Biomechanics
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Lecture - 84
Introduction to Gait and Running

Welcome to this video on biomechanics. In this video we will be introducing some basic principles basic terminologies basic principles of gait analysis. This is a topic that I wanted to discuss in much greater detail but due to unavailability of time we are only able to discuss whatever we are now going to discuss because of lack of time. And because of the greater emphasis that we placed on other topics which are also equally important like how do you measure, kinematics using IMU some practical examples.

These are topics research level topics that students can take and perhaps implementing their own work and their own research. So, as we expanded more on that this topic has become squeezed because there is very little time available. With whatever time that is available to us let us proceed.

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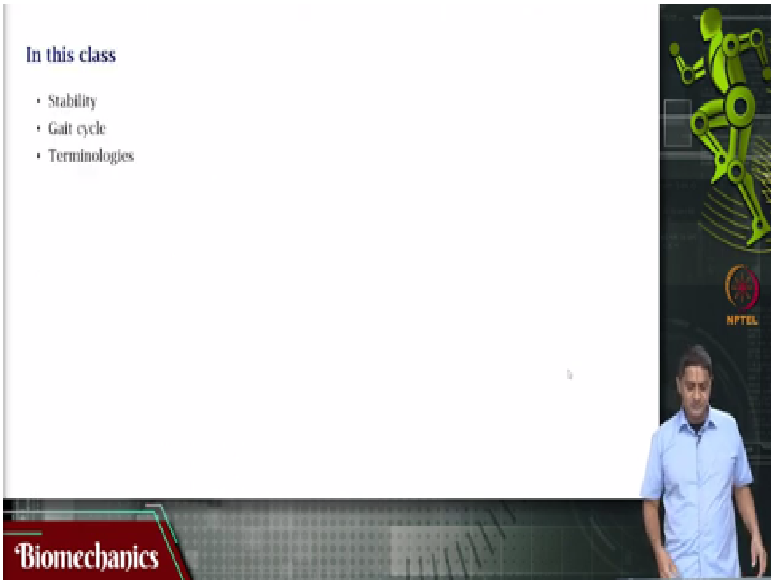

So, in this video we will be discussing stability and the various faces of gait are walking gait cycle and specific terminology related to gait. When you say stability what do you mean by stability?

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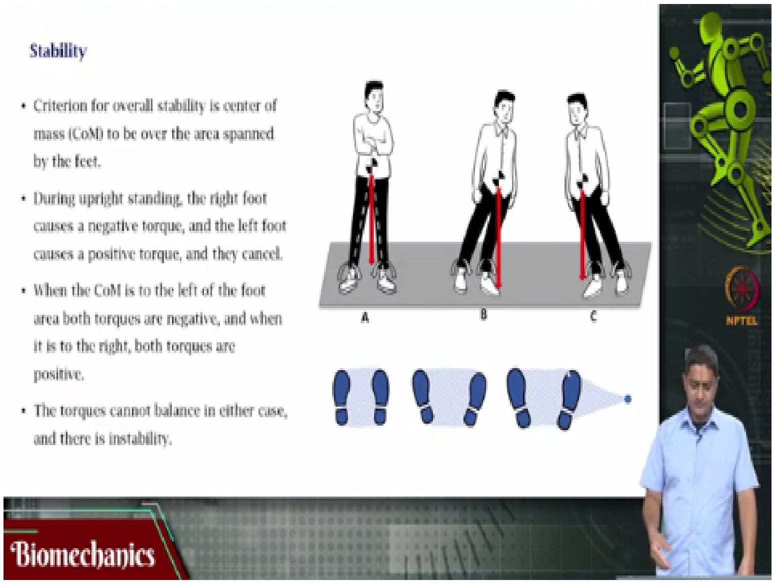

So, what is meant here is the criterion for overall stability so there are it turns out different levels are different specific definitions of stability. Here we are discussing mechanical stability the stability of the person who is standing suppose a person is standing with two legs like this. The criterion for stability is that the centre of mass lies between or lies somewhere within the area that is completely spanned by the two feet.

So, something to keep in mind something that you can also watch for is that as people get older or if there are some pathologies you will see an adaptive mechanism used by individuals to overcome lack of stability it is a common mechanism. Global adaptation to any pathology or any deficit, that is to increase the distance between the two legs. So, that are have a very broad span that way even if you slightly move away what will happen is that they will not fall.

So, this is a strategy this is something that even healthy people healthy young adults will use in uncertain situations. For example, if there is a slippery space that is if they have to walk on some say a corridor that has some oil spilled. Even we will use a broader span so that we will not fall this is not something that we do consciously because walking is something that we are doing since a very young age and adaptation to this is also something that we have probably learned from a very young age.

And we have been doing millions of steps since a young age and probably this is not something that is consciously perceived but this is something that we will do. So, whenever there is an uncertain situation people will naturally start taking steps that are farther away side by side that is medial lateral distance between the two legs increases. Of course, that will result in slowed performance but the idea here is to improve stability over performance.

Whenever it is a competition between stability and other metrics of performance stability terms everything else because falling down has a huge consequence that is a huge cost to falling down. Older adults people with Pathologists when they fall down there is a high probability that they will develop or there is at least a higher probability that they will develop injuries or disorders that could lead to hospitalization or even death.

So, it is very important for people to not fall down especially older people if they fall down there is high probability that they may not recover. This is a function of age. So, there are many aspects of this stability that comes into the picture. So, remember students of biomechanics you are having someone older be your parent or maybe a grandfather or a grandmother a grandparent something that you need to emphasize is that they do not fall down.

You need to emphasis you need to create an environment in which there are less hazards in their household in the household or in the space in which they are living. So, that there is a lower risk of falling for older adults. Also remember that older adults may have other problems we discussed this earlier. For example, women may have osteoporosis so the probability that they will recover from a fracture is much lower when compared with young healthy adults.

So, there are many aspects of this so coming back to the topic of stability. Stability essentially in implies that the centre of mass should be over the spanned area and remember this stability is different from what are broadly called as stable movements are what are broadly called as you know balance. So, how is this stability related to balance itself the sense of balance or maintenance of balance these are not necessarily the same topic.

Mechanical stability is what we are discussing, it does relate to balance but it is not a synonym for balance. So, these are different. So, how does this stability work because during upgrade standing the right foot causes you know dark in one direction, the left foot causes dark in the opposite direction and because the net torque on the human body is the sum of these two targets the it will almost sum to zero.

But moment to moment or instant to instant this will likely not be the case that is why whenever you say quite standing it is not like you are standing absolutely quietly. That is an amount of fluctuation that happens. So, when I am studying quietly there is always a little bit of sway this is body speed this is normal this is not unhealthy. This is called normal body sway. Also, something to keep in mind is this body's sway varies as a function of age, pathology.

Also, whether your eyes are closed or open will determine how much sway you are having you know this sway that happens in these two directions or medial laterals sway. If it is happening in these two directions anterior posterior direction but sway happens in both of these directions so it does not have to restrict itself to either the medial lateral or the anterior posterior. It can happen in any of these directions.

So, as you close the eyes this sway tends to increase that is another thing. So, whenever you say that these two tarps are cancelling each other so you know there is an amount of you know complete balance but that is not exactly true that if that happens then there will be no space. So, instant to instant small amount of sway or small amount of slight imbalances there but that is immediately corrected.

So, that is an amount of correction online feed forward or feedback based correction that appears to happen that ensures this stability. Let us not go into much detail into how this happens that is beyond the scope of this course and this lecture. But it appears like there is a kind of active control over this, there are many hypotheses that relate to this kind of topics now. Please check this those who are interested.

Of course, if someone is pushing you to the left someone is pushing you to the left and the centre of mass is away then there is a probability that the person will fall down or if it is on the right side then the person will fall down on the other side. If the torque cannot balance in either case and if the foot is not able to offer the right amount of friction and the other type of forces that will overcome this kind of instability in an instantaneous manner that is a likelihood.

That the person will fall and we do fall down I mean healthy humans healthy young adults also fall down. It is not like we do not fall down. But there is a higher incidence of falling in older adults and in people with motor disorders more than that there is a higher incidence of fear of falling that is falling and then there is fear of falling. The apprehension that you are going to fall is a problem.

Older adults have this problem that they might fall and so they use adaptive mechanisms to overcome this fear there is a difference between an actual problem and a fear. A fear is a perceived problem is it not. So, something to keep in mind.

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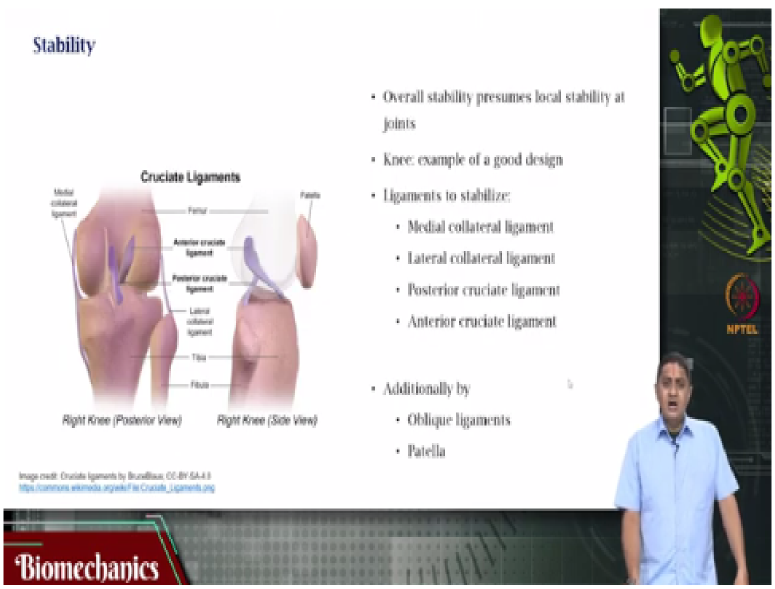

So, how is stability achieved if there is stability of the biped of the human who is standing with two legs this overall stability presumes stability locally at the many joints that are found by this no local stability. A particularly interesting or good example of good design is the knee joint.

Remember long time ago one of the early weeks we discussed the knee joint and when we discuss the knee joint, we discussed the ligaments that form the knee joint.

You know what is the purpose of these ligaments. There are two collateral ligaments and two cruciate ligaments by now you should remember this if not I requested to pause this video open a new tab and check out the knee videos. We have discussed the knee ligaments in much greater detail there. These collateral ligaments collateral ligaments means co lateral co means these same side so they connect to the same side.

Co lateral ligaments and then cruciate ligaments. Ligaments that cross over cruciate means crossing ligaments. Crossing ligament on the back side is called as a posterior cruciate ligament and crossing ligament on the front side is called as the anterior cruciate ligament. And when we discuss these ligaments, we mentioned an important role a critical role of these ligaments is to provide stability.

Of course, stability there is also a contribution to this knee stability by oblique ligaments and petal so there are actually six ligaments so there are there are not just this there are also other things that come into the picture. But the point is that it is a design that allows for a great amount of articulation in the form of knee flexion. And yet it provides the stability consider that this is a joint that is going to take a huge load and provides for a great amount of flexibility or rather articulation movements in at least in the flexion direction.

Of course, there is not a sideways movement but that is not the purpose of the knee joint. Despite all these constraints it is also built with a great amount of stability. This is a particularly great example of good design something that we have discussed in reasonable detail when we discuss the knee joint remember. So, please do check that out. So, this stability in the knee joint contributes to the overall stability.

But remember it is not just the knee joint there is stability at the hip joint there is stability of the knee joint and there is stability at the ankle joint. All this stability together leads to the overall stability. Also, what else might affect stability.

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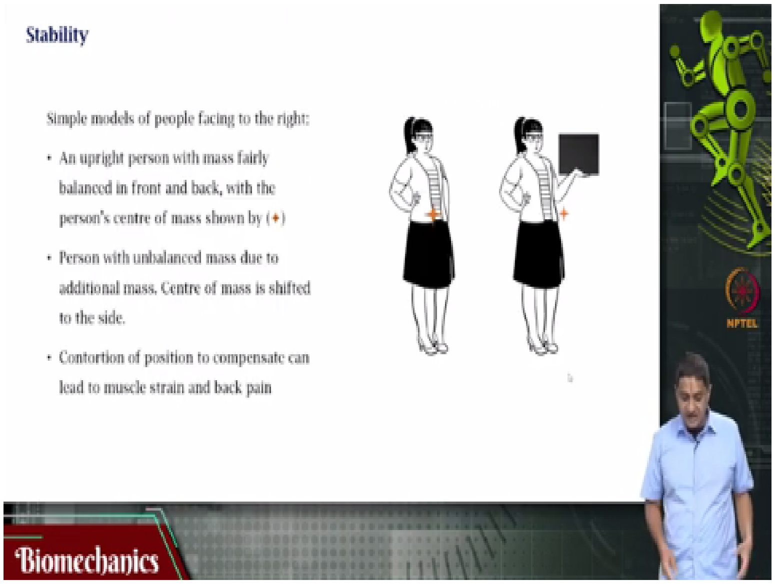

Let us say that you are carrying a weight I am carrying a weight on the side for example. If the person is not carrying a weight the centre of mass is going to be somewhere here for this person. If she is carrying a weight on the side the centre of mass is shifted. If you are doing this occasionally it does not really matter you might be able to generate compensatory torques on the other side of the body so that you do not fall.

Something that you do once, in a while and you probably can develop compensatory mechanisms or adaptive mechanisms for the time being for the few times that you are doing. So, when you are lifting this weight the centre of mass shifts outside, at least momentarily. So, there is a prop that is an amount of instability that this person undergoes. So, there is a need to compensate so there is contortion of the position to compensate.

If this is done once in a while it does not really matter but if this is your job this is something that you do regularly and this is something that you keep on doing what happens is that if this is something that you keep doing a lot of times every day. Then what happens is that there is a possibility of development of some musculoskeletal disorders muscle strain back pain and other such things.

Also, something to remember as we are discussing this people with the belly people who have big bellies this is a relatively common problem nowadays because obesity is the latest syndrome is the latest epidemic that we are all facing big bellies. What this does is that it moves the centre of mass little bit further in the anterior direction. This leads to a situation in which there has to be a development of compensatory torque in the posterior direction in the sagittal plane.

In the sagittal plane you will have to develop compensated tasks in the opposite direction and because these people will have to continuously as long as they are standing and as long as they are walking, they will have to consistently and continuously develop this compensated task with the muscles of the back erectors whatever these muscles are. There is high probability that the muscles in the back and the bone and the spinal cord the vertebral column will take a huge hit.

That is why these people end up having other musculoskeletal problems, very important to keep healthy physique in particular to avoid this big belly. If you have a big belly there is a higher probability that you will develop as a side effect there will also be this development of this musculoskeletal disorders. Another example is pregnant women for example. Pregnant women the same thing happens so there is a higher weight on the front side.

Just 2, 3 kgs no baby at in the third trimester but do not have kgs 2 do not have kgs 3 kgs for example 3 kg load but this is something that they carry throughout every moment until the baby is born. That is this tends to cause a tremendous amount of back pain to this person to these ladies. So, something that others cannot easily understand or perceive but people with big bellies can understand what this means.

So, these arising as compensatory mechanisms so these compensations can lead to other unwanted musculoskeletal problems you know here. When you are lifting a weight in an uncomfortable position compensatory mechanisms lead to a situation are leads to development of musculoskeletal disorders or poor ergonomics poor workplace ergonomics mechanics.

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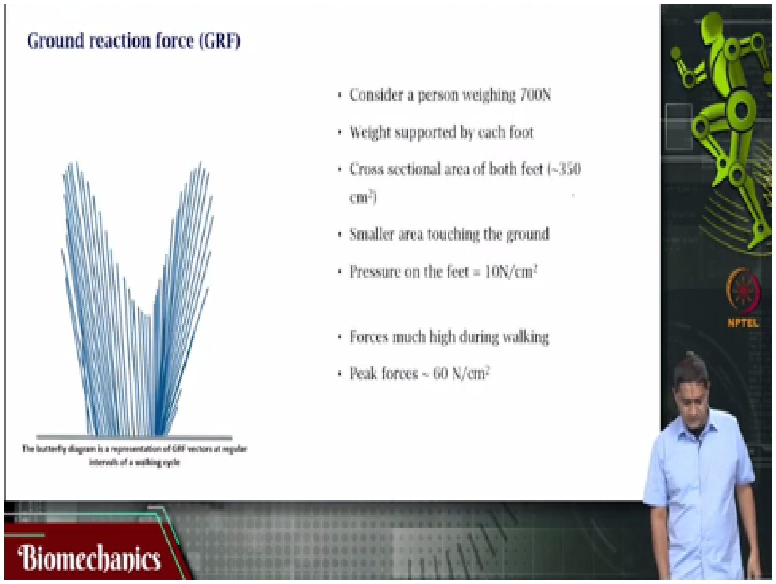

Now imagine a person is weighing 700 Newtons little more than you know 70 kg remember 70 kg is not 700 Newton because 70 kg in Newton with the G = 9.81 will be slightly less than 700 Newton. But here we are discussing about a person who is 700 Newtons and the weight is supported by the two foot and the cross sectional area of both feet how much would that be we do not know.

That obviously varies as a function of your shoe size or your foot size but you can compute that what you can do is you can take an A4 sheet you can take an A4 sheet and draw an outline of your foot. And or maybe you can do something else you can use a graph sheet and draw an outline of your foot and compute what is the area of your foot. Of course, if you want to buy footwear you would do something like this.

If you want someone else to buy the footwear for you will draw this outline and then send it with them and they will buy it for you happens in childhood for children this is something that is done. A question is what is the cross section area of your foot compute that. It varies between people of course it varies between people some people have large feet some people have small feet this so, the total cross section area of both the feet put together for an average person for a medium person it is about 350 square centimetre.

Now a question is this entire 350 square centimetre in touch with the ground, the answer is no, because it is usually the ball of the foot and the heel of the foot that is in touch but there is an arch in the middle of the foot that is usually not in touch with the ground. So, the entire area is not in contact with the ground. After accounting for all the area that is in contact and all the area that is not in contact you will realize the average pressure.

Of course, this will vary as a function of time this will vary depending on whether you are shifting the weight from one foot to the other for something that we do all the time. You may not realize when you are standing for long time you might shift like this now, I am shifting most of my weight to the right side when I am doing that for example, I am shifting most of my weight to the left side this is something that we do not at a conscious level but we do this all the time.

Assuming all these things assuming and adjusting for all these things on an average the pressure each foot right is about 10 Newton per centimetre square. Considering only some of the feet or some areas of the feet are in contact with the ground. While walking what happens is there are phases of walking during which the entire foot even otherwise the entire foot is not in contact but there are phases of walking during which only part of those parts that are in contact are in contact.

That is earlier when you are simply standing or when you are quietly standing both the ball of the foot and the heel of the foot are in contact. But if you are lifting your foot the heel first goes up the or there is plantar flexion. So, and then the toe leaves so as you are doing that the contact with some part of the foot is lost and while you are striking the ground again with your feet first contact is established with some part of the feet not the entire part.

So, the forces are the pressure during walking will be much higher and peak forces can be as high as 60 Newton per square centimetre. So, that is approximately 1 centimetre square approximately that is approximately 1 centimetre square and 60 Newton forces applied on this area then you realize this is essentially here very large force and for balance what happens is because there is a stability the ground applies an equivalent opposite force on the feet.

That is why this whole system is in equilibrium and this is not a constant this varies as a function of the amount of force applied by the feet on the ground and because the amount of force applied by the feet on the ground changes depending on the face of walking depending on the speed of walking depending on a whole bunch of factors it turns out that the reaction force supplied by the ground on the feet also changes.

So, this is also something that can be plotted that ground reaction force is also something that we can plot as a function of the phase of working as a function of time this is something that keeps varying. So, this this diagram represents the ground reaction force vectors at different phases of the walking cycle. Why are these forces in different directions? Is not it always supposed to be against gravity? No, these ground reaction forces are reaction forces to the applied load.

So, this is an indication of the kind of load that is applied on the ground by the feet. This is in another way of studying that so, this represents perhaps what the system what the movement control system is attempting to achieve during walking. This is one of the ways in which we can understand. There is too much detail that I am not getting into just touching upon this terminology.

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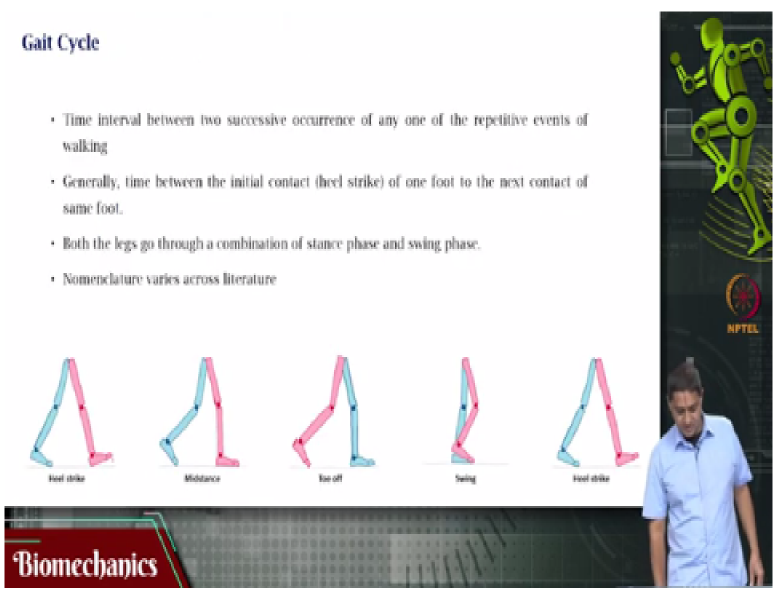

So, what are the various phases of walking? What is this various phases of walking? This is called as gait cycle so, if you take two successive occurrences of any of the repetitive events of walking and that interval and the set of all events and the time interval and the set of all events that happen within the time interval is called as gait cycle. That means that I could take this between any of this important or salient events.

And wait for that salient event to happen again because it is a cycle, I can analyse it whichever way you want but for consistency. Generally, the time between the first heel trick and the next heel trick is considered as one cycle of gait. It need not be just the heel strike but this is a standard that people use a lot of literature uses this approach so we can understand. It is a convention as opposed to a technical requirement you can take it whichever way.

You can start it at two off for example no problem but heel strike is the method that is used by many researchers and used by many papers made much of the literature. And both the legs go through these faces. The stance phase during which the leg is in contact of the footage in contact with the ground and the swing phase during which the foot is in the air. Of course, the specific details are the nomenclature changes across literature are different researchers use slightly different terminology.

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But it is useful to understand terminology. So, in general we can divide the gait cycle into two broad halves not necessarily exact halves these two parts we will say two broad parts. One is stance this is the time when a foot a given foot is in contact with the ground this is the time between heel strike and toe off of that foot. This is the time when the heel is striking heal strike means now consider my hand as the foot for example.

So, that I can explain and that means this part of the hand that is connected to the wrist is the heel and this part of the hand that is most distal is the toe for example. So, this let us assume that the index middle finger is the big toe for example actually the thumb is a big toe but it is far away so the hand is different and the leg is different. But let us assume that this is the big toe I am keeping like this when the heel is striking the ground that is called heel strike.

And then the whole foot comes in contact with the ground and as the other foot has finished its swing phase this you know this feed raises and then there is a toe off that happens. So, this time between the heel strike and toe off and the set of all events that happen during this time together is called as stance space. This happens in the following sequence first the heel strikes the ground and then the foot goes flat this is called a foot flat or the loading phase.

And then there is a mid-stance phase and then there is the terminal stance phase followed by a pre-swing face just before swing. And just and this is called as the stance phase and swing phase can be divided into two or three distinct phases the initial swing phase the mid swing phase and the final are the terminal swing phase. So, there is loading there is loading there is mid stance and this is loading is also called as what loading is also called as foot flat.

Terminal swing and then heel strike heel strike loading or foot flat, mid stance, terminal stance and then pre-swing. And then there is initial swing, mid swing, terminal swing and then the next heel strike starts. The time and the set of all events between one heel strike and the next heel strike is called as a gait cycle but I could also study it between you know one initial swing and the next initial swing or one toe off and the next to toe off for example.

I could also study it between some other salient part of the cycle and the next occurrence of the same salient part. I could do that but generally we study it between heel strike and heel strike. So, this faces the initial swing mid swing terminal swing together constitutes the swing phase heel strike onwards heel strike foot flat, mid stance, terminal stance and pre-swing together constitutes the stance phase.

The way this diagram is drawn it appears like we spend more time in the stance phase than in the swing phase and that is actually true. We do spend more time while walking we do spend more time in the stance phase than in the swing phase.

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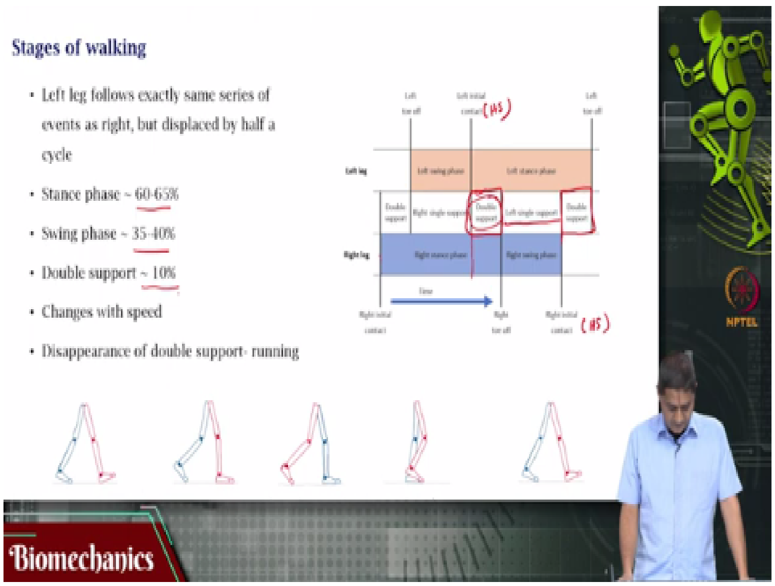

The right leg and the left leg follow the same kind of same series of events. So, there is no difference between the right and the left legs but that does not mean that they both happen at the same time that is not possible. Because if one leg is in swing phase if the other leg is also in the swing phase that means that both the legs are in air that means you are like flying or you are jumping. By the way that is a spot that we do engage in not walking.

During walking at least one of the foot is in the grounded at any given time and there is also a particular time during which both the feet are in ground this is called as double support phase. This is the time during which both the feet are in contact with the ground. So, this is the difference between walking and running. During walking there will be a particular amount of time during which both the feet are in contact with the crown this is called double support phase.

So, let us take for example the left leg is undergoing a swing phase at that time the right leg is undergoing a stance phase and that makes sense because the left leg is swinging is in the air the right leg is in contact with the ground. And then the left leg you know there is a initial contact or the heel strike that happens in the left leg. But the right leg has not yet left the ground that phase is called as the double support space.

And then the right leg starts swinging, initial swing during this time the left leg is supporting the body. And then the right leg makes an initial contact as a heel strike and then the double support phase again follows. So, and this continuous. So, about 60 to 65 percent of the time we are in stance phase and about 35 40 percent of the time we are in swing phase. And there is a small amount of time during which we are in double support doubly supported with both the legs.

This of course varies with speed of walking because fundamental difference between walking and running because there is a walking race in Olympics and there is there are running races. What is the walking race supposed to be you should not ever have a single support walking. Single support walking throughout our disappearance of the double support essentially constitutes running.

Walking is a situation in which there is all at least some amount of double support phase. I do not know if you have seen these videos do check them out when you have time when you have time to check them out walking fast walking Olympic events and the way they walk they tend to move their hips and compensate. In such a way that there is always double support but they tend to walk faster check that out you will understand better what I am saying when you check it out.

So, for example when the right leg is striking the hill there is two of here and then there is that is foot flat and then there is toe off then that this follows this cycle continues.

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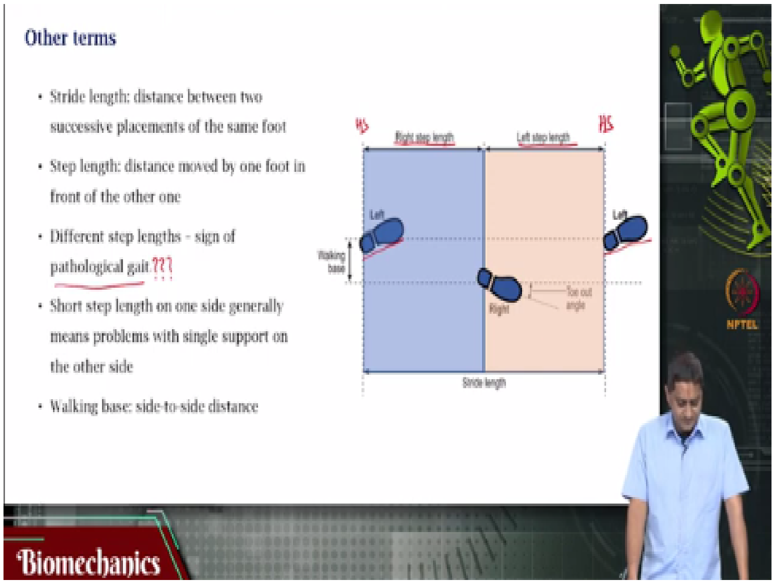

Other things are of that are of interest are straight length that is distance between two successive placement of the same foot. So, between one heel strike and the next heel strike of the same foot is called as straight length. For example, here we are considering the left foot and when the left foot again you know undergoes heel strike this is one heel strike this is one heel strike for the left foot between this the distance the total distance that is crossed is called as straight length.

Of course, some part of this would be crossed by the right steps or the right leg step and some part of it would be crossed by the left leg step. Step length is the distance mode by a single foot in front of the other one. So, straight length is the total distance crossed by a given foot between two successive heel strikes for example. But then in the meanwhile a part of this movement is made by the other foot.

So, step length indicates distance moved by a given foot one foot at a time in front of the other one this is called step length. Step lengths that are different is this a sign of pathological gait question no we need to discuss this I will come back to this gait analysis or pathological gait simply by using step lengths and straight length and times. Also, sometimes there is a tendency for people to take shots step length on one side and with single support on the other side.

Generally, means there are some problems with single support on the other side and also side to side distances you know sometimes may vary depending on the particular type of walking that is being used.

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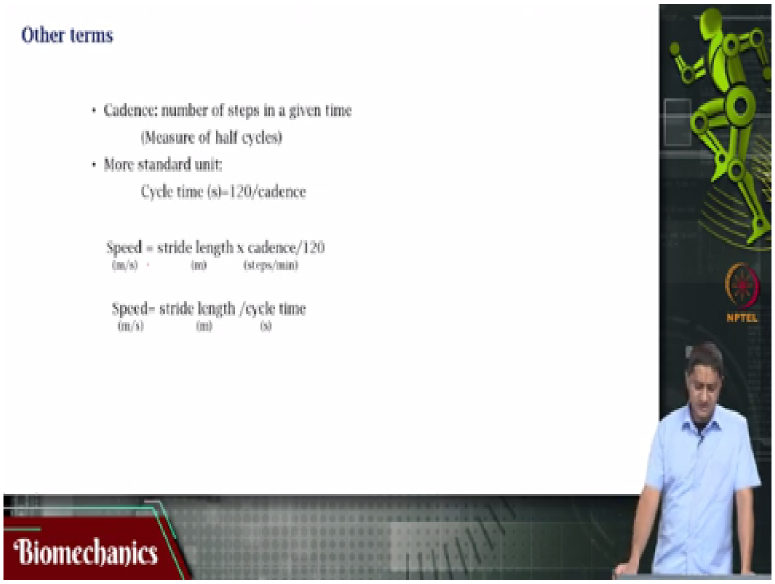

Some other terms of interest, cadence is the number of steps that are taken in a given time say for example in a minute of this. Cycle time is a more standard unit that is 120 divided by the cadence. Speed in meter per second is essentially straight length in meters multiplied by cadence but then side length is not a constant assumed to be a constant but it need not exactly be a constant of this it may vary it is known to vary.

Speed is essentially straight length time schedules divided by 120 are straight length divided by the cycle time. So, these are some other terms that are frequently used in gait literature.

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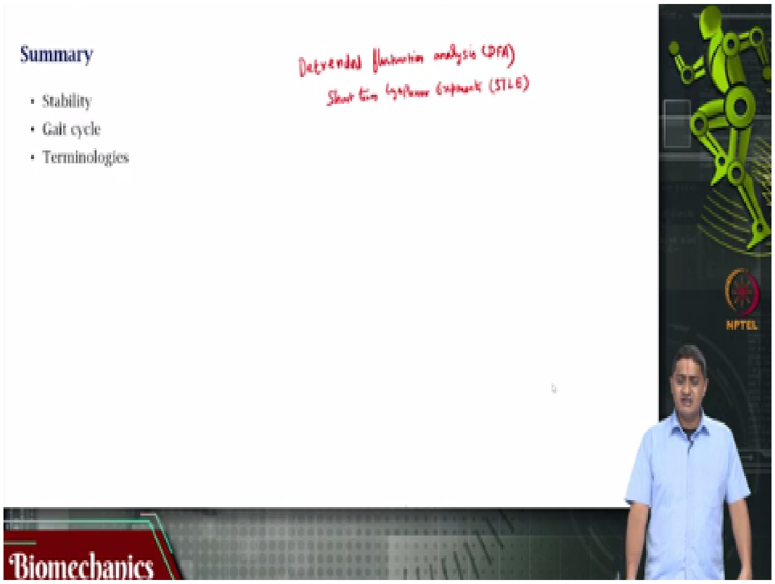

Now let us discuss briefly about how to identify and understand pathological gait by simply understanding straight length. So, something to keep in mind is what are some measures of pathology. So, if straight length is always a constant is it always a constant something to ask. It turns out that as people work with different speeds. People do not walk always with a constant velocity. Now that is a very artificial constructor.

People keep changing velocities as they walk it is very unusual for people to walk with the constant average velocity that is a very unusual situation. So, people change velocities as they walk and also it varies on the type of topography or where they are working that also varies maybe it is a slightly hilly area this there is a small hill that they will have to go about maybe it is a they will have to go down the hill or maybe it is flat or maybe it is concrete or maybe it is tar road or maybe it is a dirt road.

All these things come into the pictures plenty of factors. So, one thing that is known is obviously straight length varies as a function of speed that we can expect so. And speed itself varies as a function of many of these topographical factors. So, there is no single you know definition of this but what is known is. Do you correct for changes in straight lengths as a function of some goal let us say you want to maintain a particular speed for example.

How do you correct for these errors and how does that compare in health and disease. People have developed approaches to study this using time series analysis techniques. This kind of techniques although they do not form part of our course, I will just mention this forever knowledge. One of this technique is this so called detrended fluctuation analysis. What this does is they it trends that is it removes the trend remove the mean.

And then study is the movements as fluctuations that happen about this mean and how these fluctuations are these persistent are these not persistent. So, essentially what this does? This does require a large amount of data you need to work several hundreds of steps perhaps thousands of steps for you to get this data for you to have enough length so you can perform this analysis. There are you know modified algorithms that provide for performance of this in shorter time series data.

But that might be compromised on its you know interpretation but that is outside the scope of this discussion. The point is that there are these kinds of techniques that are used to study this so, if that is less persistence of anti-persistence so there is a tendency for people to correct for errors that happened in the previous stride that is healthy. That is something that you do not see in people with some disorders do check this to check this do not believe me.

Always check everything that I see people have also studied people have also studied this using other methods of time series analysis for example people have used short term Lyapunov exponents. So, people have used this short term Lyapunov exponents to determine how many steps are affected by the current step or rather the past how many steps are affecting your current step. So, there are these kinds of time series based analysis that could also help us classify healthy gait and pathological gait.

I am not going into the details of these but do check this out just by observing walking just by measuring straight lengths and times. We might be in a position to classify health and disease and then find a way to treat according to that. So, this is a very brief introduction to gait. So, in this video we looked at what is stability what constitute stability is stability in the joint for example stability in the knee joint.

We gave the example of that and what is a gait cycle and what is the standard way of representing or discussing a gait cycle and some other terminologies. And we also gave a very brief introduction to some of the analysis techniques that are used to study gait time series approach. With this we come to the end of this video and with this we come also to the end of this course.

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So, I would like to take the time to mention the availability of another course that is offered by me which is on neural control of momentum Neuroscience of human movement essentially speaking about the various aspects of the movement control system various neural aspects brain related control, spinal control the contribution of basal ganglion cerebellum reflexes and voluntary control various other aspects neural aspects.

So, the course does not assume any knowledge of Neuroscience. So, the course begins with the bare basics bare minimum biology physics. And the course builds from that basics to an advanced level of discussion just like this course did. So, a request you all to seriously consider taking this new sense of human movement course in future offerings. So, with this we come to the end of this course, thank you very much for your attention.