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 10
Lecture 50
Interpretation of Force Data

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

Interpreting the force data through the graph:

We have already learned about boxing and the use of force plates, as well as the key metrics we measure using them. So, here we have the graph of boxing because the subject performed all the punches in different situations, and we are going to interpret the graph.

Boxing Punches:

In boxing punches, we started with a cross punch. So, this is the graph of the cross punch. The subject's weight is 92 kg. This is the recorded graph from the force plate we used. We used a **Kistler force plate**. There are two components: one is horizontal, and the other is vertical.

If you look at the horizontal axis, we have time factors. On the y-axis, which is vertical, we have the force matrix. You can see the force ranging from 0 to over 1500 Newtons for the maximum punches. Looking at the punches, they started at around 900 Newtons. They consistently reached 1300 and improved further because initially, the boxer lacked rhythm, but gradually, he started punching better.

You can see the punch graph in blue, representing the vertical force, which is the contact force. The rest of the forces that you see here are the red color represents the red color force. So, it ranges from 250 to 300 and up to 500. So, gradually. So, that is the X force, which is the medial-lateral force.

And on the anterior-posterior side, we have the Y force, that is given by the green line. And the blue one represents the vertical force, which is the maximum force we measure. So, I hope you understand. From this, what we understand is that yes, we can identify the three types of forces using the force plate for each punch, and predominantly, the measures matrix we have is the contact force and the time. And here, on the y-axis, you find the forces in Newtons, which may not be easily understandable by the coaching community or the sports community.

Alternatively, we can express it in terms of body weight. For example, here the subject's body weight is 92 kg. And almost here, the maximum punch is almost 2 times the body weight. Okay. So, 1.5 to 2 times the body weight can be observed from the cross punch. Next, in boxing, we have the jab punch, and the same subject performed the jab. The jab is a quick punch compared to the cross. The cross had more than 1.5 to 2 times the body weight, but here we have the jab punch but in the jab punch you can see here. So, the vertical force is around somewhere 800 newtons okay you can see the consistent punches see for each punch 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 punches subject has done. At the same time in the x-axis, we find the time parameter, and also, we can find out the impulse from the time and force. So, here we have given directly the in y-axis we have given only the forces, but whereas it can be turned as the subjects the percentage of body weight or times the body weight and you can find all the 3D forces. And next comes, all four punches, jab, cross, hook, uppercut. So, you can see in the graph pattern -

The first one is **the jab**. If you see jab punch, comparing to almost, comparing to all the cyclic punches, the first one is the jab. And in one cyclic component, like if you see the first four vectors, the first one is the least. That means jab horse is the least one. It is the punch which we go for quickly.

Second one is **the cross**, and third one is **the hook**, and **the uppercut**, the boxer had maximum effort to take for the uppercut. So, this happened as a sequence and this will help us to identify the fatigue level and the consistency also. So, this is how we use force plates to identify the key important parameters in boxing.

Basketball jump shot:

We saw in the field about basketball and its jump shot. But we can see the graph of the jump shot and its data and interpretation. And you can see the jump shot interpretation, and the person who performed the jump shot had a body weight of 62 kg. And when we performed the jump shot, here we have used two force plates, one for the left foot and another for the right foot. And you can see here, the first one is the right and the second one is the left. So, the dotted line represents the left, which is in blue color; the continuous blue color line represents the right.

Here you can see on both feet, we have measured the three-dimensional forces. And again, the x-axis represents the timing and the y-axis represents the force, which is measured in Newtons. And for easy reference, you can see when the subject acts with the, what I would say is, like when the subject goes for take-off, the take-off force you can identify from the first curve, and you can see he goes for the downward movement, and then the graph goes up, and there is an interval. So, this interval is the duration where the body is in flight, and again we have the spike of the graph, and you find the vector that is the landing force. Therefore, the landing force is always higher than the take-off force, and you can find here the X, Y, and Z forces. The exact vertical force is represented by the blue line, which is the Z force. And we can have some consistent jump shots to identify the consistency of the jumper. At the same time we can also identify at which level he attains fatigue.

Volleyball:

You saw in the practical field the subject or the player was performing jump service. So, in jump service - ball toss, take off, contact and landing are all the phases of jump service and we have recorded the forces of the jump serve and here it comes.

You can see here the jump serve is taken place from the takeoff. And you can see the x-axis and y-axis. X-axis always comes with the timing and the takeoff. Somewhere the player applies up to closer to 4000 Newton. And the subject body weight is 82 kg, that means during the takeoff, the player applies almost 4 times and above the body weight, somewhere closer to the 5 times the body weight. And if you see during the landing, it is almost 10,000 Newton. So, 10,000 Newton means it is almost 12 times the body weight. So, 12 times the body weight is the load which is acting on the legs, lower limb of the volleyball player when he lands. So, this gives a very good information to the strength and conditioning population as well as the coaches and athletes

Tennis:

We saw tennis serve, so flat serve and kick serve. Yes, so already the player performed in the field which we explained in detail about the phases, and how the force plate orientation was, and here you can see the subject body weight and the flat serve. And you can find the flat serve graph, because in this, the subject did not go for a jump movement. So, he was simply standing on the force plate, he was executing.

That is why you can find out the graph in the ups and downs. Okay. So, you can see the sequence. So, when we integrate this force vector with the video graph, then we can identify the what are the phases where the force vectors are behaving differently, so that is one component. And second one is yes, the kick serves, so in the kick serve you can see the moment he goes for the task and there is a downward movement followed by just a propulsion movement for a take off.

And there is a gap between the vectors that denotes the flight phase, that means after the ball toss and at the moment of the ball contact the tennis player had an airborne movement, where both the legs are in the air, and again you can find the When he is landing after the serve, he lands. So, it is almost closer to 2000 Newton. So, that means his body weight is 67 kg. So, it is almost 2.5 to 3 times the body weight when the tennis player lands here. So, it depends on the force also.

What I show here is what we have recorded from the force plate. But to ensure consistency, you can test different body weights of tennis players and varying levels of experience, then have them serve, say, 5 or 10 times continuously. We can identify the pattern of the takeoff force and landing force for each serve, as well as the consistency. So, you can find the takeoff force vector here and the landing force here.

Squat:

The subject performed squats with weights, a barbell, and weight plates. This is the squat when he performed it continuously for five repetitions. So, you can observe the behavior. So, here we have two force plates.

That is why we have 3 vectors—XYZ on one force plate and another 3 vectors XYZ on another force plate. The Z force is always the vertical force, the Y force is the anteroposterior force, and the X is medial-lateral. So, this must be taken into consideration.

Weight Lifting:

Next, the subject performed a clean and jerk. So, in the clean and jerk, you can see when the subject performs the clean movement, he creates thrust on the ground. And on both legs, you can see he is almost symmetrical. That means equality in the application of force, and the reaction force is also present. After the clean, the subject then goes for the jerk. So, in the clean movement, the force vector peaks. So, that we can identify it.

Gait Analysis:

Next, comes the walking pattern, which is a gait analysis. We saw the subject walking on a force plate, and we observed different gait patterns. So, we had the subject walk, jog, run, and sprint. So, we will see how the force vectors are recorded and what the interpretation is when it comes to walking. [So, you can see the walking, right?]

The first phase is heel strike, then foot flat, then heel off, toe off. During this, we have the propulsion phase. Before that, we also have heel strike. So, it is almost closer to 1000 to 1200 Newtons. So that means 1 to 1.5 times the body weight is the reaction force when a subject is walking. But when he jogs, you can note down the values here and see the spike in the force vector compared to walking. In jogging, the reaction force is higher. So, you can see during the first strike, the first vector and the second one.

This gives you a beautiful and consistent uniform pattern of the ground reaction force. That is the Z force. So, you can see three force plates. One, two and three vectors are there. That means three-foot strikes are there. Three-foot strikes of the jogger are recorded using three force plates. And you can see the green line, so the green line represents the anteroposterior force. The moment you go for a heel strike, you can see the negative force, so that means you are pushing backward. The backward force denotes the negative force, then after we strike the foot, then we propel. So, we create the forward force, which is in green, and also the red tells you about the medial-lateral force. So, in jogging, you can find. But in running and sprinting, we can easily identify the other forces. I mean, marginally there will be an increase.

If you see here, almost 2400 is the ground reaction force—2400 Newton. So, from the 2400 Newton, we come to know that it is closer to three times the body weight. The vertical force—ground reaction force—is what we see here. And in running, the moment you see running, yes, you can see only two force plates recorded in running because the moment the subject runs, obviously the stride length increases. So, here we have two patterns of forces. Here also, you can find out during running, the impact is more, and the moment the athlete goes for a mid-foot strike, the braking impulse and propulsion impulse. Braking impulse is nothing but the moment you hit the first initial contact with the ground. Propulsion is after having the initial contact; then you propel, press against the ground, and propel. So, that green line easily shows the negative force followed by the positive force. This vertical force. So, since we had recorded only two-foot strikes, more foot strike data will help us identify the pattern of movement and the consistency of movement for each subject.

Sprinting:

And next comes sprinting. With the same subject, we had sprinting. So, you can see the sprinting pattern. What we observe here is, in sprinting, you can see the vertical blue line easily shows the vector, which reaches more than—I mean, closer to—3500 Newtons. The second foot strike reaches more than 3500 Newtons. So, it is almost more than four times the body weight during sprinting.

And you can even find the foot strike, the braking impulse followed by propulsion. So, and also you can see the blue and the green color, which is the anteroposterior force. So, the anteroposterior force is also marginally higher compared to walking, jogging, and running. But in sprinting, the anteroposterior force is more and higher. One more component is the medial-lateral force, which we have to think over.

So, the red line shows a marginal increase compared to the previous movements. So, this is how we determine the force vectors using a force plate. So, the impulse, the moment—I mean the moment—then the ground reaction force in three dimensions, and the time factor. So, all these can be measured using the force plate. So, we will have better clarity when we integrate the force plate with the motion capture system, where both kinematics and kinetics will help us provide better results and interpretations for the athletes as well as the coaches.

Ki-sprint:

Next, we are going to discuss the Ki-sprint parameter. So, Ki-sprint is nothing but the instrumented starting block we used. So, since it is a starting block instrumented by Kistler, they named it Ki-sprint. And we will examine in detail the key performance indicators during the sprint start from the starting block.

And this is—I mean—the graph and the key performance indicators as a report generated from the instrumented starting block. So, you can see the photograph as well as the key performance indicators, the time parameters, and velocity parameters. If you look on the right side, it is given as time.

The first one is reaction time. So, 200 milliseconds. So, obviously, this athlete had a poor reaction time because the timing is longer. So, all elite athletes tend to have between 130 to 150, 160 somewhere. So, this is the range for block release time. The block time is the second factor—how long the athlete stays in the starting block. The metric here is 648 milliseconds. Then comes the **velocity parameter**, which is the horizontal velocity of the center of mass. The laser tracks the hip and measures the horizontal velocity, which is initially 3.3 meters per second.

Next, is the **strength parameter**, which is the maximum rate of force development (RFD) times the body weight per second. RFD means rate of force development. And the front foot and the rear foot can be analyzed. Then, the power parameters and impulse parameters are here. At the same time, it is also given in graphical representation. And the force vectors can be found.

There are different colors for the force vectors. One is on the right foot plate, and another is on the left foot plate. It provides three-dimensional force details. So, it is a sophisticated piece of equipment that helps identify the block release phase. Key metrics can be identified to optimize the athlete's performance, and here you can see the metrics we have fixed.

This video can be correlated with the force graph, and I will show you each frame, so the moment—it is beautifully even—maximum force at the rear and maximum force at the front. In the second photograph on the right, you can see the moment the athlete is released: first, the hands come off. And then, obviously, as the rear foot comes first, you can see a perfect start. The athlete has a 45-degree angle of body lean. So, both qualitatively and quantitatively, we can correlate and compare the athlete's performance in the block phase. Starting phase. And these are all the metrics you can identify the average power—that is, the power in watts per kg. So, the horizontal and the maximum force here are given in blue and red. The blue represents the rear, and the red represents the front. And the velocity, which we saw there, is given as the graphical representation. And the rate of force development, so the maximum rate of force development and average rate of force development are also given here. So, you can see the results—the extracted results of the Ki-Sprint from the block. Starting block. So, that is reaction time, block time. So, strength parameters and then impulse parameters.

Impulse is how long the foot is in contact with the ground—that is, I mean force multiplied by time. And you can also find out the other strength parameters. Next comes cricket, and we saw that cricket batting and bowling, but we are going to discuss only the bowling. So, when the bowler comes for delivery, there is a pre-delivery stride and a delivery stride. Here, we have two force plates fixed to measure. The pre-delivery stride is always lesser than the delivery stride, as far as this force graph is concerned. And you can find that during the delivery stride, the athlete undergoes almost more than 1500 Newtons, which is closer to three times the body weight. But it varies from one person to another and depends upon body weight, the amount of height gained from the pre-delivery stride to the delivery stride, how much power he has, and the approach and speed also play a crucial role in deciding the force vectors.

And here you can find that there are four force plates, and for both feet, we can identify the force vectors. In the pre-delivery stride, you have two vertical force vectors measuring both feet.

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