Mechanics of Human Movement
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Lecture – 37
Biomechanics of Balance Part III

We will where looking at the mechanics of balancing, and we looked at the case where the person starts to topple and you try to arrest it by moving the other segments by transferring the angular momentum to the other segments of the body. If you look at it from our force or a moment perspective, essentially what you are doing is you are applying a moment, your muscles are your actuators.

So, right you are applying a moment to rotate your to accelerate your arms. So, to change the angular velocity of your arms so, when you do that, there is now a reaction moment applied to the rest of the body right. So, if I apply a clockwise moment to my arms in the same direction that I am toppling, the reaction moment is now actually counter clockwise on the rest of the body.

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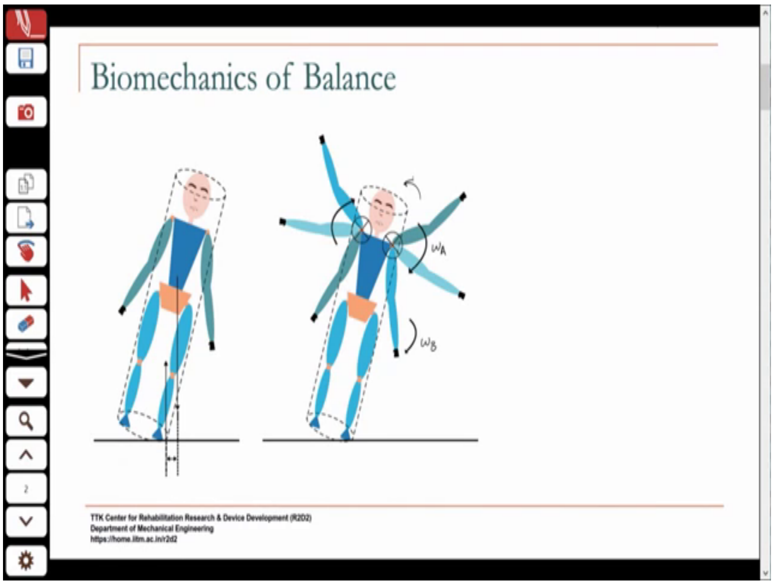

So, that is how I am trying to yeah adjust this you know change the tipping trip it back to the erect position. Say, if the moment the reaction moment is sufficient to overcome the tipping moment, then I am able to regain my balance.

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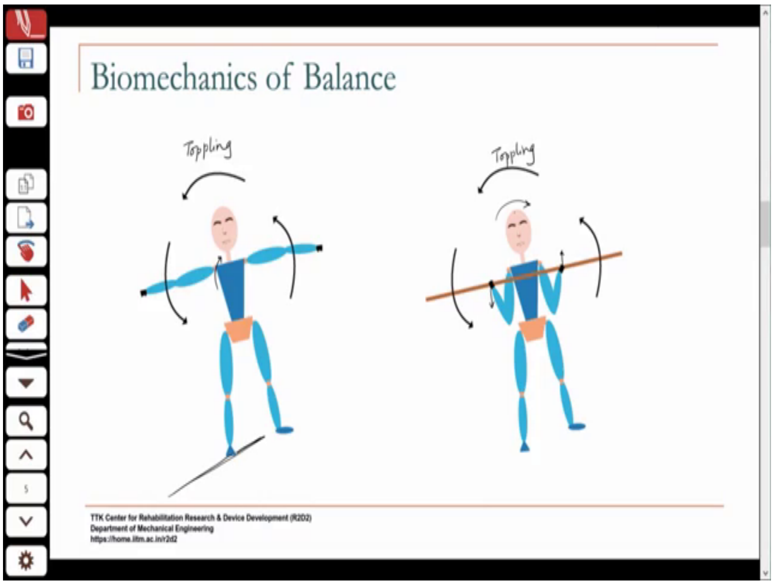

Similarly, even with the case of this. So, if I have so, that is the reason you rotate your arms in the same direction as the toppling because the reaction is what you are using to straighten the rest of the body ok. So, here for instance, if this is the direction of toppling on the our tightrope, then if I create a moment at my shoulder that will rotate the arms clockwise, then the reaction; so, if this is like this, then on this body the reaction moment is like that ok, which will tend to straighten it out. If I have the pole, which has a large moment of inertia basically I am applying so, when I rotate the pole in the same direction, I am basically applying a force like this right.

I am applying a force on the pole like this ok. The reaction force creates a moment that will try to straighten this ok. So, that is it; that is the analysis from the force or moment perspective. Because your force the actuators in your body are only the muscles and they act on these various segments in this manner to try to restore the balance. So, before we got human walking there are some. So, this is essentially what happens with a lot of our movements.

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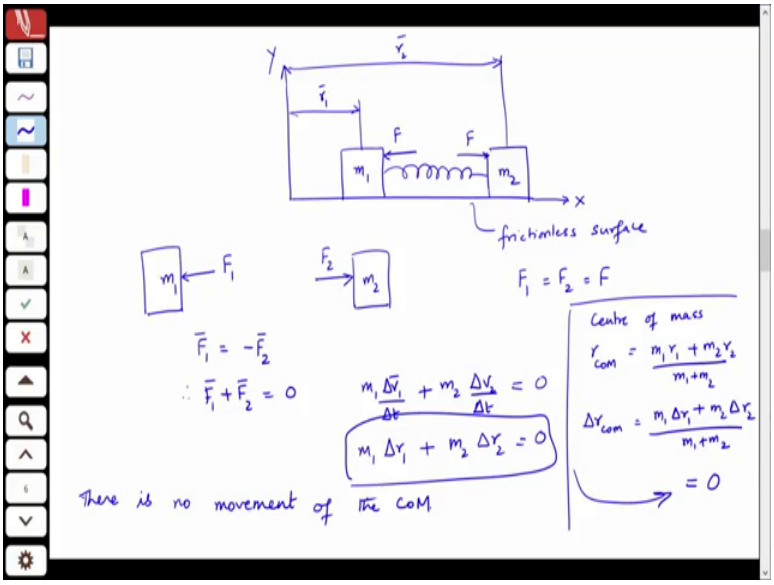

We were now looking at this case, where we started off with 2 masses right, on a frictionless surface mass 1 and mass 2. And I have some kind of an actuator that can apply a force to these masses ok. So, if this is my y axis and this is my x axis and say this is my frictionless surface, we saw that if I look at m 1 ok, I am just looking at the horizontal motion. So, I have a force F 1 apply to m 1. And in this case, say I have a force F 2 applied to m 2, and here F 1 equal to F 2 equal to F ok, I have an actuator that is applying.

So now I have in this case if I minus F 1 equal to m 1 a equal to 0, these are equal and opposite forces. F 1 equal to minus F 2 therefore, F 1 plus F 2 equal to 0. And I can write that as m 1 delta v 1 plus m 2 delta v 2 by delta t. So, suppose I take this as r 1 locating this mass, this as r 2 locating that mass, this is equal to 0. And therefore, m 1 delta r 1 plus m 2 delta r 2 equal to 0.

Now what is my center of mass of this system? If I take r com, that is equal to m 1 r 1 plus m 2 r 2 by m 1 plus m 2. If I have the center of mass of this somewhere. So, if I look at the delta of the r com it is nothing but m 1 delta r 1 plus m 2; since I am all taking everything in the x direction, I will just not use, this m 2 delta r 2 by m 1 plus m 2. So, what this tells me is that this is equal to 0; there is no change of the center of mass ok.

So, if I have 2 internal forces ok, the internal forces if one moves away, if one moves in one direction the other is going to move in another direction in such a way that the net center of mass of the system remains the same ok. There is going to be no change in the center of mass. Now let us look at the case. If I just move one segment with respect to another, and there is nothing I am isolated there is nothing else happening, you know, I apply muscle forces to move one, I cannot change the center of mass of the system. So, then how do we move from place to place, how do I because movement is basically moving the center of mass from one place to another.

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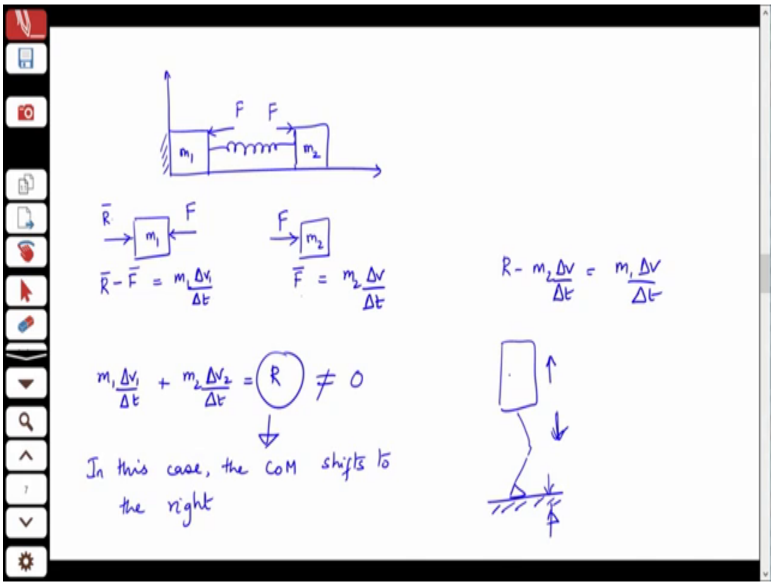

So now let us look at the effect of having some kind of a support. So, let us say in this case now, the masses at least one of them is against a support, ok. Again I do the same thing I have apply set of internal forces which are equal and opposite. And now this is a support so, it applies a reaction ok. So, if I look at the free body diagram of m 1, I have this force F 1 acting on it, I also have and R; a reaction force from the support. Then if I look at m 2, m 2 only has F 2 acting on it, so.

Student: F is an actuating force internal actuating force.

F is the internal actuating force; F is an internal force actuating force. So, I have here F 2 equal to F ok, F 1 equal to R minus F 2 in this case. So now, if I do the same thing m 1 delta v 1 by delta t plus m 2 delta v 2 by delta t, now it is non-0. When I have a support ok, this is non-0. So now, the reaction force is going to help me move the center of mass of the system. So, in a sense the reaction force it what is what becomes the propelling force; reaction force only arises because of the internal forces.

The internal forces acting on the mass which is against a support is what produces the reaction. If there was no support, then the net center of mass of the system does not change, center of mass if the system does not change. But if there is a support, now the center of mass of the system can change. See F 1 this is ok, the force on this is R minus F 1, F 2 is our did I mess that up? See F 2 equals F, this is this force equals minus F right, this.

So, let me just write it as so, I have F, I have F magnitude is this. So, if I write it in vectorial form R say this is F 1 we just call this F 1 plus F 1 equal to m 1 delta t F 2 right delta t, but F 1 equal to minus F 2 right. So now, am I F 1 is equal to the force R minus F is this. So, R minus m 2 delta v by delta t equal to m 1 delta v by delta t, you know what ok. So, this is how you get this. So, this is kind of what happens in your body.

So, when you look at so, if you take your upper body and say you take your lower body. Let us just take it as a segmented thing. Suppose you create a muscle you know using your internal muscle forces, you create upward accelerate you make your upper part of the body you give it an upward acceleration ok. That creates a reaction force on the lower part of the body, which is transmitted to the ground.

Now, that is what causes your reaction force. So, the reaction forces are caused by your muscle forces of course, gravity is also there apart from gravity. I am saying additional reaction forces come into play because of your ability to exert muscle forces. And that is what we use to move our. So, it is a the GRF is typically therefore, a good indicator of the muscular effort that you are applying.

So, you could be, so for instance when you jump you know everything is happening because of muscular effort. You are applying the muscular effort to propel yourself. To give you a GRF that is enough to lift your center of mass. So, if you are airborne ok, when you are airborne you do not have any support; assuming negligible air resistance there is no support acting on our body.

In that case you can move your limbs any which way you want, but the motion of the center of mass of the body will be influenced only by gravity. So, if you look at a lot of airborne movements, if you are looking at the linear motion, you only treat the center of you take the center of mass you treat it as a particle, and you look at the motion of the center.

There someone is doing a somersault or you know a jump or something like that, you can treat it if it is only under the influence of gravity then you treat it as a point mass. Because, there is no amount of internal manipulation that you can do when you are airborne to change the center of mass because if one part moves up the other part moves the opposite way so, that the system center of mass remains the same ok.

On the other hand, if you are airborne you have a net external force which is gravity, but gravity acts through the center of mass. So, there is no external torque on the body. So, when you are airborne angular momentum is conserved in that case ok. The angular momentum of the system remains constant once you are airborne. So, if you start off with some angular momentum, then when you are airborne you cannot so, what you can do is what can you change when your airborne?

Student: (Refer Time: 15:36) to present of.

You can change your the distribution around the center of mass. So, the reason you can do you know somersaults are you can do flips and do things like that once you are airborne is because you can still change your moment of inertia. So, when you are airborne you cannot change your center of mass, but you can change the moment of inertia about the center of mass, because angular momentum is conserved in that case.

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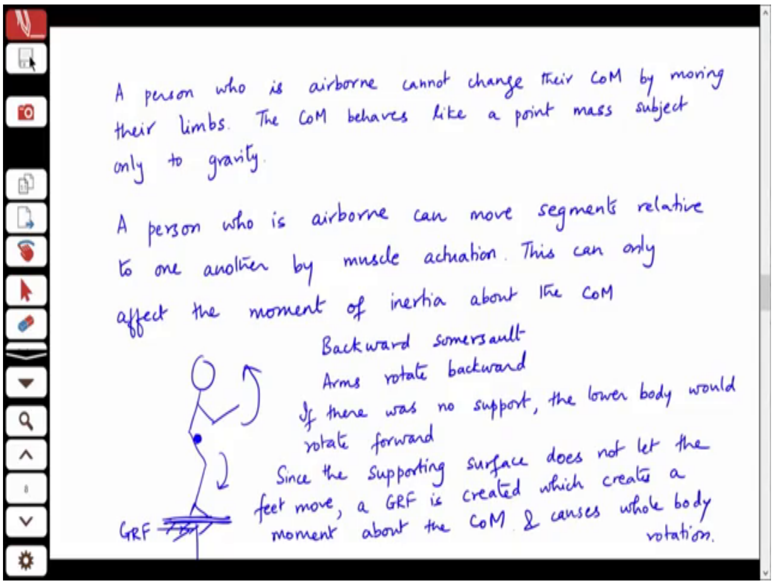

A person who is airborne can move segments one another by muscle actuation. This can only affect the moment of inertia about the center of mass. That is why when a diver tucks their body when they move it, then they start having a greater angular velocity. Because they have changed their moment of inertia.

But so, whatever angular momentum they had when they got off the diving board. That is not going to change. That is conserved because there is no external torque acting on the system once they are airborne. But that they can change because by changing the moment of inertia they can change their angular velocity.

Student: Mam flipping is about the center of mass (Refer Time: 18:46).

So, I will so, how do they first gain that angular momentum in the first place ok. They have to have some angular momentum, if you just drop a person like that right, they their movement will only be influenced by gravity. No matter how much they move. They have to have some initial angular momentum in order to be it able to do that. That is why divers do not just jump straighter. They do some kind of you know, they use the diving board in a specific way to gain that initial angular momentum. Then with that angular momentum that angular momentum will be conserved when they are in the air. And with that they can play around with how they change their moment of inertia and hence their angular velocity.

So, how do you do that? So, for instance if you wanted to do a backward somersault for instance how do you use your? So, you have your arms. What you do is you apply a moment, an internal moment on the arms to say throw them backward ok. You throw the arms backward, what happens now? So, I am applying say a counter clockwise moment on the arms.

So, on the rest of the body I am going to have a clockwise momentum. Now I have a support which prevents this from rotating. Now what is that support do? It generates a reaction force. Now this reaction force acting about the center of mass of the body causes that rotation applies the moment. So, that is how you so, if they are on the diving board, you know depending on how they want to flip. They would move their arms in that manner.

So, here if so, if you want to so, you want to flip backwards so, they will stand this way then move their arms up then what happens is the diving board provides that reaction to make them do the back flip ok. And once so, this moment that was created, this angular moment momentum that was gained at the beginning of the flip will remain the same, because there is no other external torque acting on the body.

Because this is caused by an external torque, the ground reaction force cause the moment about the center of mass. But that cannot change because there is no other, it remains the same because there is nothing else acting on the body once it is airborne other than the force of gravity ok.

So, that is how they do, this is how you use the reaction forces to perform various movements ok. And this is how basically you generate the ground reaction forces. So, if you want to do a backward somersault, your arms if there was no support the lower body would rotate forward.

Since there is a supporting surface, since the supporting surface does not let the feet move a GRF is created which creates a moment about the center of us and causes the whole body rotation. So, with this we will kind of wrap up the kinetics portion that we have of this course.

So, if you remember so far, initially we did a lot of static analysis, then in the kinetic analysis we initially started off with modeling as you know point masses for linear motion, then we looked at angular motion you know then using that to find the internal forces. Then we looked at inverse dynamics analysis which helps you go from segment to segment to find the internal joint forces and moments.

And then we looked at some cases of whole body motion, like how do we use this how do we use our internal forces against an external support to help make some of these movements. We also looked at the influence of balance. So, this is what we have looked at in kinetics. In the next few classes we are going to focus more on specifically human walking.