

**Exercise & Sports Biomechanics**  
**Prof. Viswanath Sundar**  
**Department of Physical Education & Sport Science**  
**Visva-Bharati University, Shantiniketan (WB)**  
**Week 01**  
**Lecture 01**

**Introduction to Exercise & Sports Biomechanics**

Hello everyone, welcome to this course on exercise and sports biomechanics. First, let me take you back in time and compare the actual performance in the Olympics. For that, let's watch the 100-metre performance of the 1912 and 2016 Olympic performances. The 1912 Olympics was won by Ralph Carrick and 2016 was won by Usain Bolt. Let us see what is the difference between these two videos. It is just like spotting the difference. The first one is the camera technology. In 1912, they were using the black and white video camera. But in 2016, we are using high-tech color video cameras.

If you watch carefully, in 1912, they were using only two cameras, where one at the start and another at the end, which is in the finishing line. In addition, if you notice that the camera is not panned, it is just a fixed camera, one at the start and another one at the end. But in 2016, the camera was panned; it was zoomed in and zoomed out very carefully to capture the entire movement of the 100-meter performance.

**In recent years, they have been using a 4D replay system. What is meant by that?**

It means that the entire event was captured from multiple cameras simultaneously. As and when the event is finished, this system can show the entire event in 360 degrees, so now you can see from the side view, from the back view and from the front view.

**The next one is the surface and shoe:**

Because they interact with each other in the entire event, in 1912, the sprinters competed on gravel, whereas in 2016, they competed on synthetic track. The problem is that gravel absorbs more energy, making it harder for runners to maintain speed. In addition, they were using leather shoes with fewer spikes because the foot traction was very low; synthetic tracks provide a better grip because the spike pattern in the shoe facilitates the athlete for better forward propulsion, which allows the athlete to run faster.

**The next one is the starting mechanics.**

I will zoom in a bit; you can notice some equipment on the ground where the athletes dug holes in the gravel for placing the foot. This process was highly inconsistent. Later, they have introduced the starting blocks.

It was highly sophisticated, which helps the athletes to accelerate from the starting block much faster and better when compared to the traditional method.

## **The next one is clothing.**

In 1912, the athletes wore loose cotton clothing, which created more air resistance, known as drag, and since it is cotton clothing, it absorbs the sweat and increases the weight of the cloth, which reduces the performance of an athlete. Currently, athletes are wearing tight synthetic suits, which reduces air resistance. In turn, it supports and increases the performance of an athlete.

After all these transformations, do you know that in 100 years of span, the performance was increased by 1 second, which is from 10.6 seconds to 9.6 seconds. It is just 1 second performance was improved. Can you imagine that the gold medal performance in 1912 is no longer eligible to compete in the current Olympics because the qualification time to compete in the recent Olympics was 10 seconds? - I hope you understand the transformation of sports in 100 years.

Let me give you another example: a marathon in the year 1912. Ken McArthur completed the race in 2 hours 36 minutes. After 100 years, the Eliud Kipchoge gained 30 minutes by clocking 2 hours and 8 minutes. But if you plot the 1912 performance in the 2016 Olympics, he was ranked 132nd position. If you notice that all three athletes finish so closely in the 2024 Olympics, gold, silver and bronze medalist performance.

It is less than 90 seconds, which is a 1% difference between the gold, silver and bronze. To validate the 1% difference, I will show you another example. let's watch the 2016 rowing performance, and if possible, you can identify who won the gold and the silver medals. it was so close, and if you notice the performance of the athletes is 6 minutes and 41 seconds with the photo finish, the difference was less than 0.01 per cent. We are focusing on that 1 percentage gain to improve the performance of the athletes. High performance is a process from novice to elite level.

If the process breaks, what happens? The performance of the athletes will deteriorate, or the athletes will get injured. Usain Bolt ended his last race with a hamstring injury, and Eliud Kipchoge ended his last race with severe back pain in the recent 2024 Olympics. High performance is the integrated approach between coaching, sports science and sports medicine to improve the performance of an athlete and minimize injury, which includes sports biomechanics, physiology, strength and conditioning, nutrition, psychology, anthropometry, and a lot more.

If the entire world is using the same formula, why is there a difference in the medals? If we compare, United States achieved more than 2500 medals since 1896, but India has achieved only 41 medals since 1900. If we say that we are progressing on time, the answer is no, because if we compare with China, they have started actively participating in volume since 1984, and they have secured more than 700 medals, which means we are lacking in something. The real problem is integrating coaching and sports science. Coaching is all about practice-based approach and it is purely a traditional method.

Coaches always rely on their instinct and feel, based on their experience with the athletes and due to that they can understand the dynamics of the game, usually the focus of the coach is on result and performance they usually judge the success based on the outcome of

the results, but on the other end Sports Science takes an evidence-based approach purely relying on research and facts. It is all about studying performance through precise measurement and tracking data like speed, strength, endurance and other biomechanical parameters. It identifies exactly what works for the athletes and what does not to optimise the performance of an individual. Based on the research, it clearly understood that sports scientists are having lack of communication with the coaches.

It is just a lack of communication, which means sports scientists are unable to translate the information in the coaching language. That is the key factor to improve the performance. Another research was conducted by Emmy Waters in the year 2019 on British coaches to understand the experimental knowledge on coaching and biomechanics. She concluded that coaches have inconsistency in the understanding of biomechanics theory during support services, both in training and competition. It is also the same in India, right?

That is why this course is designed to address this gap. Let us first decode what is exercise, sports and biomechanics. Before that, we need to understand what is physical activity. Physical activity is any bodily movement that is produced by our skeletal muscles and burns some level of energy is physical activity. For example, if you are walking, running, swimming or if you are climbing stairs, everything is considered as physical activity.

Simply, any movement that uses energy is physical activity and exercise is the subset of physical activity. So what is exercise? Exercise is the planned, structured and repetitive movement that helps to improve or maintain the physical fitness of the athletes. Let us understand this in deep.

What is meant by planning?

It means the activity is not random. We need to set a goal like three times a week or four times a week as a part of strength training or whichever training you are planning for. In this scenario, we take a barbell squat as an example. In this, we need to plan how much weight the person has to lift; how many sets? how many repetitions? Everything needs to be planned very clearly.

**The Next is structure.**

This involves a proper setup. In this scenario, we have taken barbell squat as an example. In this, we need to focus on placing the barbell on our shoulders and maintaining a good posture. We have to initiate the squat by lowering the body and then returning back to the standing position, and we have to focus on the foot position like whether we are kept straight or with averted. This structure ensures the exercise targets the right muscles like quadriceps, hamstring, gluteus and core muscles.

**The last one is the repetition.**

Repetition is the key to building strength or endurance. In barbell squats, if you are performing multiple reps and sets like 3 sets of 10 repetitions or 3 sets of 4 repetitions according to the principles of training. The second one is sports. The primary focus of any sporting activity involves physical exertion and skill. In addition, it is a competitive in nature with the structured rules.

For example, javelin throw, soccer, field hockey, weightlifting, etc. Without understanding sports, we can't apply mechanics to them. Finally, biomechanics. Bio means living being or life. Mechanics means it is a branch of physics.

By combining, It is the application of physics principles in any living organism. There are different branches of biomechanics. If I am asking a simple question, what is the smallest unit of life? Cell, right? If a cell interacts with the physics principle, it is referred to as cell biomechanics.

For example, in sports, everyone has experienced some kind of injury. But what exactly happens after we get injured? Cells near the wound site begin to migrate towards the affected area to start the healing process. The research led by John Group, funded by the MRC, studied the cell movement and found that the wound heals faster during the day compared to the night; the injuries at night take longer to recover; it goes up to 60 per cent when compared to day.

### **Next is plant biomechanics**

The first one is the structure of the tree. If you look at the tree you will notice the trunk is thicker at the bottom and thinner as it goes up. Since the base is wider, it gives more stability and strength where it is needed the most. Which is similar to the sports, right? The branches of a tree are very flexible. This means they can bend and move with the wind instead of breaking. It is not fragile. when the branches sway the pressure of the trunk and the root is reduced, keeping the trees safe during the strong winds. You can see biomechanics everywhere in nature.

### **Next is animal biomechanics**

Animal biomechanics is a study of how animals move and interact with the environment using physics principles; for example, in equestrian Sometimes horse fail to clear high obstacles due to inefficient takeoff mechanics during jumping. Because it is an Olympic sport, we must focus on it. The biomechanical analysis was conducted to identify what would be the optimal takeoff to analyze the performance of the horse. And they have used a motion capture system for this.

### **Moving on, to human biomechanics**

It especially focuses on body postures and their effects. For example, when we are looking down at the phone, the head tilts forward, which increases the load on the neck. The more the head leans forward, the greater the forces on the cervical spine. For instance, currently, I am in the neutral position, which I am looking at you.

Based on the research, now the current weight is almost 5 kg. If I am looking down, that is by 30-degree angle, so then the weight increases up to 18 kg. If I am looking down much more like 60-degree angle, then it goes up to 27 kg. If you are watching this course on mobile, mind your postures for better health.

### **The next one is the occupational biomechanics.**

It is all about health. studying how our body moves and work during the different tasks at the workplace. Many jobs like lifting heavy weights or doing the same movement again and again can cause strain or even injuries over time. By understanding the posture when we are executing the task, the movement and the force acting on the body, we can design a safer workspace to reduce the entire risk for the individual.

For example, if you are working in front of the computer for a whole day, which means you have to make some kind of adjustment on the table or on the chair and make sure the computer screen is at a high level. You can use an ergonomic keyboard and mouse, which reduces the strain on the neck, shoulder and wrist joints. This not only prevents long-term problems like back pain or joint issues but also helps you to work more comfortably and efficiently.

### **The next one is the rehabilitation biomechanics.**

It is an application of mechanical principles to help athletes recover and gain back to normal movement after injury. In addition, it also focuses on improving athletes with physical impairment, like Paralympic athletes, to enhance their quality of life and performance in their respective sports. For example, ACL rehabilitation is one of the leading methodologies that everybody is focusing on. It is a structured process to monitor the athlete from day one of the operation till they return to active sports.

### **The last one is sports biomechanics**

It is an application of physics principles in all sports movements. The primary goal is to enhance the performance and minimize the injury among the athletes. In recent years, the application of exercise and sports biomechanics has played a crucial role in modern sports.

It helps the athletes to move effectively and efficiently. It also helps in designing new equipment such as lightweight shoes or better equipment like rackets or hockey sticks tailored for specific athletes to improve performance. Lastly, it facilitates the designing of effective training methods, ensuring the athletes train smarter, not harder, for optimal results. So, where does biomechanics fit into the sports ecosystem? What is the role of biomechanics here? As a bio-mechanist, the first step I need to do is gap analysis.

### **What is meant by gap analysis?**

It is a process of identifying the difference between the actual performance, the current performance and the desired performance that you want to achieve. It helps us to pinpoint where exactly the improvements are needed for the athlete.

For example, if a shot putter is throwing 15 meters and needs to hit 16 meters of distance, which is exactly 1 meter. From here, we can able to plan what are the KPIs that need to be improved or tweaked.

## **What is meant by KPI?**

KPI is the key performance indicator, which is the action variable where we are going to provide some kind of intervention to it. It provides a clear roadmap to bridge the gap and how to achieve the specific target.

The second step is to create a deterministic model. The deterministic model helps us to break down the performance into smaller measurable factors that will directly affect the final outcome of the athlete. It will help us to understand how these different variables contribute to the performance, and it will show what the relationship between them is; for example, in short put, the distance the shot travels depends on factors like release height, release angle, release velocity and strength of the throwing arm. This deterministic model organizes these factors logically and makes it easier for the coaches, sports scientists and the athletes to identify what to improve exactly.

During the regular training and competition simulation, we recorded the performance of the athlete, and we made simple mathematical modelling to identify what are the key performance indicators that need to be tweaked. If you look at this table, during the training and competition, we recorded the initial velocity, height of radius and angle of projection. In addition, we have recorded the actual throwing distance. Based on these three parameters, we have computed this throwing distance and compared it with the actual throwing distance.

Both the values are almost matching to each other. And from here, I have identified which is the best performance among these eight trials. And 15.22 is the best performance among these all. So I have taken all these three components which I have told you and I started to model only these three parameters. As a first step, we have increased only the angle of projection from 34 to 45-degree angles.

And we have noticed that at the angle between 40 to 42, the athlete achieved 15.78 as a maximum performance as a model. And we have kept the initial velocity and height of release as the same. Then, we have integrated this into our training program by following the concept of skill acquisition stages to ensure consistency in maintaining the higher angle of release. After 6 to 8 months of training, the athlete gained approximately 1 meter of actual distance in one of the international competitions. So, this simple mathematical model works perfectly for this athlete to identify the actual angle of projection. From there, if you notice the initial velocity, we have increased from 11.6 to 12 by keeping the height of release and angle of projection the same as in the previous model we approached. If you notice that the performance was increased by above 1 meter from 15.2 to now 16.76 in the modern. So, how do we achieve that? We have taken a multi-discipline approach to address this gap.

To increase the initial velocity, the first step is to increase the power. For that, We need to work on strength and conditioning, focusing on the exercise that builds explosive strength, right? To build the power, we also need to target muscle hypertrophy, which involves increasing the muscle size. And, for hypertrophy to happen effectively, we need to focus on nutrition to ensure the optimal intake that supports muscle growth and recovery.

Finally, sports psychology will be an added flavour to improve the performance of the short putter. It is an integrated approach where the entire sports science team should work together with the coach and the athlete to enhance the performance of the athlete. Some of you might be wondering if changing the release angle just a little bit really makes a difference in performance. or some may be thinking about how much the scientific support actually helps in performance these are valid questions, and the answer lies in something called chaos theory.

**The chaos theory** states that performance is influenced by a lot of unpredictable factors, even small changes. For example, a fraction of a degree in the release angle, which we have shown in the example, a slight wind shift, or an athlete's mindset on the competition day can have a very big impact in the performance.

This is often referred to as a **Butterfly Effect**, where a small cause can lead to a big effect. For example, in Snooker, we are going to track the cue ball, which is white in color. For this, all the balls were arranged similarly in two tables. And if you notice on the second table, the green ball was moved slightly forward to observe the butterfly effect. Until this point, both videos are exactly the same. From here, the changes begin. This is what we call the butterfly effect, where even a small change can lead to big effects.