. So, imagine a soccer player sprinting down the field with the ball.

The player has a lot of momentum because they are running quickly and have a high mass. So, we all know that momentum is what? It is mass times velocity. And the players are big and strong also. So, if a defender tries to stop them, it is harder to do so if the attacker is already moving fast.

Because it takes more mass to stop the player's momentum. Coming to basketball, in basketball, if a player is driving towards the hoop at full speed, they have a lot of momentum. When they jump to take a shot, their momentum can help them get higher into the air. A defender might try to stop them by jumping as well, but the offensive player's momentum will make it harder to block the shot without fouling.

Have you ever imagined why two shot putters seem to defy gravity?

It is all about momentum and force. In throws, athletes do not just rely on brute strength. Think of it like pushing a heavy shopping trolley. The harder you push, the faster it goes, right? It is the same with throws in sports.

When the thrower is in action, they generate momentum using their body mass and strength. Momentum is the product of mass and velocity. So, the more force they apply and the faster they move, the greater the momentum. Imagine a spring being compressed and then released.

That is the athlete's muscle storing and unleashing energy into the object. The key is to transfer as much momentum as possible from their body to the object. So, the next time you see a thrower in action, remember it is all about combining strength, speed, and a bit of physics magic.

### **Impulse:**

In simpler words, Impulse is the product of force and time.  $\text{Impulse} = f \cdot t$

And the unit of impulse is the Newton second. So, when we simplify this terminology, it is the duration of application of force or we can say the timing of application of force. For how long the force has been applied. Remember one thing also that impulse is directly proportional to the change of momentum. Or you can say that the change of momentum depends on the impulse.

With that being said, when a force is applied to an object, the resulting motion of the body depends not only on the **magnitude of the force** but also on the **duration of the force application**. Let us take some examples. Example from cricket. When a cricket player hits the ball with a bat, the bat exerts a force on the ball over a short period of time. The longer the bat stays in contact with the ball, the greater the change in the ball's momentum.

Just remember, the longer the time is basically part of the equation. So, if the batter swings with more force or if the bat is in contact with the ball longer, the ball will travel faster. It means they are generating higher momentum. Let us explore this example a bit more. So, a bowler is bowling a ball towards a batsman, and the ball reaches the batsman within a fraction of a second.

Within a fraction of a second, the batsman has to decide in which direction to hit the ball. So, the ball is coming with certain momentum, mass, and velocity, obviously, and by applying the force at a particular time, the force and time is what? Impulse. So, by applying good impulse, the batsman is changing the direction of the momentum of the ball from this

direction to the one where he desires. So, the success of the particular shot depends on the force as well as the time.

Or I can say the change in momentum of the ball depends on the force and time. That is nothing but the impulse. In tennis, when the player hits the ball, they apply a force over a very short time. Since the contact time with the racket is very brief. And if they apply a strong force, the ball will change its momentum significantly.

For example, a powerful serve has a large impulse, resulting in the ball moving at high speed across the court. Similarly, in golf, when a golfer swings their club to hit the ball, the club exerts a force on the ball over a short period of time. The greater the force the golfer applies, obviously by swinging harder, and the longer the club stays in contact with the ball, the greater the impulse. This is why a powerful drive can send the ball flying far down the course.

Coming to boxing, in boxing when the boxer punches, the force exerted on the opponent's body during the short contact time is what generates the impulse. A punch delivered with a greater force over the same amount of time will have a large impulse and cause more of a change in the opponent's momentum. This is why a strong, fast punch can knock an opponent off balance or even knock them out, as the impulse is large enough to change their momentum dramatically.

Example from volleyball. When the player spikes the volleyball, the force they apply to the ball over a short time generates a large impulse, propelling the ball downward at high speed. The more force the player uses in the spike, the larger the impulse, and the harder it is for the opposing team to block or return the ball. Just remember one thing: To change the momentum, it is necessary to have a proper impulse. And impulse depends on two things: force and, obviously, the timing of the force.

In sports biomechanics, impact and the coefficient of restitution are crucial concepts that influence performance, equipment design, and safety. The impact refers to the collision between two objects, such as a ball and a bat, a foot and the ground, or a racket and the shuttlecock. This collision can be classified into elastic and inelastic impact. The elastic impact is the one where the kinetic energy is mostly conserved.

For example, a super bouncy ball. On the other hand, the inelastic impact is the one where some energy is lost as heat, sound, or deformation. For example, a clay ball. In sports, the way forces are transferred during impact affects the motion of the athlete and equipment, influencing factors like speed, accuracy, and injury risk.

These are some of the examples which help us understand the concept of impact. As you can see in the first picture, the boxer punches the opponent. So, there is an impact between the boxing glove and the opponent's body. On the other hand, in the second picture, you can see the impact between the bat and the ball. In addition, the impact may result in injuries as well.

As you can see in the example of F1 Formula car racing and in soccer. The **coefficient of restitution** is a measure of how much energy remains after a collision, and it is defined as  $e = v_f / v_i$ , where  $e$  is the coefficient of restitution,  $v_f$  is relative velocity after impact, and  $v_i$

is the relative velocity before impact. Where  $e$  is the coefficient of restitution,  $v_f$  is the relative velocity after impact, and  $v_i$  is the relative velocity before impact. If the value of  $e = 1$ , that means it is a perfectly elastic collision. Therefore, there is no energy lost.

For example, an idealized super ball. And if the value of  $0 < e < 1$ , it means it is a partially elastic collision. This means some energy is lost. Most of the sports scenarios come under this particular category, and if the value of  $e = 0$ , we can say it is a perfectly inelastic collision, meaning the maximum energy is lost. For example, a lump of clay hitting the floor. The coefficient of restitution determines how high a ball bounces or how fast it rebounds. In cricket, tennis balls are tested for the coefficient of restitution to ensure consistency.

The basketball must have a regulated bounce to maintain fair play. In the case of golf, the coefficient of restitution between the club and the ball affects the distance the ball travels. Golf balls are designed to optimize the coefficient of restitution for distance and control. In addition, running shoes have materials with specific coefficient of restitution values to optimize energy return. The long jump takeoff boards are designed to maximize elastic energy return.

The coefficient of restitution plays a crucial role when talking about injury prevention. Safety gear like helmets and padding in contact sports use low coefficient of restitution materials to absorb impact energy and reduce injuries. Artificial turf and gym mats have controlled coefficients of restitution to reduce excessive impact force.

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