Exercise & Sports Biomechanics

Dr. Rajinikumar Palaniyappan
Centre of Excellence in Biomechanics Cum High Performance Centre for Sports
Department of Sport Biomechanics & Kinesiology
Tamil Nadu Physical Education & Sports University, Chennai (TN)

Week 05
Lecture 25
Application in Sports

[Hi, everyone! Welcome back to this course].

Previously, we have discussed the introduction to linear kinematics and angular kinematics, followed by how we will analyze any movement with regard to linear and angular kinematics, which is the topic of discussion now.

[First, we will discuss the tools and techniques]

Tools and techniques used in kinematic analysis in exercise and sports biomechanics:

First, whenever we analyze any movement without any equipment, our eyes are the tools we use for visual observation. So, you just need a notebook and pen to analyze a movement. So, you can just note down the area of interest or whichever movement you are interested in. So, that will give you better insight.

Second comes **video analysis**. Whether you have a video camera or a mobile, you can just shoot or capture the video of the movement, any sports skill, or any movement, and you can just analyze it with the playback and note down the components. Since digital video has come into the market, movement analysis has become very easy because it is quite inexpensive and cost-effective, and we can do a lot of analysis. There is a lot of freeware available on the market, and one of them is Kinovea, which is used to analyze the movement. So, **Dartfish** is another software that comes with trial versions.

And the advanced technology that we have is a **3D motion capture system**. So, the Vicon and Qualisys mocap systems use cameras, which are infrared cameras, to capture the movement of any athlete or any skill. And these cameras use Nexus and QTM. The QALYSIS uses QTM software, which is QALYSIS track manager, and VICON uses Nexus software to analyze the movement. And these cameras come with marker-based and markerless options.

Another tool that is used for athlete assessment is **wearable sensors.** The wearable sensors are **IMUs** (inertial measurement units), which are very easy to use. They include accelerometers, gyroscopes, and magnetometers combined, and are very easy to use in the open field. Athletes' kinematic components can be easily measured. We also have goniometers, which are used to measure the joint angle. **Electrogoniometers** are used to measure the joint range of motion when the athlete is in movement. Before we analyze anything, we need to have a fundamental basic understanding of the phases of any movement. So, unless you understand the phases of any movement, you cannot measure it. One is the tools you use to measure, which may be handheld tools or advanced tools.

The technology always uses the best tools, but the technology becomes obsolete over a period of particular years. Technology has kept on changing over the years, but the phases of movement remain the same. The moment we understand the phases of movement, it is easy for us to understand what the key performance indicators, variables, and parameters to be measured are.

Whenever we analyze any skill, we need to simplify it and split it into different phases for easy analysis. The first one is the preparatory phase. The second one is the execution phase. The third phase is the follow-through phase. In each phase, we need to understand the key performance indicators that we need to assess. As far as this linear and angular kinematics lesson is concerned, we are going to deal with only the temporospatial parameters, which are going to play a vital role in any movement.

[I joined Tamil Nadu Sports University in 2008, and we are the first university to start sports biomechanics courses of study in post-graduation. But when we started, we had only one camera. And so, this is how we started. This is the picture taken in 2008-09 with my PG and MPhil scholars. And we had one hired camera. We used to have only one camera to do some 2D analysis with free softwar].

So, we need to understand if you have only one camera. So, first, if you want to do some linear or angular kinematic analysis. So, the first thing you need to have in mind is to understand the nature of the movement. And then, you need to have a better understanding of the technique and phases of a skill or a movement. Then, you need to have a video camera.

Nowadays, we have a lot of cameras that come with different features. So, if you have a digital video camera, that is fine. And the moment you have a camera, you need to understand the frame rate, the number of frames the video camera can capture, and the resolution, right? Whether it is HD or full HD, these are the things you need to understand. And then, shutter speed and aperture.

So, these are the three important metrics you need to understand when analysing any movement in two dimensions. The moment the video is captured, you need to have software analyze the movement. So, we have **Kinovea and Dartfish**. Kinovea is completely freeware. Dartfish comes with a trial version.

You need to understand the software tools and how to measure the important distance and time parameters. The moment you take the measurement, you have to compare the measurements, and finally, the major components you need to understand are the joint angles, time, distance; and apart from this, the linear and angular kinematic components you have to understand and measure. But finally, after taking the measurements and creating the report, the biggest part is interpretation. So, you need to have better knowledge and insight to interpret the collected data. So, this is how you have to proceed. So, whenever you go for 2D analysis, if you have only one camera, ensure that the camera is placed perpendicular to the plane of motion.

For example, if you are measuring the walking pattern of any individual, the camera should be placed perpendicular to the plane of motion. And before that, you need to understand the capturing volume, whether it is three meters or four meters, and you need to fix the distance of the camera, the height of the camera, and the camera lens panning. The camera lens should be perpendicular to the plane of motion, and ensure that the whole image of the athlete or the person who is going to be assessed is being captured by your camera. So, these are all the fundamental positioning of the camera.

Moreover, if the movement is fast-paced, you need to have a better frame rate camera. For example, if you are analyzing a walking movement, 30 frames per second is more than enough, but when you are analyzing running or fast-running movements, you need to have a minimum of 60 frames per second. So, when we are assessing any other fast movements, like a golf swing or sprinting analysis, we need to have more than 100 frames per second camera. So, these are all the fundamental components you need to have before you start doing any analysis with regard to linear and angular kinematics. Then, after 2D analysis, we have the 3D analysis. [This is our lab, the setup we have in our Center of Excellence in Biomechanics and High-Performance Center for Sports. So, this is the setup we have used to do drag flick analysis in field hockey. So, we have a drag flick hockey turf, and the cameras are kept so as to capture the movement volume where the drag flicker will be performing].

Throughout the length of the distance, and here you can see the picture, the subject is being fixed with the markers. So, and another one is cycling. So, we have done a cycling analysis. So, the cyclist comes and sits on the cycle, and the markers will be fixed on both the cycle and the subject. The cameras are positioned in such a way to capture the athlete's cycling performance in three dimensions: X, Y, Z. And next comes the IMU sensors. So, IMU sensors are nothing but inertial measurement units. They come with a magnetometer, accelerometer, and gyroscope with nine degrees of freedom. So, here you can see the essence, IMU sensors which are placed on the subject. So, very easy to fix, and you can calculate all linear and angular kinematic variables. These are all the advanced systems in the market, which are expensive. But just to start with, you can start with minimal equipment, whatever you have.

The only thing is you need to validate the measurements. In kinematic analysis of walking, we have linear kinematics. The variables that come under linear kinematics are spatial parameters, that is, distance parameters. So, we can assess the step length.

What is step length?

The **step length** is the distance between the heel strike of one foot to the other, and the two subsequent step lengths are called stride length and step width. The **step width** can be measured from the frontal plane. The camera has to be placed in the frontal plane so that we can measure the step width, the distance between the heel strike of one foot to the other in width-wise.

The rest of the components, step width, step length, and stride length, can be measured from the sagittal plane.

[Next comes temporal parameters].

The **temporal parameters** mean the time parameters. So, we can measure the number of steps per minute and then the gait speed. So, at what speed the person is walking, whether they are walking at 4 meters per second or 5 meters per second, we can measure. And then step time. So, step time means how long they are taking to complete one step. Foot contact time is how long their foot is in contact with the ground. And then we can measure the angular kinematics. So, what are the angular kinematics we can measure? So, we can measure the joint angles and each phase of the gait. So, the range of motion, and then we can measure. So, these are all the key performance indicators we have to measure in gait, but before that, we need to understand the phases of gait. The phases of gait are the stance phase and the swing phase.

Stance phase is the period when the feet of the person are on the ground, and swing phase is the period when the feet are in the air. So, the stance phase can be single support or double support. The single support means one foot is in contact with the ground, and the double support means both feet are on the ground. So, in these phases, we need to analyze and measure the linear and angular kinematics. So, to do the analysis, you need only a single camera or a mobile device is enough to perform this analysis.

Because you have to capture the video, you need to take the video and analyze it using free software after capturing it. So, that is how we can measure the matrix of gait. After measuring the matrix of gait, you need to plot the information in an Excel sheet and create a graph. And you have to create and generate the report. After generating the report, you need to interpret the data to complete the analysis.

[Next comes the **hundred-meter sprint analysis**].

So, when you have only a stopwatch, how can we measure each 10-meter speed? Say, for example, you can have the split of each 10 meters or the split of each 20 meters. So, 0 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 50, 50 to 60, 60 to 70, 70 to 80, 80 to 90, and 90 to 100. There are 10 split phases.

If you want to assess the 100 meters in each 10 meters. Or if you have only 5 stopwatches and 5 personnel to measure the timing of the athletes. You can have 0 to 20 meters, 20 to 40 meters, 40 to 60, 60 to 80, and 80 to 100 meters. You can make the assessors stand in 5 places or 5 slots. Ensure that for each phase or each station, you need to have three timers standing one after the other. You can make the subject or the assessors stand one after the other or you can make them stand on opposite sides, totally opposite.

So why we have to have three timers in each station is to have better valid, reliable, and objective data. So, the moment the athlete is given the signal, 'On your mark, start,' either you can use a gun, a clapper, or a whistle to start. The moment the whistle is blown, each and every timer will start the timing. The first 10 meters station assessors will stop the timing the moment the athlete crosses. Similarly, at each station, the timers will stop the timing.

And after the timing is taken, each 10 meters or each 20 meters, depending on your assessment pattern, you have to note down all the timers' timings in each station. And ensure that, for example, in the first 10-meter station, three timers have taken the timing. And if any two timers' timing is the same, you can take that timing. If all three timers have different timings, you have to take the middle time, not the average time.

You have to take the middle time. This is how you have to take the timing. Final timing in each 10-meter station or each 20-meter station. After taking the timing, you need to make the calculation that is distance. If you have the station each 10 meters, you have to calculate the average speed of each 10 meters by dividing the time taken. Similarly, you have to measure each 20 meters. Time and you have to calculate the each 20-meter speed. After calculating each 10-meter or each 20-meter speed, in Excel, you have to plot the data. After entering the data, you have to plot the graph, and you can find out how the athlete Increases in his speed, that means the velocity of the athlete increases over every 10 meters, and which distance he attained or reached the maximum speed, and up to what distance he maintained the maximum speed, we can find out.

So, this is the easiest way where we can assess the hundred-meter sprinter performance by having only a stopwatch. When you do not have the stopwatch, our mobile phone is enough to take the data. So, the reason why I tell you this method is not everyone will have the advanced equipment. Not everyone will have the timing gates.

Not everyone will have the sophisticated motion capture system. To start the analysis, so, to understand the basic kinematics, the average speed in each and every 10 meters or 20 meters, to give some insight and input to the athletes, so you can start doing this type of assessment when you have timing gates. It is fine; that is the most valid assessment you can follow that rather than timing, I mean handheld dynamics, and when you have cameras. Say, for example, when you are having 5 or 6 cameras, you can keep the cameras each and every 6 meters or 7 meters, depending upon the capturing volume, what it can capture. So, based on the camera, you can find out the number of steps an athlete takes. Also, you can find out the foot contact time of the athlete, stride angle of the athlete by having the video of the athlete, and you can analyze it by using the camp freeware called Kinovea software. So, Kinovea software is an important tool where you can assess the temporospatial parameters. And apart from the 100-meter sprint, we can go for kinematic analysis of the long jump.

When you analyze the long jump kinematically, you need to understand the phases.

The long jump has an approach run, penultimate stride, takeoff stride, takeoff from the takeoff board, flight, and landing. Normally, before we do the analysis, we need to understand the particular event and sport. The long jump is always run with an approach run with a distance of 40 meters to 45 meters. The athletes have the linearity or the privilege of starting the approach run at any distance from 40 to 45 meters.

Then, the approach run is run up to the takeoff board. So, we need to understand the speed of the athlete, the number of strides he is taking, and the stride frequency.

What is stride frequency?

The number of strides per second is the stride frequency. Then, the moment the athlete comes nearer to the takeoff board, that step before the takeoff step, that means the takeoff stride, I would say, So, before the takeoff stride is called the penultimate stride. The last stride before the takeoff stride is called the penultimate stride. So, what is the length of the penultimate stride, and what is the length of the takeoff stride? How long is the athlete on the takeoff board, and what is the takeoff time? At what angle is the athlete projected into the air? What is the horizontal velocity? What is the vertical velocity? The athlete would have reached the maximum speed during the approach run, and the moment he hits the takeoff board, there will be a small reduction in speed. So, we need to understand what the speed loss is.

We also need to understand the distance jogged and how long the athlete is airborne, because after the takeoff, the athlete uses two types of techniques to clear the distance: one is the hang style, and the other is the hitch-kick style. The movement you see here in the picture is the hitch-kick style. This is the style the athlete is using. So, you can say he is using a cyclic pattern to cover the maximum distance in the long jump. Further, you can see in this video the approach, takeoff, flight, and landing. These are all the important phases of the long jump that you need to assess and measure.

In this picture, you can find the last third step, the second-last step, and the last step. So, you can find the length of each step, understand it, and compare it with other athletes. In the long jump, after the takeoff, the distance jumped is always taken into consideration. So, you need to understand the takeoff distance and the flight distance. The flight distance is always determined by the takeoff speed, and the takeoff speed is determined by the run-up speed of the athlete and the takeoff impulse. How long is the athlete in contact with the ground at the instant of takeoff? Then, the mean force which he applies and the time on the board determine the takeoff impulse.

The athlete's mass also determines the takeoff speed. The takeoff angle determines the flight distance. So, as we discussed earlier, long jumpers aim for a takeoff angle of 18 to 23 degrees. Sometimes it is 18 to 25 degrees. And the takeoff height.

At the instant of takeoff, the height of the center of mass of the athlete has to be determined. Then, **aerodynamic factors**. So, in the long jump event, you can find one equipment fixed 20 meters from the takeoff board. That is the **wind gauge.** The wind gauge is an equipment that runs the moment the athlete starts the approach run.

So, it runs for 10 seconds. And the equipment is in operation for 10 seconds. And if the wind velocity is plus or minus 2 meters per second, the athlete's performance is considered for a record. And sometimes, if the performance is achieved, if the long jumper creates a record, but the wind velocity is more than 2 meters per second, where the jumper got assistance from the air. So, that record will be null and void, whereas the athlete's performance position will be valid, but that performance will not be considered as a record.

And we need to understand the **landing distance** also. And here in this picture, you can find out how the takeoff distance, flying distance, and landing distance are measured from the takeoff to the landing. The center of mass is the one which we measure instead of the center of mass and takeoff foot. The distance between the takeoff foot and the center of mass line determines the takeoff distance. The moment the athlete releases his foot from the takeoff, the moment he comes into the flight, the moment he hits the ground, so that is considered as the flight time, and the moment he hits and the distance from the landing foot to the center of mass is called the landing distance. The total flight distance, the total distance covered by the athlete, is determined by the takeoff distance, flight distance, and landing distance. And you can find the ground contact time the moment the athlete, the long jumper, hits the takeoff board, so here the athletes spend 0.13 seconds.

Next, comes the **takeoff angle**, but at what angle the long jumper goes for takeoff. So, it is 18 to 23 degrees. Sometimes it is 18 to 25 degrees. It depends upon the nature of the competition and the standard of the athlete. And so, elite male long jumpers can achieve a horizontal velocity of approximately 8.8 meters per second during takeoff. So, we have already discussed vertical velocity and horizontal velocity. And the horizontal velocity and vertical velocity have to be taken into consideration.

So, before we analyze cricket bowling, we need to understand the phases of fast bowling. So, bowlers always go for a run-up. So, in the run-up, they are preparing for a run-up. to build up momentum. So, you need to understand the distance of the run-up as well as the time of the run-up. So, that we can understand the speed of the run-up.

Then comes the **pre-delivery stride**. The pre-delivery stride is otherwise called the penultimate stride, and the length of the penultimate stride can also be measured. So, for this, you need to keep the camera at the instant from the distance where the cricketer is moving. So, perpendicular to the plane of motion. And you can have two cameras for assessing the run-up and the delivery phase.

And during the **delivery stride**, we can understand the delivery stride length, the ground contact time, and at what height the ball is released. And then the follow-through. So, the moment the ball is released, the ball release speed can be measured, as well as the knee flexion at the moment of landing during the ball release. Here we have a 3D motion analysis of a spin bowler. So, this is captured with IR cameras, infrared Qualisys cameras.

We used 12 IR cameras and 2 video cameras, totaling 14 cameras in the capturing volume of the spin bowling. So, the purpose of this spin bowling was to check whether the athlete is throwing the ball and whether the elbow's flexion and extension are within the range of 15 degrees.

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