Exercise & Sports Biomechanics
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Measurements in force plates

[Hi everyone! So, today we are going to discuss the **instrumented treadmill]**.

What is an instrumented treadmill?

An instrumented treadmill is nothing but a treadmill with a force plate. So, when an athlete runs on a treadmill, all the force vectors can be measured in three dimensions. The running mechanics, whether it is walking mechanics or sprinting mechanics, all the ground reaction force, contact force, center of pressure, moment, and contact time of the foot and flight time, all these biomechanical variables will be measured in an instrumented treadmill. The instrumented treadmill can also be integrated with a motion capture system.

Type of instrumented treadmill:

[Let us see in detail about the instrumented treadmill. So, you can see here a treadmill where the athlete is walking, and underneath the belt, the force plates are fixed. And let us see the features of the instrumented treadmill]

We have two types of treadmills, with belts, that is, a **single-belt treadmill** and a **split-belt or dual-belt treadmill**. So, what you see here in this picture is a split-belt treadmill where the athlete or the person is walking on the treadmill.

Further, we can see here the force plate. The force plate is embedded or underneath that belt of the treadmill and the force plate can be one dimensional where it will give you only the ground reaction force or there are certain force plates which are fixed with the treadmill with three dimensional. So, we come to know about there are two types of treadmill one is single belt another one is split belt and we have instrumented treadmill with one-dimensional force plate and three-dimensional force plate.

Features of treadmill:

The speed of the treadmill can be from 0 to any number. The instrumented treadmill are manufactured from 0 to 25 kilometers per hour. And based on the demand and requirement of any person, the treadmill can be manufactured. Normally for sports application the treadmills are manufactured with the speed of 0 to 40 kilometers per hour and even if our requirement is more than that the manufacturers can design and manufacture an exclusive tailor-made and custom-made treadmills. So, the treadmills can be manufactured from 0 to 45 kilometers per hour based on the demand and requirement.

And there are certain treadmills from 0 to 48 kilometers per hour. Whether it is one dimensional treadmill or three-dimensional treadmill, they produce with 0 to 25 kilometers

per hour. But when it comes to sports application, so when you want to assess any sprinter or long-distance runner, or middle-distance runner. We must have at least from 0 to 40 kilometers per hour Speed treadmill. And Treadmetrix is a company that produces treadmills with a maximum speed of 0 to 48 kilometers per hour. Whereas H/P/Cosmos and Bertec produce treadmills from 0 to 40 kilometers per hour, and H/P/Cosmos and Demand produce from 0 to 45 kilometers per hour. And here are the products, who are all the manufacturers of treadmill. AMTI, then Treadmetrix, H/P/Cosmos and then Bertec. So, these are the four international manufacturers produce and manufacture instrumented treadmill for sports, research and rehab applications. There is one more brand called **Zebris**. The Zebris is produced with pressure mapping.

With treadmills of Zebris brand, we can measure the pressure metrics of the athlete while walking and running. When it comes to integration, so the treadmills can be integrated with motion capture system, IMU sensors, Electromyography that is EMG, ECG (electrocardiograph), then EEG (electroencephalograph), and heart rate. So, the heart rate monitors can be integrated with the treadmill. And AR, VR that is augmented reality, virtual reality and then eye tracker can be integrated.

Furthermore, the physiological measurements can be taken along with the biomechanical parameters when we integrate all these physiological hardwares as well as the EMG and other motion capture hardwares are integrated with the treadmill. We have further features in the treadmill, which we will discuss with regard to applications.

What are the uses of an instrumented treadmill?

An instrumented treadmill can be used for measuring the walking gait, both kinematics and kinetics when it is integrated with the motion capture system and running and then sprinting and it is also used for clinical and rehabilitation purpose and the instrumented treadmill is used in space as well as defence and research and development and before we see the belt dimensions, let us discuss about the applications.

For example, we can measure a person's walking gait, running gait, and sprinting gait on the instrumented treadmill. Furthermore, the pathological gait of a population can be measured on the treadmill to identify their key performance indicators and provide remedial measures. When an athlete is injured, we can measure them on an instrumented treadmill to analyze the loading on each joint, plantar pressures, ground reaction force, and foot contact time. All these metrics will be vital for rehabilitation and clinical specialists.

When scientists, particularly when they go to Mars or the Moon, where there is no gravitational force acting on the body, the bones become brittle and weak, and mineral density is lost. Therefore, in space, they must exercise using specifically designed instruments, such as instrumented treadmills. At the same time, instrumented treadmills are also used in defense. Defense personnel traverse different terrains, including steep areas, and stay in places like Siachen for weeks or months. To reduce the load, they use **Exoskeletons**. Exoskeleton research utilizes instrumented treadmills for further design and development of optimal exoskeletons.

Feature of Instrumented Treadmill:

We consider belt dimensions. The treadmill operates as athletes run on the belt, which rotates or moves. Belts come in different dimensions. At the same time, the acceleration and deceleration are another feature. How fast the belts can be accelerated and how quickly they can decelerate. So, these are all the other features, whether it is 15 meters per second squared, 20 meters per second squared, or 25 meters per second squared.

Furthermore, the treadmills will have safety features like handrails, on the front side of the treadmill as well as the sides, so that the athlete or patient may feel comfortable and safe while running or walking. At the same time, they also have a harness. The harness is what helps the person prevent falls, and the treadmills will also have an emergency stop. So, either the subject will have control, or the tester will have control. Some treadmills will come with one safety emergency stop, and some will come with dual emergency stops.

Additionally, the treadmills also come with incline and decline options. So, how many degrees they can incline and how many degrees they can decline. Moreover, the treadmills will indicate how much load they can bear. For example, whether it is 5 kilo Newtons, 10 kilo Newtons, or 15 kilo Newtons of force that can be borne by the force plates. So, this is the maximum limit for any force plate. So, that is also an important feature in the treadmill.

What are the variables you can measure?

We can measure **kinematic variables** like distance, time, speed, velocity, acceleration, and then we can measure cadence in kinematics, stride length, and stride frequency. Then, speed and joint angles can be measured for each phase of running. Additionally, foot contact time and flight time can be measured.

Next come the kinetic variables because it is an instrumented treadmill with an inbuilt force plate. So, whether it is one-dimensional or three-dimensional, we measure ground reaction force for each foot strike. Thus, braking impulse and propulsive impulse can be measured. Then come joint moments, center of pressure, and the path of the center of pressure can be measured.

We can also measure physiological variables when we integrate the hardware of physiology with the instrumented treadmill. So, we can find out heart rate variability. Then, **VO2 max**, which is the volume of maximal oxygen consumption. Then, we can measure EE and MR. MR means metabolic rate, and EE means energy expenditure. And, we can also integrate with EMG (electromyograph).

The instrumented treadmill gives us complete information about human movement when they walk, run, or sprint, combining with other metrics like physiological variables, HRV, VO2 max, metabolic rate, energy expenditure, and EMG. Apart from this, an eye tracker can also be integrated to assess gazing. Particularly in pathology, such as pathological gait, when we want to measure the difference in limb contact and reaction force, it is most useful. So, instrumented treadmills come with different features, whether for sports applications, the footwear industry, or pathological assessment. Each field needs a customized treadmill, and that is how we can use the treadmill for different applications.

Components of an instrumented treadmill:

Let us see the components of an instrumented treadmill. You can see here that the instrumented treadmill comes with a frame. So, underneath there is one frame, and it will be screwed to the floor. So, the base is there. At the same time, we have an elevation frame for inclination and declination. So, we have an elevation frame. At the same time, on the front side, the instrumented treadmill has to run or be operated by a motor. So, the motor will be there. The motor will only make the belt move. So, it is a single belt by H/P/Cosmos, and a pressure plate can also be added. At the same time, you can see this treadmill will have a panel, a control panel, and apart from this, it is connected. All the data will be transmitted to the computer, and all the metrics can be measured by automated software. So, these are all the basic components of a treadmill, and the treadmill will also have handrails, and harness.

Instructions on how to position a treadmill:

The position of the treadmill can be underground, level with the surface. So, the treadmill which you see here is a split-belt treadmill, and it is fixed in line or level with the ground. That means before the installation itself, they will dig a pit in the ground and fix the treadmill so that the surface will be in line or level with the normal surface. There are certain treadmills where they can fix the treadmill on the floor as an elevated structure.

So, here you can see the treadmill can be fixed as an elevated structure. It can be moved from one place to another very easily. And, the treadmill also has a harness. So, you can see the harness lying hanging on the second treadmill. So, the harness is the one which is attached to the body of the athlete to prevent falling. And the treadmill comes with one-dimensional and three-dimensional force plates.

Integrate the Treadmill with Mo-Cap and interpretation of data:

And here you can see the treadmill can be integrated with Visual 3D professional software to provide real-time data. There are certain treadmills that come with their own software, while the rest require us to take the raw data and post-process it. And you can see the 3D instrumented treadmill data and find out that X always denotes the medial-lateral force when a person is walking, running, or sprinting. And you can see the first graph at the bottom where the X-axis represents the time parameters, and the Y-axis represents the force parameters. Now, the force can be measured in Newtons or times the body weight. [Next, comes the Y force].

Y force is the anteroposterior force. [Then comes the Z force],

Z force is the vertical force. You can see the pattern of each force. The X force will have a different pattern. The Y force, which is the anteroposterior force, will have a different pattern. And the Z force will also have a different pattern of ground reaction force.

Since the treadmills come with automated software, it will give us instant data. And so here, on the right side, we have instant data of the forces. And the body weight is given on the vertical axis, and the timing is given on the X axis. And so, the force of the left foot, which is the Z force (ground reaction force) and the anteroposterior force, is given in the second graph, and the third graph is for the medial-lateral force. So, in 20 seconds how

many footsteps have occurred are measured, and you can find many values that have a similar pattern. So, that means the gait variability is less.

When there is an abnormality in this pattern of the graph, we can understand that there is poor mechanics of running or walking, or the athlete is fatigued. So, due to fatigue, the foot mechanics have changed. Even if you see here, the body weight is shown as the force, and then we see the Y force and then the Z force.

How to select a treadmill, which treadmill is useful?

With regard to speed, which speed treadmill should I purchase? It is a question. And most of the time, the end users may not be aware of the fact that a 20 kilometers per hour treadmill or a maximum 25 kilometers per hour treadmill will not serve the purpose. Even when the athlete is running a marathon, the marathon distance is 42.195 kilometers.

You can see the reduction in the timing of the marathon from 1905 to 2020. So, considerably, there is a decrease in the timing. So, if you see the last record, it is almost closer to 2 hours, which means that the performance of the athletes keeps changing and moves toward betterment day by day, year by year. If you see the men's world record in the marathon, it is 2 hours and 35 seconds. The world record holder is **Kelvin Kiptum** from Kenya.

The record was set in 2023 at the Chicago Marathon. And if you see, the women's world record, the women ran 2 hours, 9 minutes, and 56 seconds. The runner is **Ruth Chepngetich** from Kenya. And the record was set in 2024 at the Chicago Marathon. And

What is the average speed of marathon runners in both the men's and women's categories? So, the average speed is 21 kilometers per hour for men and 19 kilometers per hour for women. So, this is the average speed. Maybe the athlete can still run faster than this. A marathon runner may sprint during the last 200 or 300 meters of the marathon. So, in that case, we have to use a higher-speed treadmill.

Even a 25-kilometer-per-hour treadmill is not suitable for measuring athletes' running, whether long-distance, middle-distance, or short-distance. So, those types of treadmills can only be used for clinical purposes.

What is the advantage of using a treadmill to assess the performance of marathon runners? Because marathon runners can run at different speeds, increasing or decreasing speed, and with different inclinations and declinations. So, what we can measure is the point at which the athlete becomes fatigued. At the same time, we can assess whether any mechanics are changing due to fatigue, along with all the physiological parameters. And obviously, in marathon runners by definition, they will be increasing their speed.

Sometimes, some of the athletes may sprint to finish. So, the moment they sprint in the last phase, the speed of the treadmill should obviously increase to accommodate the runner's pace. We can also measure the foot strike pattern of the athlete to determine whether they have proper or poor mechanics. In the case of poor mechanics, we can provide remedial measures. Along with the motion capture system and physiological parameters, we can fully assess marathon runners on an instrumented treadmill.

Next are the Indian national records in 200 meters, 400 meters, and 800 meters. They are held by **Amlan Borgohain**. In 400 meters, by **Muhammed Anas**. In 800 meters, by **Jinson Johnson**. If you want to measure their speed or average speed, we can determine that. Here, it is 35 kilometers per hour, and the 200-meter national record holder is listed. So, if you want to measure the Indian national record holder in 200 meters, you need a minimum of 35-plus, meaning the average speed is 35 kilometers per hour. Still, the athlete may improve. So, ideally, a 40-kilometer-per-hour treadmill is the best option.

At the same time, if you see the 400 meters—yes, the 400-meter runner's average speed is 32 kilometers per hour. And even including the 800 meters, if you see, the speed of the 800 meters is—the average speed is 27 kilometers per hour. So here, this foresight comes into the picture. So, not only this—this is the metric, this is the information visible or again, it will be a catalyst for any sports science researcher when they go to purchase a treadmill. So, that will give them a clear idea—they can get or assess the ideal treadmill.

[Next come the women's national record holders].

National records in 200 meters, **Saraswati Saha** clocked 22.82 meters, and so, when it comes to 400 meters, it is **Hima Das** with a timing of 50.79 seconds. But when Hima Das's average speed is calculated, it is 28 kilometers per hour. At the same time, you see in 800 meters—24 kilometers per hour. So, obviously there must be minimum 30 kilometers per hour, 30 to 35 kilometers per hour speed treadmill must be there for female. When in the case of male, it is 40 to 45 kilometers when you want to assess athlete on a treadmill. And here is the information about 1500 meter national record. So, 1500 you can see.

Next comes 5000 meters. The national record in 5000 meters is **Gulveer Singh** and it was held in 2024 in Japan and the timing of 5000 meters is 13 minutes, 11 seconds and 82 seconds. And the average speed of the 5000 meter runner is 20 kilometers per hour. So, why I am showing all this information is that, so you can decide the speed of the treadmill whenever you go for some instrumented treadmill.

At the same time, it is a women 5000 meters national record, **Parul Chaudhary**, the timing of 15 minutes, 10 seconds and 35 milliseconds, and the average speed of Parul Chaudhary is 20 kilometers per hour. And men's 10,000-meter national record. So, if you see the men's 10,000-meter national record, so the timing is 27 minutes, 14 seconds and 88 milliseconds. And on average, the treadmill has to have minimum 22 kilometers per hour plus 5 kilometers per hour speed. So, this is for female, it is 19 kilometers per hour.

Force platform with particle applications in strength and conditioning:

How the force plates are used in strength and conditioning?

You can see it is a portable force plate and I mean the half squat is being done on the force plate. So, we can easily identify the strength asymmetry between the right and left leg. So also, the COP how it is shifted and the ground reaction force in three dimension can be assessed.

Functional assessments in strength and conditioning:

What are the functional assessments in strength and conditioning domain?

One is CMJ shortly they say and everyone uses CMJ that is counter movement jump. So, the counter movement jump helps us to find out the stretch shortening cycle and it also further useful for assessing athletes with respect to their strength metrics and explosive metrics.

There are variation in counter movement jump. You can perform the counter movement jump which is shortly called as CMJ with free hand and hands on the hip and second comes the squat jump and the third comes the repeated hop jump then standing broad jump and drop jump. Not only this, there are balance and stability parameters the force plate is helpful in measuring. And the body sway, the single leg body sway, double leg body sway, when your eyes are open, how much body sway is there? When the eyes are closed, how much body sway is there? These are all the topics we will discuss in detail.

Software for Different Parameters on Force Plate:

When we measure certain parameters on a force plate, it has its own software. Particularly, each brand will have its own software.

The software you see here is **MARS software**. So, the full form of MARS is Measure, Analyze, Report Software. Then, MARS comes with a restricted version as well as a full version. In the full version, we can determine the power and strength of the athlete through vertical jump tests, sideways jump tests, and fast alternating movements on a 3D force plate. So, apart from power and strength, these force plates are used to measure balance and stability.

At the same time, the software provides many insightful metrics. Other than MARS software, every force plate manufacturer comes with their own software, including templates and key performance indicators. First, we will discuss the counter movement jump. What do you mean by a counter movement jump? So, the counter movement jump is when the athlete stands on the force plate, lowers their body, quickly brings it up, jumps, and then lands.

Used of counter movement jump:

We will see in detail about counter movement jump. The counter movement jump is used to find out the explosive power of the athletes. At the same time, how much height the athlete jumps and what is the force production, at the same time when he lands and how much amount of force he will execute on both legs. These are all the fine metrics we can measure through counter movement jump and here we can go for counter movement jump by having the hands on the hip by having, I mean flexing the ankle, knee, hip. So, they have to go down and it is like a stretch shortening cycle. They have to stretch and further quickly shorten the muscle fibres so as to produce the explosive power. And the one more component what we measure here is that amortization phase. So, lesser the amortization phase is the better jump and that is indicator that the athlete is having better explosive power.

Phases of counter movement jump:

And if you see here, this is how the counter-movement jump is being performed by having the hands on the hip. So, in the stretch shortening cycle, the concentric-eccentric contractions are happening at the same time. So, you can see the amortization phase which is happening at the switch between the concentric to eccentric phase. And so, you will see further about the phases of counter movement jump.

The force graph will always give you the force and time parameters. So, we will measure the athlete's body weight. Then, in the unweighing phase, that is, he will be lowering his body. So, when he lowers his body, the quadriceps will undergo eccentric contraction, and the moment he reaches the maximum, he then goes into the concentric phase.

The concentric phase is the propulsive phase, where he propels the body against the ground. Then, the moment there is no vector, when there is a plane zone, it is called flight. That is the flight duration we can measure, and based on this, we can also find out the flight height. Then, the moment he lands, you can find that the ground reaction force is high when an athlete is landing.

Parameters of a counter movement:

What are the parameters of a counter movement jump?

Here, we can measure the peak force of the take-off and landing, as well as asymmetry. The asymmetry between the right foot and left foot can be calculated in percentage. So, all elite athletes should have less than 5 percent asymmetry. And relative peak force. And further, the work, which is measured in joules. And then, peak power, which is measured in watts. And then, takeoff velocity. Then, peak velocity. So, push-off time. Then, rate of force development. And then, impulse and force-impulse ratio. So, these are the metrics we can measure from the countermovement jump.

Counter movement jump – VALD graph:

[Next, comes] when we measure the countermovement jump in a VALD one-dimensional force plate. So, this is how we get the graph, which shows - the one-dimensional force plate with one pair. So, during the unweighting phase, the quadriceps undergo an eccentric phase, and during the concentric phase, the quadriceps undergo concentric contraction.

The moment the athlete is airborne with his flight phase and again after the airborne, he will have the landing phase. You can see the pattern of the force vector during the counter-movement jump.

Counter-movement jump - BioWare graph:

The Kistler force plates always come with the basic BioWare software. we also measured the movement in the BioWare software with three-dimensional force plate.

While this VALD is having only one-dimensional force plate, whereas the Kistler force plate is using three-dimensional assessment and you can see so, both the takeoff and landing, always the landing has the higher force. But apart from this, we can also find out

the red line and green line. So, the red line and green line also are the two vectors acting on the body. And as usual, the force graph comes with the time and time in the x-axis and the force developed in the y-axis.

Counter movement jump - MARS graph:

When we perform the counter movement jump using the MARS software by the Kistler. So, this is how the data will be and the horizontal axis will have time, the vertical axis will have the ground reaction time or ground sorry ground reaction force. So, this is a graph taken from the MARS software of the Kistler and here in the X-axis you can find out the timing which is measured in seconds. At the same time, the ground reaction force is measured in Newton or times the body weight.

Drop Jump:

Drop jump is also another metric to find out explosive power and these are the phases of Drop jump, so we have a **braking phase**, **propulsive phase, flight phase, and landing phase.** So, the braking phase is nothing but when he drops, goes for a drop jump, the landing is called the first initial contact, which is braking, and the moment the subject or athlete pushes against the ground is propulsion. Then there is a flight phase followed by a landing phase. So, we can get all the three-dimensional data. So, the data is the force measured in Newtons and time measured in seconds. And we can determine the process of a drop jump. So, the drop jump can be unilateral or bilateral. So, the athlete can jump from one leg or can also jump using both feet.

What are the phases of a drop jump?

We have a flight phase, ground contact phase, eccentric phase, concentric phase, and further

The bilateral drop jump is given in this picture for easy understanding. And we do have **a unilateral drop jump**, which is shown here. So, unilateral means using only one leg to land and jump. And general parameters what we measure through this.

We can measure the drop height, ground contact time, jump height, reactive strength index, landing mechanics, and stretch-shortening cycle. What are the basic drop jump parameters and force impulse parameters? [You can find out here from the metrics what is shown].

Body Sway:

The body sway is measured to find out the athlete's stability and balance. So, here the center of mass, how it changes in millimeters, that is in the anterior-posterior direction and medial-lateral direction. So, this body sway is measured for athletes who are in shooting as well as archery. And you can find out the body sway pattern.

Types of body sway:

One is **anterior-posterior body sway** may happen, and **medial-lateral body sway** may happen. And we can test the body sway of the athlete in **eyes-open** and **eyes-closed**

conditions. And we can also find out the vestibular perturbation while testing the body sway.

Different testing conditions:

We have different testing conditions. One is the parallel stance. Another one is semi-tandem stance that is half foot behind the front foot and the tandem stance. So, completely the other foot is behind and in touching the heel of the front foot. And we can also use single leg standing conditions on the left as well as on the right. So, we have different testing conditions to define the body's sway which measures the body balance as well as the stability.

We can also have different manipulations by keeping the arms sideward out and keeping the arms chest crossed. And so, we can also measure with barefoot, running shoes, walking shoes and high heels. And this is how the data will look like and given the given time duration and how much amount of distance the COP has moved from anteroposterior distance as well as the medio-lateral distance. So, we have seen the different functional movement applications like counter movement jump, drop jump and body sway, which will be a key performance metric for assessing the athlete's explosive power, particularly the body sway measures the sportsperson's balance and stability.

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