**Mechanics of Human Movement**
**Prof. Sujatha Srinivasan**
**Department of Mechanical Engineering**
**Indian Institute of Technology, Madras**

**Lecture – 35**
**Biomechanics of Balance Part I**

So, we started looking at the Biomechanics of Balance, because essentially you have your human body which is a multi segmented collection and you know connected by movable joints. So, the stabilization occurs because of the muscles. So, even when we are just standing still there is muscle activity. So, your center of mass is not moving anywhere.

So, even though you are theoretically doing no work your muscles are constantly adjusting you know. Because, you have all these joints and it is ensuring that your CG falls within the base of support so that you maintain balance.

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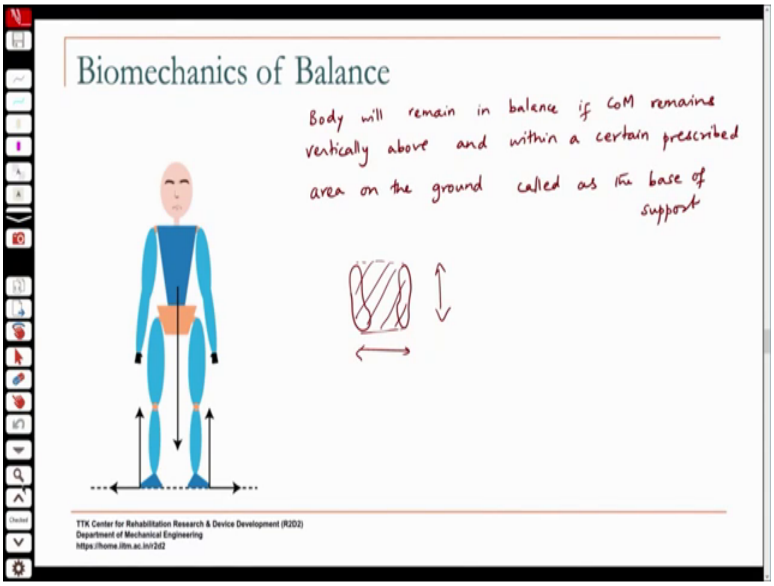


So, this is muscle active and as you can see your base of support in the A-P direction is typically much smaller then what you have in the M-L direction, because that I also have control over how I can how I spread my feet to some extent. Ok, but in the A-P direction especially it is very critical and a lot of the major motions also are happen in the surgical plane the flexion extension at the joints.

So, maintaining that balance is very crucial ensuring that the CG stays within this base of support especially in the A-P direction is a very crucial task for the body to perform. So, if you look at it and if you look at say balancing on hands that is even more offer difficult task.

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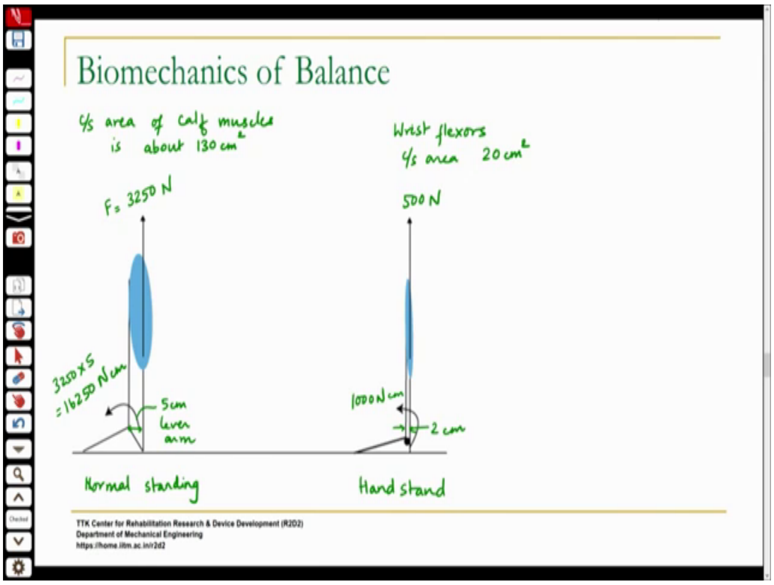


So, if you look at if you are normally standing this is normal standing, this is a hand stand ok. Basically, somebody standing with their hands as the base of support.

So, very difficult tasks to perform for 2 reasons, one in normal standing if you look at it, your calf muscles are yeah pretty strong you know they have a large cross sectional area. So, if you look at the soleus and the gastroc muscles, which are your ankle planter flexes because, that has to prevent the body from falling you know moving about the ankle joint.

So, if you look at the ankle extensors right then the average cross section the cross sectional area is about calf muscles, it is about 130 centimeter square ok. And you have a 5 centimeter lever arm about the ankle. These are capable of producing a maximum force of about 30 to 50 Newton's.

So, the maximum moment that can be applied about the ankle to counteract the effect of gravity is basically 30 to 50 into 5 which is 16 to 50 Newton centimeters, which is a pretty high moment 162.5 Newton meters. Ok, it is a pretty large moment that can be applied about that ankle by the calf muscles in order to counteract any imbalance.

On the other hand, in the hand stand your wrist flexors are the ones the area is cross sectional area is about 20 centimeter square. So, which can lead it leads to a maximum force production of about say 500 Newton. And the moment arm that you have about your wrist that joint this is also reduced to about 2 centimeters. So, the maximum moment that can be produced is a 1000 Newton centimeter.

So, when we are standing normally there is quite a bit of leeway that we have for shifting. We, we tend to shift forward and backwards and you can still maintain your balance. If you are doing that is why if you do yoga if you do a sheerasasana, you basically lock your arms like this that is your base of support. When you put your head down you lock your arms like this and because that then becomes your base of support. So, you have a little more leeway.

Whereas, if you do a hand stand like a gymnast where this is all it is then you have very little scope for not losing your balance. And your arm muscles also have to be extremely strong to be able to because you have you can apply only a much smaller moment to stabilize yourself.

So, you can lose balance that much more easily if you are doing a hand stand as supposed to when we stand normally. You may have seen in some if you does anybody here know karate or taekwondo or anything like that?

Yeah, you are aware of the stance that they take right. When they get into the fighting stance they usually they have their legs spread out in the fore aft direction in your A-P direction. The reason for that is it is much harder for somebody to push you and make you lose your balance than if you are standing straight like this.

So, you have one leg forward the other leg backward and then you lower your CG also it is always with the with your knees bend that you that is your stance fighting stance as they call it right. And that is basically so, that you have a better chance of having keeping your balance when you are in this when you have to fight.

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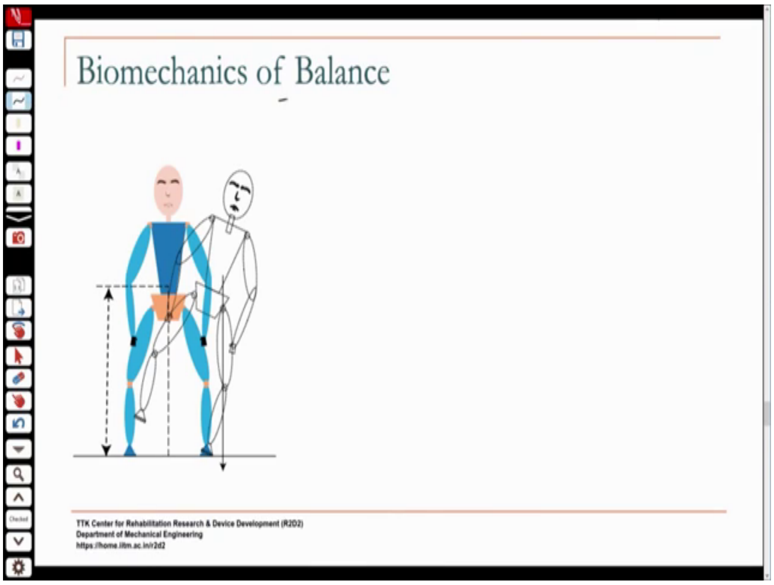


Let us look at this case where I have up and even in the frontal plane when you see them stand their stance is more like this. They actually spread their feet out and then sit the sitting is to lower the center of gravity and the wider stance gives you the better the larger base of support.

So, if you look at let us look at this case, where I have say the CG located.

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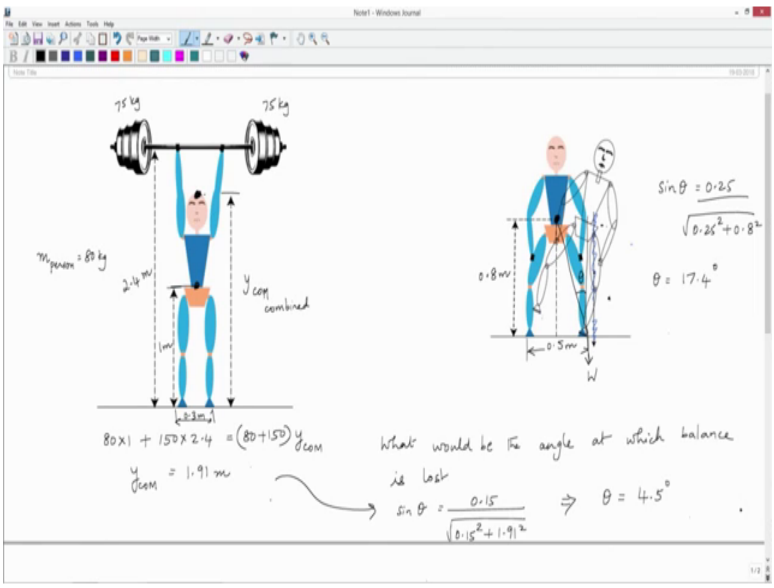


So, let us say through what angle so, the question we want to answer is say a person is just standing and here you have a weightlifter through what angle can you displace the person before balances lost in the frontal plane? Ok, so, here actually I just realized that this diagram is not accurate.

So, this ignore this arrow balance will be lost when the line through the CG when the line through the CG just crosses the edge of the foot ok. So, when the line through the CG just crosses the edge of the foot so, if that is W. So, when you are first standing and let us say this distance is 0.5 meters. The CG is located initially at 0.8 meters.

Now, if somebody gives the person a push and there now the CG is falling towards the edge then what is this angle have to be for this to happen? So, I am interested in finding this angle theta ok. So, that is fairly straightforward, I have this distance is. So, if I look at sin theta, sin theta is nothing, but this distance is 0.25 by the hypotenuse of this is 0.25 square plus 0.8 square this is actually from end to end this 0.5.

So, theta then is about 17.4 degrees in this case, now what happens? So, if you look at this weightlifter who has a load of a total load of say 75 kg's on either side. And the person is say mass of the person is 80 kg's you have and say this is (Refer Time: 10:57) to a height of 2.4 meter.

And initially just the body if the persons COM is at a distance of 1 meter ok, I can find the combined COM combined let us say a somewhere here now when the person lefts this weight right. How can I find that? I can just take moments about the horizontal line.

So, I have 80 into 1 plus 150 into 2.4 right equals the total 80 plus 150 into y COM of the system ok. So, I get y COM as 1.91 meters. So, now, the center of mass for this for this weightlifter has moved from 1 meter above the ground to 1.91 meters when they are holding it like that.

So, now how much leeway do they have to maintain balance? So, if I look at the same kind of thing if the person in the frontal plane you know shifts a little bit like that ok, what would be the angle at which balance is lost? And let us say this time and there standing straight like this the distance between the feet is 0.3 meters, they are not using a wide stance. Now, your sin theta is for this case 0.15 divided by square root of 0.15 square plus 1.91 square you get a theta of 4.5 degrees. You have much smaller leeway for something to go wrong and lose your balance ok.

So, a wider stance like I said in you know when somebody stands with their knees bend and a wide stance then you cannot displace them that easily you cannot make them fall that easily lose balance that easily because, you would have to push them through a larger angle for the line from the COM to pass through the edge of the foot ok. But, it is very easy to lose balance if you are and if you are carrying a high load like that above your head because, if as your center of mass goes up right you have less ability to recover from losing your balance.

So, in the frontal plane it is critical that to maintain balance you keep your CG low and a wider base for standing. You do the same thing like I said if you expect. So, like if you expect the opponent to attack you in the sagittal plane, try to displace your balance in the sagittal plane in the anterior posterior direction, then you widen your stance in that plane ok.

So, you put one leg in front of the other and you widen that stance. So, that then you have you can you have more time to sort of recovery of balance or do something to you are less likely to lose your balance easily when you do that ok. So, when you carry a load what happens?

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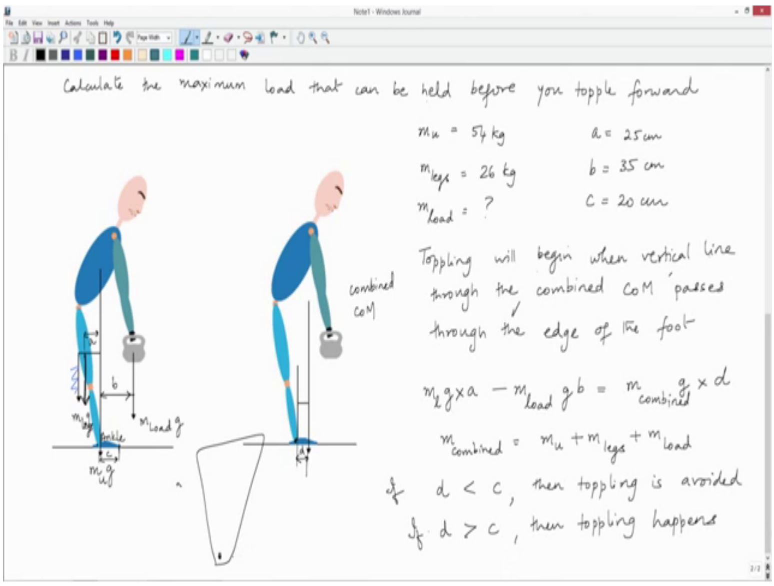


So, you are carrying a load what is and so, the weight lifter itself right you have the person having to lift the load, bend and lift the load ok. At what how much load can you lift before you again could lose your balance? Ok.

So, if you look at say the mass of the legs is here this should actually be here. You have the mass of the legs say this is your ankle joint, the pivot about which you are looking at. You have the weight of the upper body. So, you have m upper body, g acting here, m legs, g acting here and this is your m load times g ok.

So, let us say this distance is a, this distance is b and this base of support that you have is c. So, your foot you have that much in front of the ankle joint c. So, we want to calculate the maximum load that can be held before you topple forward.

Student: It is just only diagram that mass of the support is passing through their (Refer Time: 18:11).

This case it is taken that way.

Student: But it is not that.

It is not necessarily the case; it is not necessarily the case.

Student: So, c is the distance from

So, right now here it is assume to pass through the ankle. So, c is essentially you are looking at the body toppling you know moving about the ankle joint ok. So, in this case because we want to get rid of that moment we are saying that the person is standing such that because that is a significant portion and you are saying that I am assuming that the weight passes through the ankle joint.

So, if you look at for instance ballet dancers when they stand on tiptoe right we talked about balance when you are standing and the hand stand. When they stand on tiptoe they plan to flex their ankle to such an extent that the ankle joint is an line with the toe. So, that you are eliminating that one joint about which you can lose the balance right.

So, when they stand you know they stand on pointed toes if you look at their foot. In fact, many of them their foot becomes like that like because of sustained practice their. They will stand on this toe and they plant of flex it to the extent that the reaction actually passes through the ankle so, that they can maintain so, that there eliminating that moment about the ankle.

Student: Is this always the case or like it may (Refer Time: 19:49).

No, for this particular it is not necessarily the case. So, when you would know the distance about which that. Say essentially you are calculating the net of these forces; it is not necessarily the case. Here, you are just for simplicity I am just eliminating the moment due to that force moving back such that the weight of my upper body passes through the ankle. But, it is not always the case, I could be inclined at some other angle and that is again going to affect how much load I can carry.

So, if I bend and lift you know a certain load and hold it versus if I straighten up more and hold it you know that is going to make a difference on how much load I can carry because of this, because of the effect of this.

So, let us say I have give you some values m u upper body is equal to 54 kg’s, m legs is 26 kg’s what is m load? When I am given this a equal to 25 centimeters, b equal to 35 centimeters and c equal to 20 centimeters. So, toppling when will it begin? When the combined center of mass passes through the edge of the foot ok.

So, again here it is not correct, toppling will begin when this combined center of mass, the edge of this foot this would be the combined COM, vertical line through the combined COM. Now, if I call this distance as d from here to that is the same as so, I have if I take moment.

So, let us just call it some c just to no that is c taking the, if I take moments about that then I get. So, if I take moments about the ankle joint what do I get for this? Let us say before let us first generally say that this passes at some distance d and then develop the condition for you know if d is less than c then you will not topple, if d is greater than c you are going to topple has.

So, to find the distance at which the combined center of mass passes, it is essentially so, m l g into a minus m load g into b should be m combined g into d right.

So, if I look here about the ankle one creates a counter clockwise, one creates a clockwise moment net moment this will be the effect of that. Where m combined is mass of the upper body plus mass of the legs plus mass of the load ok. Do not forget the mass of the upper body because here we it does not contribute to the moment because I am assuming it is passing through the ankle, but it would contribute to the total mass.

So, if this d is less than c then toppling is avoided. If d is equal to c that is imminent you know that is when say if b greater than c then toppling happens so, the limit is c and so, I can calculate what could be the maximum load that you can carry by using this relationship.

So, essentially from here if d equal to c then I can compute what m load should be or what is the maximum load I can carry to avoid toppling ok. That is why is lifting smaller loads it is less risky, but if you are trying to lift a very heavy load then it is likely that you may lose your balance, does not happen when you are lifting smaller loads but, you again if you reach too far to lift a smaller load.

Then again the upper body if it falls outside the base of support that contributes a moment that you could that could cause you to fall. So, your body maintains this you can also find what is the. So, if I want to look at say my back muscles extensors right.

So, here in this case what kind of moment do they have to exert for me to maintain this position ok, to prevent me from falling forward. Because, of this was there was no muscle control then it is just a matter of it is not just disjoint you know I have n other joints about which I could fall forward ok. So, at every joint there is muscle action that is preventing, that is stabilizing that joint and preventing motion about that joint and to maintain this balance.

So, that would just be an inverse dynamic analysis. You know where the external loads are you can find out at that joint what would be the moment that would have to be applied by the trunk extensors in order to maintain that particular posture ok. That would just be a function of the d stabilizing moment. D distances your distance of the combined center of mass. So, these multiple loads are there right, I am computing one combined center of mass.

Student: (Refer Time: 27:51) movement of the leg the axis of the d?

Movement of the legs (Refer Time: 28:00).

Student: Because that is where the body will pivot right.

This is my ankle that is my ankle joint I am computing the moment about that.

Student: But, because of the.

I am assuming everything else is maintained as one. So, that is why I am saying like there are muscles acting. I am assuming that the ankle is my weak link here that. So, if you think of this body has just pivoted about the ankle that is it. What is the d stabilizing moment at the ankle? Ok.