Quantitative analysis

Hello everyone, welcome to module 5 of Human Movement Science. In this section, we will discuss about the quantitative analysis. So, in this section, we will learn about or start with the introduction to the quantitative analysis followed by the measurements of various biomechanical parameters or variables and then we will look into the instrumentation used to measure these biomechanical parameters. So, first we will start with quantitative analysis, what quantitative analysis is? Quantitative analysis is nothing but which involves the actual measurement of human movement and usually this measurement is done in terms of numbers or it can be described as numbers. Now, let us have a brief comparison between qualitative and quantitative data. So, qualitative is descriptive in nature whereas the quantitative is numerical in nature.

It can be further subdivided into discrete or continuous data and it can be counted or measured whereas in case of qualitative data, it depends upon the senses and feeling. For example, you can see something, hear something or smell something. Qualitative data is subjective in nature whereas quantitative data is factual in nature. So, usually the quantitative analysis is performed at elite or professional level.

The two major considerations to perform quantitative analysis at elite or professional level include expense involved to have a quantitative analysis and the time considerations also. It is utilized to monitor the changes in training, technique improvement or once an athlete is injured, it is being utilized to monitor the progress in rehabilitation from an injury. This also provides data for biomechanical research. For example, having numerical comparison between pre or post injury data collection sessions or once you change a technique or have changes in their training program, whether they affect the performance of an athlete in a positive or a negative manner. So, these changes which we are talking about in quantitative analysis involve biomechanical parameters which we cannot distinguish without the use of specialized instruments.

In this section, we will discuss what are the different specialized equipment's which are required to collect the quantitative data. Before moving towards the various equipment or instrumentation required for quantitative analysis, we first need to understand the nature of data collection. So, the data collection in sports can have two different environmental factors. For example, whether the data is collected in a laboratory setting, which is a controlled environment or in field data collection where we cannot control the environmental variables as compared to laboratory environment. So, the various factors which involve to select instrumentation to collect quantitative data depend upon the environmental considerations also.

For example, the first thing which we consider for laboratory versus in field data collection is cost and accessibility. So, in order to set up a biomechanics laboratory, it is a costly affair

because the specialized instruments are very expensive in nature and particularly not all the practitioners or researchers have access to these specialized equipments. So, the next consideration in the quantitative data collection is the environment itself. So, in a laboratory setting, the movement which an athlete or a volunteer will perform may not accurately reflect the real world conditions. So, this might affect the performance or particularly the movement pattern of an athlete in session or particularly any individual or the volunteer which we are looking for.

Another important consideration is the participant comfort. So, when in a laboratory environment, athletes or the participants may not perform naturally or comfortably as compared to their natural environment. And finally, the lack of control. In laboratory environment, we can reduce the variability in data collection because we can control the various environmental conditions. For example, the lightning or the background or even the temperature inside the laboratory.

Whereas, in in field data collection sessions, these variables are very difficult to control and that might result in variability in the data collected. So, now, let us look at the various tools which are used to measure the biomechanical variables. So, broadly these can be classified as the tools to measure the kinematics. So, kinematics is nothing but the analysis of motion without the knowledge of forces which cause that motion. So, it is just looking at the movement pattern or just look at the motion itself.

So, the various tools or instruments include timing devices, velocity measuring systems, optical imaging system, which can be further subdivided into manual or automatic digitizing, accelerometers, again, these can be either uniaxial or triaxial in nature, inertial measurement units and finally, a complete motion capture system. Whereas, in order to measure the kinetics, so kinetics is nothing but looking at the motion or analyzing the motion with consideration of forces which produce that motion. So, the tools or various equipment utilized to measure kinetics are force transducers, pressure sensors, force platforms and electromyography. And finally, another tools which we use for measuring biomechanical variables include computer simulation and modeling. Now, we will look at these tools one by one.

So, first thing or the first device which we look is the timing devices. So, the timing devices why we need to look into the details of timing devices because time is a fundamental dimension in mechanics. So, it is very important to measure the time. So, the simplest devices to measure time are watches, but we cannot measure all the time related parameters using watches only. The reason being if the duration of an event which is under consideration is happening over a time which is long enough, then simple stopwatch can be utilized to measure the time point effectively.

However, if we need more accuracy for events which are short in nature, then automatic timing devices are important. So, in case of automatic timing devices, we use either electronic clocks which are present in computers specifically or other digital devices. So, these devices work either using electronic or mechanical switches which will start the recording of time and then also stops the clock to measure the duration of time. So, these switches can be triggered by a variety of means. For example, they can be triggered by pressure sensitive maps in which the clock start or stop as the person steps on to those specific pressure sensitive mats or by using light as a trigger as shown in the image itself.

Here you can see this component is the emitter and this component is the receiver. So, what happens when the emitter emits light, the receiver will receive the signal in terms of a light. But once an athlete breaks that signal, so that is registered as a timing. So, these are also known as photogate timers. So, the next tool to measure kinematics are velocity measuring systems.

So, the timing gates as we discussed in the previous slide, they can also provide us the average velocity. How it works? If we use multiple timing gates or photo timing gates at a particular distance or a known distance and subsequent events involve crossing through those timing gates, then we can find out the average velocity for that particular activity. However, there are specialized timing measurement systems for example, radar guns, which work on microwave radio signal. So, you might have seen the troopers who catch speeders on highways are using these radar guns to find the over speeding vehicle on the highways. So, how they work? A radar gun transmits a microwave radio signal of a particular frequency and measures the frequency of the signals that are reflected back from the object.

So, when the object is stationary, what will happen? The same frequency that was transmitted by the radar gun was received by the receiver. Whereas when the object is moving, the reflected signal will experience a shift in its frequency, which is also known as the Doppler effect. And then this will give us the velocity of the object determined by looking at this frequency shift in the signal. So, another velocity measuring system is based on lasers. So, it is similar in operation to a radar gun, but it uses a laser and the reflection of laser light to measure the velocity.

The laser velocity measuring devices are more accurate for measuring the velocities compared to a radar gun. So, the next kinematic measurement instrument is accelerometer. So, in accelerometer, they as the name indicates, they are used for measuring the accelerations. So, these are very light and small in size. So, this is an exaggerated picture showing the basic circuit being utilized in an accelerometer.

So, they have very high frequency response. So, this is an advantage where the events happen over a very small period of time. So, with high frequency response, we can analyze

that particular event in more detailed manner. They can be either uniaxial or triaxial. What does it mean? They can measure the acceleration in one direction only or the three directions as we discussed in our previous module, where whether we are looking at three dimensional data or just one dimensional data.

The another important aspect to consider accelerometer to measure kinematics is they can be attached to the body and can be utilized both in field as well as in the laboratory settings. So, the next thing which comes to measure kinematic parameter are inertial measurement units. So, these are nothing but a combination of accelerometers and a gyroscope. So, they are again very light and small in size, have very high frequency response and they can also be either uniaxial or triaxial. So, for example, to compare the size, so I have this IMU or inertial measurement unit.

So, if you compare it with my hand, so you can see they are very small in size and can be placed effectively on the different body parts to measure the acceleration using the accelerometer and angular properties of that segment using the gyroscope. So, they are expensive related to a basic two dimensional video based motion analysis system, but they are cheaper compared to a three dimensional motion capture system. Another important aspect of IMUs is they are available in our smartphones, tablets, laptops and netbook computers also. So, the next system to look at the kinematic parameter is the optical imaging systems. So, recording visual images of performance is most widely used tool in biomechanics and the most popular optical imaging system is video cameras like which we use in our day to day life.

For example, this one, they can be in fixed position or they can be mounted on tripods or other mobile systems as shown in this image. So, video cameras what they will do is, they provide us sequential two dimensional image of a movement when we use just a single camera. However, if we use multiple cameras that give us a three dimensional data. So, the optical imaging system can be further subdivided based upon the digitization process. So, either they can use manual digitization in which what will happen is the video is divided into still pictures or they are also known as frames and in that particular image or frame, the analyst has to digitize the important anatomical points on the athlete or volunteer in consideration.

So, if the system is manual, then what you have to do is, you have to identify those important points manually for every frame and this process is very time consuming and very much prone to errors also. But there is another way or another type of optical imaging system which utilize automatic digitization. In this specialized software and computational resources are needed and for automatic digitization, we need subject preparation also. For example, the placement of markers. So, these markers can be active markers, so such as small LEDs which are placed at different anatomical locations on the body of an participant.

These can be passive markers. So, these are nothing but a reflective markers as shown in figure where you can see these white dots, they are reflective markers. So, when infrared light fall on these reflective dots, what will happen? That infrared light get reflected back and then captured by the recording device. So, that way you can find the exact location of those anatomical points. And third type of markers are electromagnetic markers. So, why we need electromagnetic markers? Because in case of active as well as passive markers, you need a clear sight of the marker.

However, in certain movements or during certain specific activities, you might cover the marker itself. But the electromagnetic markers, they are based upon electromagnetic properties of the equipment or electromagnetic signal being utilized to track those markers. Even though you cover visually the marker, but still you will get the electromagnetic signal. So, now let us look at the whole motion capture system or which is also known as the gold standard for measuring kinematics. So, this is a typical motion capture system where you can see you have multiple cameras placed at different strategic locations to capture the kinematic parameters.

So, these motion capture systems are used to capture a digital image or digital form of three dimensional movements of the whole body. So, typical motion capture system use multiple cameras, usually six or more are required to perform a complete capture. These are the most accurate systems. They also have a very high frequency response. They are very expensive relative to the basic two dimensional video based motion analysis systems as we discussed in optical imaging systems.

Another consideration or another important aspect of motion capture system is they need a very specific environment and space considerations. And then to operate these systems, we need specialized training, particularly to collect reliable data, then process the collected data and finally, to create meaningful reports out of this data. So, let us look into further detail how these motion capture systems will work and what are the considerations to collect, process and report these data. So, in this image you can see these passive markers or the reflective markers are placed at anatomical landmarks on this particular athlete or participant. So, what will happen is, you have to be careful while placing these markers on the anatomical landmarks.

So, this will help us to collect reliable data. The next step would be you have to track the movement during that particular activity using these markers. And finally, you have to process the collected data to get meaningful results. So, now let us look at an snippet where you can see how the data collection will happen in a motion capture system and how it looks when it is not being processed yet. So, here you can see it is nothing but these dots are just moving in the three dimensional space.

So, over here you can see we can just see these black dots. So, this is just the raw capture data. This is how it looks like when you collect kinematic data using a standard motion capture system. The next thing important thing is to track or to look at the trajectories of those markers throughout the event. So, in this case you can see the different trajectories of the markers being tracked during the process during the tracking component of the data processing.

So, in this you can see like there are certain events during which we miss the tracking of a specific marker. For example, like these markers are not tracked properly. So, what you do is in processing you will use that specialized training how to track the location of markers reliably so that we will have a reliable data which can give us further insights into the mechanics of the movement. For example, in this once the processing is being done, so here you can clearly see all the markers are being tracked accurately or reliably and then there are no missing tracks for any of the markers which we utilize for this particular workflow. So, this is a typical example or this is how a typical motion capture system will give us output after being tracked and then being processed the whole data which is being captured and then utilized for preparation of reports.

So, now let us move our discussion towards the tools or equipment used to measure the kinetic parameters. So, the first instrument or tool utilized to measure the kinetic say are known as force transducers. So, one of the typical example of force transducer is as shown in the image. So, they are usually used for measuring the forces and why it is important to measure these forces because you can measure these forces which are being applied on implements or equipments. For example, you are jumping for a dive from a board and during the dive you press against the board and then take the dive.

So, how much force is being applied on the jumping board that is important to understand the effect of those forces on the different body parts or segments and then how that will help us to understand the mechanics of movement. So, these force transducers are available in different shapes and sizes and they work on different principles also. For example, they can be strain gauge based load cells which are nothing but they utilize strain gauges and use the Wheat Stone Bridge principle to calculate the force. Similarly, they can be pneumatic load cells. So, the term pneumatic means it is dependent upon the air pressure.

So, what will happen? They utilize the piston cylinder assembly and put a diaphragm on one side of the piston and then air pressure is being applied. So, when there is a movement or there is displacement of the piston, so that will result in change of pressure and that pressure is proportional to the force being applied and that will help us to understand the forces being applied on the system. Similarly, they can be hydraulic load cells. So, in this case instead of air the fluids are being utilized typically an oil is being used and during the movement that force is being applied on the piston cylinder assembly and pressure gauges are used to measure the pressure inside the chamber and once a movement occurs there is

a change in pressure of the fluid and that change in pressure will give us the information on the force being applied. Another type of force transducers are piezoelectric load cells.

So, piezoelectric are natural occurring crystals. What they will do is once there is a change in their shape, so when you apply some force on piezoelectric crystal what will happen? There is a change in or there is a deformation in the crystal and that deformation will create an electric current or electric signal. So, that electric signal is then amplified and captured by the measurement system and that signal or electrical change or electricity generation is proportional to the force being applied. So, the next thing which we will see to measure the kinetic parameters are force platforms. So, these are the most commonly used devices for measuring kinetic variables. So, they use the basic force transducers only but they use multiple of them and they can measure the reaction forces and in addition to measuring the force only they can also measure the point of application as well as direction of the resultant force.

These systems are capable of measuring multi-dimensional forces. For example, vertical ground reaction force, force in the interior posterior direction as well as in the medial lateral direction. So, typically a force platform looks like a tile or a metallic tile. So, what happens is there are multiple force transducers either they are strain gauge based or piezoelectric in nature are placed at the corners of this plate and then they use the information recorded by these independent sensors combine them using mathematical model to give us the resultant force along the three dimensions. For example, if this denotes x, this denotes y and this denotes here z.

So, we will have information about the forces along x, y and z direction and they can also give us information on the moments being generated about the center of the force platform. So, why we need the information from force platform? Typical example from sports perspective is so you see like shot putters or discus throwers. So, how much force they are producing while you know making those throws or if we look at long jumpers or triple jumpers, how much force they produce at the takeoff. So, this information is very important to analyze the biomechanical parameters of the motion or mechanics in general. So, another type of kinetic measurement systems are pressure sensors.

So, these are usually thin maps with the array of four sensors embedded. For example, you can see this black mat. So, this might be the direction of walking. So, what will happen is athlete or the participants they walk along this path and then come back to this side depending upon the protocol being utilized to capture the data. So, they provide a very detailed information on the pressure between the contact points of the foot and the ground.

They are also capable of measuring the resultant reaction force and they represent the nature of forces quantified by the pressures. There are different type of pressure measurement sensors for example, one type as shown over here shows a thin mat array.

However, there are in sole pressure measuring devices also. So, they are nothing but they look like the sole of your shoe and you just place it inside your shoe and then perform the activity. So, that will give you the pressure mapping at the various points on the sole of your feet.

So, the output from these will look like this as shown in the image. So, over here you can see how the pressure is being distributed at the different positions under the sole of your feet. So, the next thing to measure kinetic parameter is electromyography. So, this is how an electromyographic equipment or system looks like.

This is specifically a wireless system. So, where the electrodes can transmit the data wirelessly. So, as the name itself indicates, so if we divide this word, so electro means related to electricity. And myo is nothing but muscles and graphy means producing a graph. So, what these systems do? They measure the electrical activity of the muscles.

So, there are different types of electromyography equipments. For example, they can be placed on the surface of the skin to measure the activity of the underlying muscles or they can be inserted into the skin or into the belly of the muscles using very fine wires. So, those are known as the indwelling electrodes. So, the information which we get from these systems include activation and deactivation of the muscles. So, during that particular event whether the muscle was active or not. However, in research various researchers are looking at the correlation between the muscle activity and the muscle force being produced.

However, it is not being widely utilized as a practice but still in the research phase. So, now let us look an output from a electromyographic analysis. So, over here the blue color represents the left side and the right color represents the right side. So, here we are presenting two muscles on left and right limb of a participant.

For example, for Vastus lateralis as well as medial hamstring. So, in this image you see there is a gray band at the bottom. So, this represents the instant during that movement where the muscle should be active. For example, in case of left Vastus lateralis we can see the muscle turned off like this shows the activation of muscle or on and this region over here shows the off point for the muscle or the muscle is not active at that point. So, over here we can clearly see the muscle is not active during the whole activity where it was supposed to be active.

Similarly, for other muscle groups also we can clearly see. For example, the right medial hamstring it should be active during this period only but it is active beyond that period also. So, this information can be utilized to make certain adjustment in the technique to utilize the muscle forces optimally to get the enhanced performance. Now, next thing which we can discuss is the computer simulation and modeling. Although this is not a measurement technique but more like a tool for processing the information which we already have. So,

this helps us in the design creation and evaluation of complex systems which cannot be measured directly.

For example, in order to measure the joint forces and moments we have to place the sensor inside the body or where the in the vicinity of the joint. But if we have computer models which are mathematical models we can predict those forces and moments without putting the sensors inside the body. The designers, program managers, analysts and engineers use these simulation and modeling tools to find out the what if situations. For example, what if the angle was like if we consider the knee angle at a particular event was 20 degrees. What if the angle was 40 degrees? So, what will happen? So, you can change those parameters in the mathematical model to have insight on the what if scenario.

So, computer simulation and modeling is also important when the changes to the actual system are very difficult to implement or involve very high cost or sometimes very impractical also as we discussed in case of measurement of joint forces and moments. So, what are the benefits of using computer simulation and modeling? So, they give us better understanding of a process, also help in identifying the problem areas or bottlenecks during the whole process, provide us the effect of system of process change on the performance of the athlete or the movement itself and also help us to identify the actions needed to a given operation either to improve or mitigate the processes for events. And finally, they also help us to evaluate the impact of changes in the implementation process. Now, let us look at the various instrumented gait analysis systems. So, here instrumented gait analysis means where specialized equipments are used to record or measure both kinematics and kinetics.

So, we will look at the various instruments which we discussed during this section, look at their advantages, disadvantages and some examples of the manufacturers also like which manufacture these equipment. However, I would like to emphasize like these are not the only manufacturers for these instruments, there are other manufacturers also just as an example I included couple of them. For example, the pressure mat, so they take very less time for the setup and very easy to operate, you do not need very advanced trainings. However, the disadvantages involved they are very costly as well as not portable, they are restricted to overground trials only and require very specific operational space.

The manufacturer include like tech scan or novel electronics. The next thing is we discussed about the pressure in soles also, they are portable in nature, very cost effective and does not require specific operational space because you can just put it inside your shoe and then use them. They are useful for both indoor as well as outdoor setup. However, their disadvantages include they have less accuracy compared to the pressure mat and the same companies also or the same manufacturer also have the pressure in soles also which provide pressure mats. The next thing is motion capture systems, so they are very accurate in nature and useful for recording very complex task which involve movement in multiple

planes. They are very expensive, non-portable and require additional time for initial setup and calibration.

To operate these systems we need specialized training and they are restricted to indoor. However, with technological advancements in motion capture systems, now the systems which can be utilized outdoor also are available. However, there is a drawback because you have the setup time will increase exponentially because you have to connect the system or synchronize the system as well as you have to look for the various environmental considerations also. So, the various manufacturers includes Northern Digital and their product is known as Opto-Trak, Qualisys, Vicon or Motion Analysis Corporation, BTS. These are the different manufacturers which produce or which can provide us the motion capture systems and finally the wearable sensors like IMUs.

So, they are very low in cost compared to the motion capture systems, they also do not have very specific operational space requirements and they can be utilized both indoor and outdoor setting without too much time on setup and calibration. However, the disadvantages include they need special algorithms to combine the data from multiple sensors to give us a meaningful output and some of the manufacturers for these systems include Xsens, Shimmer or Gaitup. So, with this I would like to thank you for your time.