Exercise & Sports Biomechanics
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Week 09
Lecture 41
Introduction to the Center of Gravity

[Hello friends! In this section, we are going to discuss the **center of gravity**.

The center of gravity plays a fundamental role in biomechanics, as it represents the point where the body's mass is evenly distributed. Its position influences stability, movement efficiency, and posture control, making it a key factor in understanding and optimizing human motion. Our body is constantly subjected to forces, even when there is no motion.

When this condition exists, the body is said to be in equilibrium. In sports, it is called balance, position, or stance. You can have a look at this particular picture as well. So, if this kind of condition occurs, the sum of all the horizontal forces becomes zero, the sum of all the vertical forces becomes zero, and the sum of all the moments that cause rotation becomes zero. You can have a look at this particular picture, where the body is in a position of equilibrium.

Equilibrium: What do you mean by equilibrium?

When all parts of the body are at rest or moving with a constant angular velocity, the body is said to be in a state of equilibrium. For example, a gymnast performing a cross on a still ring. The concept of equilibrium is important in determining the amount of force required to upset the equilibrium.

For example, in the construction of a hurdle. You must have noticed that in hurdles, when an athlete is crossing, sometimes it happens that the athlete touches the hurdle with their foot or another body part. So, the hurdle basically falls along with the athlete. This is because the center of mass or the equilibrium position of the hurdle is designed in such a way that it is easily disturbed by a small force from the athlete. Otherwise, it may cause injury to the athlete.

Concept of the Center of Gravity:

It is important to discuss the concept of the center of gravity along with equilibrium, as it is the theoretical point where gravitational force acts equally in all directions. It is the point in the human body that marks the intersection of three primary planes and their axes. The center of gravity plays a role in determining an athlete's balance, stability, and movement efficiency. Understanding the center of gravity helps athletes and coaches optimize performance, prevent injuries, and enhance movement mechanics. In a rigid body of homogeneous mass, the center of gravity is at the geometrical center of the body. As the density of the body changes, the center of gravity shifts toward the more weighted area.

You can understand by looking at some of the examples, like you can see in the first picture, as the body weight moves towards one particular side you can see the center of gravity is

moving towards that side. Same in this picture and that picture as well. So the human is made up of number of segments capable of adopting many postures. Accordingly, the center of gravity keeps on shifting. The location of center of gravity is extremely important in determining the state of equilibrium at any moment.

The location of center of gravity:

The center of gravity is a point where the sum of all the forces and the force moment becomes zero and it is called the equilibrium point. In a standing human, the center of gravity is typically located around the pelvic region near the navel. But it shifts based on the posture and the movement. As it is already said that it shifts towards the more weighted area. So, it is approximately at the level which is 56% of the standing height or the standing position.

This position changes according to the position of a human body. As it is told that it shifts towards the more mass or the more weight area, the center of gravity determines how a body interacts with external force like gravity, enabling balance and control movement. It is a key factor in postural stability and energy efficiency movement.

Looking at this particular, you can see in the A example, the center of gravity shifts a bit up because the weight is more on the shoulder of this particular person.

In the B picture, you can see the center of gravity shifts towards the right side because a man is hanging a bag on the right shoulder.

And in the C picture, you can see that the books are held in front of the body, so the center of gravity moves forward. The same thing is happening in this particular picture, in this, in this, and in this as well. And it has been noticed that while running, the center of gravity or the center of mass moves in a parabolic fashion.

Type of Equilibrium:

There are three kinds of equilibrium that we can discuss here.

1. Stable Equilibrium,
2. Unstable Equilibrium,
3. Neutral Equilibrium.

Stable Equilibrium:

When a body is in equilibrium and has a tendency to return to its original position when an unbalanced force is applied to it, then the body is said to be in a state of stable equilibrium. For example, this water bottle is in stable equilibrium because its gravitational potential energy increases as its position moves away from the equilibrium position. This is because the center of mass of the water bottle rises as the position moves away from equilibrium. In other words, the water bottle naturally returns to the equilibrium position when it loses gravitational potential energy.

Some other examples are the gymnast hanging on a bar, the horizontal bar, the punching bag in boxing that returns to its original position, and the pendulum as well.

Unstable Equilibrium:

When a body has a tendency to move away from its original position to a new stable position, when an unbalanced force is applied to it, then it is said to be in a state of unstable equilibrium. This dry-erase marker is in unstable equilibrium because its gravitational potential energy decreases as its position moves away from the equilibrium position. This is because the center of mass of the dry-erase marker lowers as the position moves away from equilibrium.

In other words, the dry-erase marker naturally moves away from the equilibrium position when it loses gravitational potential energy. Some other examples are the handstand on the parallel bars. The gymnast is in a new equilibrium all the time. A swimmer standing on the starting block, ready to take the start.

Neutral Equilibrium:

The third type of equilibrium that we are discussing here is **neutral equilibrium**. The body has a tendency to change its position under the influence of an applied force. But the newly acquired position is similar to the original position. Or, I can say the equilibrium point does not change. An effort to disturb the body will neither raise nor lower the center of gravity. The center of gravity remains at the same point.

This ball is in neutral equilibrium because the gravitational potential energy of the ball remains constant regardless of its position. So, the graph of the gravitational potential energy of the ball with respect to its position is a horizontal line because the gravitational potential energy is constant.

The factors affecting the Center of Gravity in sports:

Following are the various factors affecting the center of gravity in sports.

1. **The body position:**

The body position is one. So, changing posture shifts the center of gravity. For example, crouching lowers it, while standing on tiptoes raises it.

2. **Base of support:**

Some more factors are the base of support; a wider stance improves balance, while a narrow stance makes stability more challenging. Now, talking about the base of support. So, the base of support is basically the area covered by the body parts on the ground. The length or the area that is covered—the area of the ground that is covered—is called the base of support. For example, if I am holding a stick in my hand like this, this particular part will also be covered under the base of support. This way, I may have more area for my stability or for my equilibrium.

Relation of base of support and line of gravity:

When talking about the base of support, it is even more important to discuss its relationship with the line of gravity. So, the line of gravity is basically the imaginary line—you can look at this red line—the imaginary line that passes vertically down through the center of gravity to the ground.

A body maintains its equilibrium only as long as the line of gravity falls within the base of support. For this reason, a gymnast walking on a balance beam keeps their arms stretched out both ways. You can see in all the pictures, the red line. So, this is the base of support for the particular position.

So, you can see the line of gravity falls within the base of support. So, I can say the person is in an equilibrium state. Here, the person has changed their stance. So, the base of support changes. But still, the line of gravity is coming into the base of support.

And here, the person is walking with a wide stance. So, the base of support increases because this point also comes under the base of support now, and hence the area for the line of gravity to travel increases, so the chances of falling decrease. As already discussed, a body maintains its equilibrium only as long as its line of gravity falls within the base of support, and this is the reason a gymnast walking on a balance beam keeps their arms stretched both ways.

In addition, following factors also affect the Center of Gravity in Sports:

1. **External force:**

External force could be another factor that affects the center of gravity, such as wind resistance, opponent contact, or uneven surfaces affecting center-of-gravity adjustments.

2. **Equipment:**

Equipment and instruments may also affect the center of gravity, such as skis, skates, prosthetics, and shoe modifications. These all may affect the athlete's center of gravity and biomechanics.

3. **Gender difference**:

Gender differences also affect the center of gravity; males usually have a higher center of gravity due to more mass in the upper body, while females tend to have a lower center of gravity mainly because of a wider pelvis, and this affects movement mechanics.

Importance of the Center of Gravity in Sports:

1. **Balance and Stability:**

The first and foremost importance is balance and stability. So, stability depends on the height of the center of gravity, the base of support, and the body's alignment with gravity.

A lower center of gravity increases stability. A wider base of support, for example, standing with the feet apart, enhances balance and reduces the likelihood of falling. Examples include gymnasts and ballet dancers. They make fine adjustments to their center of gravity

to maintain balance during routines. Coaches train athletes in stability exercises such as squats, lunges, and balance drills to improve center of gravity control.

Stability:

Let us discuss stability in more detail. Stability is the ability of a body to maintain balance under unfavorable conditions, and it is a measure of equilibrium.

Factors Affecting Stability:

There are various factors that affect stability like,

1. **The relationship of the line of gravity to the base of support:**

A body maintains its equilibrium only as long as its line of gravity falls within the base of support, as we discussed earlier.

2. **The height of the center of gravity:**

A lower center of gravity increases stability, which is why athletes in sports like wrestling and judo adopt a lower stance. Have you ever wondered why wrestlers and judo practitioners adopt a wider and slightly lowered stance? Because the main objective in such sports is to disturb the opponent's balance and make them fall.

And if your center of gravity is lower, it means you are more stable, and it is more difficult for an opponent to disturb your balance. So, the athlete basically adopts that position to have more stability and better balance.

3. **Size and Shape of the Base of Support:**

The other factors are the size and shape of the base of support. So, the wider the base, the greater the stability. We have already discussed this in the previous slides.

4. **Mass of the Body:**

The mass of the body—obviously, it requires more mass to offset the whole body.

5. **Friction:**

Inadequate friction reduces stability.

6. **Posture:**

When all the segments are aligned in a single vertical line, the posture is not only pleasant in appearance but also places less strain on the joints and muscles. The center of gravity changes based on posture.

For example, in a standing upright position, the CoG is close to the pelvic region. In a leaning-forward position, like that of a sprinter, the center of gravity moves forward, increasing the risk of instability. In dynamic postures, during activities like running or jumping, the center of gravity shifts outside the body to maintain momentum and control.

7. **Physiological factor:**

Physiological factors are another thing that can affect stability. So, disturbance in any physiological system is likely to affect balance, and stability is compromised.

8. **The visual and psychological factors**:

You know, sometimes balance is lost even when we walk over an unsupported edge. High above the ground despite a wider base. I hope many of you must have experienced walking on a glass ground or a glass surface. So, when you walk on glass, although it is stable and well-supported, when we look down, we basically have a fear of falling. So, this is how the psychological or visual factor affects stability.

The Importance of the Center of Gravity in Sports:

1. **Motion and Acceleration:**

In motion and acceleration, the athlete adjusts their center of gravity to optimize movement efficiency and speed. For example, a tennis player lowers their center of gravity before a shot to enhance reaction time and stability when moving laterally.

The sprinter leans forward at the start of the race to shift their center of gravity forward, allowing for a faster acceleration phase. In sports like football and basketball, players use quick center of gravity shifts to execute agile movements and rapid changes of direction.

2. **Rotation and Angular Motion:**

In rotation and angular motion, like in sports that involve sprinting or flipping, controlling the center of gravity is essential for achieving controlled and efficient rotation. Bringing limbs closer to the center of gravity increases spin speed due to the conservation of angular momentum, as we discussed in the previous week.

For example, a figure skater tucks their arms and legs in to rotate faster in the spin, while divers do the same for the somersault. Gymnasts adjust their body position to control somersaults, twists, and flips by managing their center of gravity placement.

3. **Leverage and Force Application:**

Leverage and force application are other important aspects. In the case of the center of gravity in sports, the position of the center of gravity influences how efficiently an athlete can apply forces and generate power. In weightlifting, keeping the barbell close to the body ensures the center of gravity remains within the base of support, reducing strain and improving lift efficiency.

In combat events like boxing and martial arts, shifting the center of gravity forward enhances the power of a punch or kick. We can take the example of a shot-put athlete. They lower and shift their center of gravity strategically to maximize thrust and distance.

4. **Manipulating the CoG in aerial sports:**

Talking about manipulating the center of gravity in aerial sports like jumping sports, the body's center of gravity follows a predictable trajectory, even though different body parts may move independently. The Fosbury flop technique in high jump allows the body to clear the bar while the CoG remains below it, optimizing energy use.

Gymnasts use body positioning to shift their center of gravity and perform complex flips, maximizing rotation and minimizing instability. Take the example of a long jump. A long jumper manipulates their center of gravity by extending their legs forward mid-air to increase the jump distance.

[Thank you, and see you in the next video].