Exercise & Sports Biomechanics

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Lecture 11

Introduction to Kinematics & Kinetics Types of Analysis

[Hello, everyone! Welcome back to this course on exercise and sports biomechanics. In this video, we will start with an introduction to kinematics and kinetics.]

Biomechanics:

Biomechanics is all about studying how forces affect our body. It is the science of movement, understanding what happens when we move, why exactly we move that way, and how we can improve it.

Biomechanics can be broken down into three main areas: Fluid mechanics, Deformable body mechanics and Rigid body mechanics

Fluid mechanics:

The first one is fluid mechanics. This deals with the fluids in our body, like blood flow, how our lungs work, and even how we move in water, like swimming or other aquatic activities.

Deformable body mechanics:

This focuses on tissues like bones, ligaments, and tendons. It is about how strong they are and how they are able to handle the forces.

Rigid body mechanics:

This is about solid structures and how they move, which is really important in exercise and sports. Rigid body mechanics is further divided into two sections: statics and dynamics.

Statics:

Statics is about objects or bodies that are at rest or moving at a constant speed. For example, think of a gymnast holding a steady handstand that is static or imagine a person pushing a box, but it does not move because of the friction, that is also static.

Dynamics:

It is all about motion. Dynamics looks at objects that are accelerating, like when you sprint, jump, or throw a ball. It is very relevant when we study human movement in exercise and sports.

Dynamics is further divided into two parts: kinematics and kinetics.

Kinematics:

Kinematics is the study of motion without forces. For example, kinematics measures how fast you are running, like speed and velocity, how far you have gone, like distance and displacement, and how quickly you are speeding up or slowing down, which is known as acceleration. But remember, kinematics does not care about the weight or forces behind the movement. It is just describing how the movement looks.

Kinetics:

Kinetics studies the forces that cause motion. For example, when you run, your leg muscles generate force to push for propulsion. Kinetics studies how much force your muscles produce, the energy used, and even the power behind your movement. So, in simple terms, kinematics tells you how we move. Kinetics explains why we move.

So, we need to understand how these technologies, which are available in the market, measure the kinematical parameters. It can be either in video or in a motion capture system. The core thing here is we just need to identify exactly where the athlete is with reference to position and time. So, based on the technology, we will receive the position versus time graph. Imagine that the athlete moved from point A to point B. Now, we need to identify how far he has moved from point A to point B. For this example, instead of taking the entire movement, I will take a part of the movement. I will make it as P1, position 1. And position 2. If we identify how far the athlete travelled from point 1 to point 2, it is known as distance. Similarly, if we identify what the change in position is from point 0.2 to 0.1, it is known as displacement.

In addition, we know the time point of position 1 and the time point of position 2. If we calculate distance divided by time, then we will get speed. $d \: / \: t = s$

If we calculate displacement divided by time, we will get velocity. $^{dis}/_{t} = v$

So, in one graph, the system can generate distance, displacement, speed, and velocity. Based on this, the velocity versus time graph will be plotted, and from there, we can identify acceleration. Imagine that we are considering this as the initial velocity and this one as final velocity, and we know the initial time and final time. If we compute the change in velocity divided by the change in time, we will get acceleration. $\Delta \, ^{v}/_{\Delta} \, t = a$

So, the slope of this velocity versus time graph calculates the acceleration. If we apply the same thing in the acceleration versus time graph, This is initial acceleration and final acceleration.

With reference to time, initial time and final time, the change in acceleration is known as jerk. So, from the technology, we are receiving the position versus time graph. From there, we can compute all this information from a kinematical perspective. When we want to calculate kinetics, engineers can measure forces directly in machines, but as biomechanists, we cannot directly measure muscle forces in humans unless we use some kind of surgical implants, which is, of course, not practically possible.

So, as a biomechanist, we need to use an indirect method called **inverse dynamics**. First, we measure the motion, which is kinematics, and then apply Newton's law to identify the forces. It is like solving the puzzle backwards. On the other hand, engineers use direct dynamics, where they already know the forces in their machines and can calculate the resulting motion.

There are two types of analysis: qualitative and quantitative analysis.

Now let me ask you, have you ever seen a coach or a trainer watching an athlete closely and providing immediate feedback on their performance? That is what we call qualitative analysis. It is just to observe and understand the quality of movement to improve performance.

Difference between quantitative and qualitative analysis:

Quantitative analysis is when numbers and measurements are involved. For example, if someone performs a standing broad jump, the observer might say that jump was 2.1 meters long. This provides precise numerical information.

On the other hand, qualitative analysis focuses on describing the quality of the human movement without using numbers. For the same jump, the observer might say that was a very good jump or a bad jump. It is important to note that qualitative does not mean it is vague or general information. The qualitative description can be very detailed. Let us take an example: If an athlete is running, a general qualitative description might be the athlete is either jogging or running, but a more detailed one could be whether the athlete is running with the heel touch, mid-foot, or on the toes. We can check if the trunk is leaned forward or not to get the depth of running analysis in the qualitative approach. Both types of analysis are valuable in biomechanics. Researchers often use quantitative methods to gather precise data, but qualitative methods are essential for real-time observation and immediate feedback for the coaches.

The stages of qualitative analysis:

Nowadays, Qualitative analysis is not just about watching someone perform a skill and making comments. It follows a structured process. Let us start with the preparation stage.

Preparation stage:

This is the foundation of the whole process. In this stage, we focus on understanding the activity, the athletes, and the environment. If we are analyzing a hundred-meter sprinting performance, what do we need to prepare? the first one is the needs analysis. We will determine the goal. For instance, the goal is to reduce the time to cover a hundred-meter performance or to improve running efficiency. Next, we need to study the mechanics of sprinting. This means understanding its phases. The start, acceleration, maximum velocity phase, and deceleration phase. Each phase has specific movements we need to focus on.

And lastly, we identify the key elements that define a good sprinter. These include stride length, ground reaction force, arm swing, and body posture. These are the parameters which we are going to observe. For example, imagine we are working with a sprinter who wants to reduce their time. We will first gather the details about their Current technique, their performance history, and even their training environment. This preparation gives us a roadmap for what we will be observing next.

[Next comes the observation stage. Now comes the actual observation].

Observation stage:

Here we decide how to watch the movement. What is the best angle to observe the movement? Whether it is a front side, side angle, or from the top view, should we use any tools like a video camera or just rely on our eyes? In this example, for sprinting, we would probably use only a high-speed video camera to capture the sprint in more detailed information. We have focused on specific phases like Starting block push-off, the transition to upright running, and maintaining speed.

So, these are the things we can observe, and we need to observe from multiple angles, which is more important. For example, from the side, you can see the stride length and body posture. From the rear, you can check the symmetry in the arm and leg movements. In the example, if you are observing the athlete, you might notice that the sprinter's foot placement or the athlete may perform too much vertical movement, which wastes energy. This information will be observed during this stage. And always remember to take multiple observations because a single view might not give you the depth of information.

[Now, we move on to the evaluation and diagnosis stage].

Evaluation and diagnosis stage:

In this stage, we will analyze everything that we have observed. Here, we will analyze the strengths and weaknesses of the performance, compare the sprinter's technique with the ideal model, or we can compare the athlete with an experienced athlete. So, we can evaluate specific metrics like stride length. For example, when you are overlaying the video, the analysis shows that the sprinter's stride length is shorter than the experienced athlete in the maximum velocity phase. You might find that this happened because they are not extending their hip fully during the push-off phase. This lack of extension is limiting their ability to maintain top speed.

[Finally, we have the intervention stage].

Intervention stage:

This is where we provide feedback and take corrective action. For example, use visual feedback and show the sprinter a side-by-side comparison of the technique with an allied sprinter. This helps them to see the difference and understand what they need to change. Then, drills or exercises should be recommended to address these issues. For instance, if the sprinter's stride length is too short, you could suggest downhill running or a resistance sprint. These drills focus on improving hip extension and explosive strength.

The intervention stage is all about turning observations into improvements. Let me show you how we have applied qualitative analysis in field hockey. For that, we will take the penalty corner as an example. Before going into what exactly we have done, I will explain the basic information about the penalty corner. If you look into the model, the first person to initiate the penalty corner is the pusher or injector. So, he is the pusher. He will push the ball towards the top of the circle. The attacker will receive the ball outside the circle and then hit it towards the goal post. So, this is the sequence of the penalty corner from the attacking perspective.

When you see the defensive perspective, in the goal post, we have five defenders. Out of the five, we have one goalkeeper. As soon as the pusher initiates the ball, the defender will rush towards the attacker to stop the ball. So, this information we will explain by comparing with different countries how we are approaching the penalty corner from a qualitative perspective. The success of the penalty corner highly depends on the person who is going to initiate it, who is the pusher.

The entire penalty corner will take place in around 1.9 seconds for the male and 2.3 seconds for the female. So, what is the expectation for the pusher? He has to push the ball as fast as possible, and it should be accurate enough to send the ball only to the receiver, and most importantly, the ball has to be flatter. So, the ball should not have any bouncing action. It will be difficult for the receiver to stop the ball.

If we divide the phases of the push-in, the initial phase is the stance, and then he will drag the ball to a certain distance, and then the pusher will release the ball with the follow-through. So, the entire push-in is divided into the drag phase and the follow-through phase. In this research, we have identified different techniques of push-in. The first one is the Netherlands, the second one is Australia, and the third one is Malaysia. And we have compared the push-in performance against the first runner of the defending team, namely England, Spain, Korea, Pakistan, Germany, Australia, Netherlands, and Malaysia. So, in total, we have analyzed 37 penalty corners. The first technique is from the Netherlands. You can see very clearly that the right knee is completely extended, and the whole body weight is shifted towards the front foot, which is the left leg. As and when the pushing is initiated, you can see that the right knee is flexed and is almost parallel to the ground.

And, if you clearly notice that the right foot is still in contact during the follow-through phase. The second technique is from Australia. In the initial phase, you can notice that there is a slight bend in the knee when compared to the Netherlands. Similarly, the right knee is flexed when executing the push-in. And it is parallel to the playing surface.

Lastly, if you notice that the right foot is still in contact during the follow-through phase. The last technique is from Malaysia. You can clearly see that the weight is equally distributed between the left leg and the right leg. During the execution phase, the center of gravity is shifted towards the front foot, which is from the right leg to the left leg, and during the follow-through phase, you can clearly notice that the right toe is no longer in contact with the ground.

Now, we need to identify which technique is better so that we can score the goal as fast as possible. For that, we are trying to identify what the ball distance is in relation to the first step of the defender. If you notice, we are introducing numbers to identify the distance. But still, we are trying to understand the concept from a qualitative perspective.

That is why this is known as semi-qualitative analysis. When we compare the three countries, the Netherlands has gained 8.22 meters, and the last one is the 6.84 meters by the Malaysian pushing technique.

The next one is the total time taken for the ball to reach the top of the circle. When we compare, the Netherlands pushed the ball in 1.05 seconds, followed by 1.1 seconds by Australia and 1.12 seconds by Malaysia.

The last one is the flicker and defender ball distance. When you look at the graph, When the Netherlands is flicking the ball, the distance between the defender and the flicker was 4.22 meters. It is followed by Australia, and the last one is Malaysia, where the distance is only 2.89 meters. Why is the flicker and defender distance more crucial?

We will look into this model. As and when the attacker receives the ball, he is entering into the circle. When the defender is closer, like when the Malaysian team is pushing the ball, the opponent is as close as possible, with around 2 meters. When it comes to Australia, they are a little bit back by 3 meters, and the Netherlands is around 4 meters.

So, why is it important? If you look from the front view, as in when the athlete, the distance is more, the attacker will get the field of view of the goal post is much larger when compared to the attacker when he is closer. So, based on the above information, we come to know that the technique of the Netherlands is much better when compared to Australia and Malaysia. In recent years, If you notice, there is no longer the athlete standing and pushing the ball; rather, he is taking multiple steps to push the ball to generate more power and accuracy for the attacker to receive the ball as fast as possible. We have identified why the Malaysian team is lacking in the push-in, in the few milliseconds.

If you notice that in the image, the initial position of the leading leg, which is the left foot, is kept ahead of the right foot. This causes the delay in the pushing. How? Initially, the pusher is dragging the ball away from him, and then he is dragging it towards the line of the stalker. This is the cause of the delay for a few milliseconds.

[Next, we move on to qualitative gait analysis].

Qualitative gait analysis:

If you have a mobile camera or a video camera, you can record the video and do the basic qualitative video analysis. Let us dive into it.

The first one is the **foot strike pattern**, which is a critical concept in running biomechanics, as it can influence both performance and the risk of injury. In this picture, you can see the **three different types of foot strike**:

First, we will look into the **rear foot strike**, where the heel is the first part of the foot to make contact with the ground. You can see here the runner's heel is touching the surface before the rest of the foot rolls forward. This is the most common strike pattern among recreational runners. It usually happens when runners land in front of their center of mass, causing a higher braking effect. This type of running strike, can lead to increased force on the knee joint, making runners more prone to knee injuries like patellofemoral pain.

The next one is the **midfoot strike**. In this case, the middle part of the foot lands almost flat on the ground. The heel and the ball of the foot touch the surface almost simultaneously. This midfoot strike provides a good balance because it aligns with the runner's center of mass, reducing the braking force compared to the rear foot strike. It is often considered a more efficient running style for reducing joint stress.

The last one is the **forefoot strike**. Here, the runner lands on the ball of their feet with the heel barely touching the ground during each stride. This strike minimizes the braking force and reduces the impact on the knee, but it shifts more load onto the calf muscles and Achilles tendon, which helps to improve the forward propulsion of the athlete.

The next one is the **foot inclination angle**. This angle is formed between the sole of the foot on the ground. In the image, you can notice that there is a high foot inclination angle, which means the toes are pointing upward. In the higher inclination angle, it often results in increased ground reaction force. This leads to a higher load on the knee joint. This is because it creates a higher braking effect, which slows down the momentum of the athlete. When it comes to image B, you can notice that there is a very low foot inclination angle. This reduces the braking force and decreases the risk of pain in the knee joint.

Next, we move on to the **tibia angle**. If you notice in image A, the tibia is angled forward, which means the lower leg is more extended at the time of contact, leading to higher pain, braking force. If you notice image C, the tibia is angled backward. You can notice that there is a knee flexion which minimizes the braking force. And in image B, the tibia angle is almost vertical at the moment of contact. When you compare all these three images, Image A has a higher braking force, while both images B and C have less braking force, which dissipates the load to the hip, knee, and ankle joints.

The next one is the **knee flexion during stance**. If you see in image B, it has a greater knee flexion when compared to image A. If the runner has a greater knee flexion, it allows better shock absorption, which reduces the impact force through the leg, and lesser knee flexion leads to a high impact force on the leg. This is because, with lesser knee flexion, the leg might be stiffer and unable to absorb the shock effectively.

Next, we move on to the **trunk lean**. When you compare images A and B, image B has more trunk lean than image A. The research found that if you have less trunk flexion, it means it is associated with a greater knee load. In contrast, increased trunk flexion helps to dissipate the force and minimize the injury.

The next one is **overstriding**. To analyze that, you need to make three markers: one at the hip, one at the knee, and one at the ankle. In image A, if you notice that when the athlete is running, the pelvis marker is in line with the foot marker. But when you compare image B, if you draw a line, there is a very big gap between the pelvis and the ankle marker. So, now you can recollect the information: when the runner is overstriding, you can see that there is an increased foot inclination angle. So, you know there will be an increase in the braking force, and it causes a higher load on the knee joint.

Next, we move on to the **vertical displacement of the center of mass.** In this, you need to draw an imaginary line at the highest point and the lowest point of the running. And if you measure the displacement between this highest and lowest point, image A shows a higher displacement, while image B shows a lesser vertical displacement. Based on this information, it clearly shows that in image A, the athlete is trying to run with a bouncing action compared to image B, where there will be excess energy loss for the runner.

The last one is the **pelvis drop**. If you place a marker on the posterior part of the pelvis and analyze the athlete, compared to image A, image B has a little bit of hip drop. This is because of the weakness of the gluteus muscle. It is unable to generate the force to maintain the posture. When you apply all these principles in the actual scenario, the leg is moving inward, which means the medial part of the muscle, the adductors, is weak compared to the lateral part of the muscle. With this information, try to record a video from multiple angles and provide feedback to the athletes.

[So, thank you, and see you in the next video.]