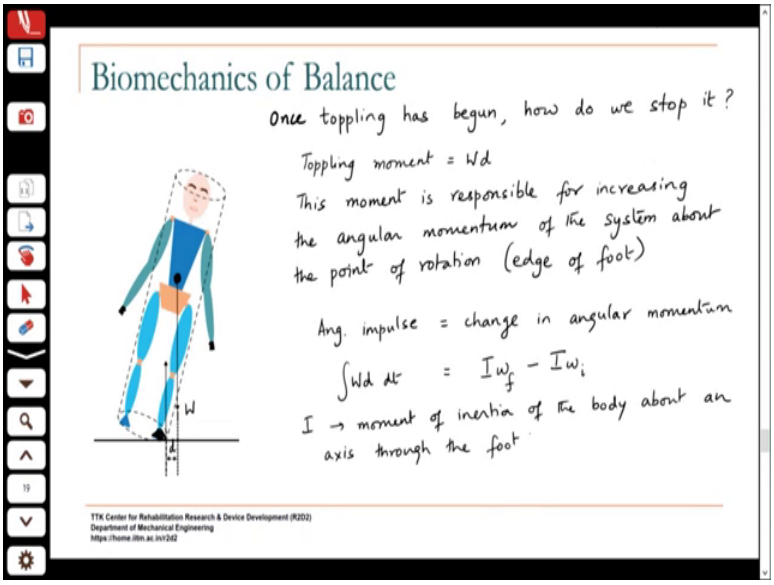
Mechanics of Human Movement
Prof. Sujatha Srinivasan
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Lecture – 36
Biomechanics of Balance Part II

So, we have looked at what causes balance to be maintained or what causes loss of balance basically.

(Refer Slide Time: 00:27)



So, you know if the line through the center of mass, the vertical line through the center of mass falls outside the base of support then the body starts falling. So, today we will look at some strategies you can use to recover balance. So, if you are losing balance how do we recover that balance and we will look at you know the mechanics of it and see how to do that. So, once toppling has begun, how do we stop it? So, because we all do that, you know, every time we lose balance we do not necessarily fall. You can recover your balance up to point so, will look at what that is.

So, here let us say you have will approximate the human ok, and say the person is losing balance and falling because of this w falling outside the base of support. And if you look at the distance perpendicular distance from the edge of the foot, then that let us say that is d, then the toppling moment is essentially w into d ok at a particular instant.

The problem is d will keep increasing as you are falling. Ok d keeps increasing once there is a disturbance that causes you to fall. So, this toppling moment so, when you have a moment essentially it is job is to increase the angular momentum of the system. So, this moment is responsible for increasing the angular momentum of the system about the point of rotation which is the edge of the foot.

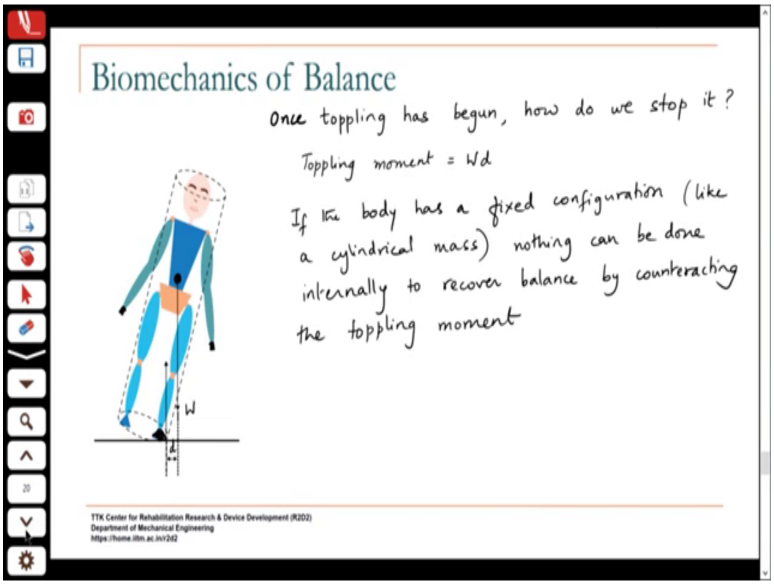
Student: Mam, yesterday when we are looking the how much inclination that it will take? Is that the maximum value of the movement of the inclination?

Yes, beyond which you are going to fall. So, the question was yesterday when we looked at the balance of this person, right? We said what is the inclination after which the persons going to start toppling. So, yes, so, beyond that angle that is when this starts happening, the toppling starts to happen ok. So, we need some way of opposing this external moment, in order to recover balance. And really in the absence of any external so, I could hold on to something and that could provide me.

So, you know if somebody pushes me, and I am near a wall I could just push on the wall and that can help me straighten myself. I do not have that luxury. So, I have to figure out what I can do with my body to try to with the internal muscle forces that I can exert. What can I do to recover this balance? What movements can I initiate, what can I with this multi segmented system that I have to try to recover the balance.

So, that is the problem we are going to look at today. So, if you look at this in terms of the angular impulse so, because your movement ok, let us just look at it the angular impulse equals the change in the angular momentum because the moment equals the rate of change of the angular momentum. So, this means integral of w into d dt equals whatever is the moment of inertia of the system about that point, omega final minus omega initial. So, I is the moment of inertia of the body about an axis through the foot.

(Refer Slide Time: 06:47)

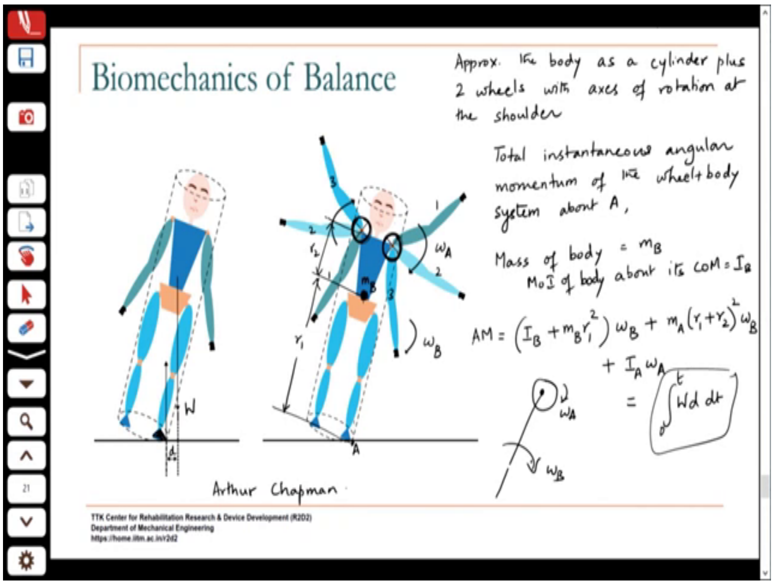


So, since this d is going to be increasing very quickly, you can only recover balance if you act very quickly ok. So, beyond the point there is really not much you can do.

So, let us see if the body has a fixed configuration like this, where you think of the body as like a solid cylinder, then there is really not much you can do. You start toppling like that you are just going to fall, unless there is some external intervention. But fortunately our body is not a single solid rigid body, we have all these segments that we can use to sort of transfer the gaining angular momentum, and that is what we are going to look at.

So, if the body has a fixed configuration, nothing can be done. Because there is no way of counteracting this increasing angular momentum; can be done internally, externally you can always apply a moment to counteract the, to recover balance by counteracting the toppling moment.

(Refer Slide Time: 08:49)



So, let us look at now instead of just the body now I have my arms ok. I separate the body into a cylinder ok, and I say my arms are like 2 wheels, I can approximate them as 2 rings, 2 wheels that are pivoted at the shoulder. So, I am modeling my body now as the rest of the body and the arms, which I can represent as 2 wheels. So, here if I look at, now let me write the angular momentum of this system.

So, I have let us say the initial angular velocity was 0, but now let me say that the body the whole body has an angular velocity about this point about which you are toppling of omega B. And I am now rotating my arms about the shoulder with an omega A ok. So, I start doing this, I start rotating my arms in the same direction that I am toppling, you know, I have I am falling like this, but I start rotating my arms. Of course, we are assuming here that you can do a full 360 degrees in a plane which is not really the case, but you know for the purposes of modeling; let us assume you can do that ok. We are assuming this is a wheel.

So, approximate the body as a cylinder plus with axes at the shoulder. So, the body has omega B arms are rotate so, if the body has a clockwise velocity omega B the arms are being rotated at omega A also in the clockwise direction. So, this is we are talking about the frontal plane.

So, you can see here this color and this color. So, you lift one arm and then you start rotating, you see these 2. So, if this is 1, this is also 1. The colors kind of show that, but yeah that that is 1, then this is 2, this is 2, this is 3, this is 3. So, that is the relative location of the arms that you are seeing; 1 1, 2 2 and 3 3.

So now if we look at the total instantaneous angular momentum of the system of the wheel plus body system about this axes through the foot. So, this is my A ok, about A, axes through the foot. Then I can write this angular momentum equals so, I have the let us say this is m, m B and the mass of the arms is m A me just call each one m A by 2 arms.

The arms are approximated as wheels mass of body equals m B, and let us say it is moment of inertia about the center of mass is I B, and similarly for and let us say this is located from that point A, this is located at a distance r 1, and then from the center to the center of mass of the body is r 2, ok.

So now I can write the angular momentum, the instantaneous the total angular momentum of this system is I have I B angular momentum of the body about it is center of mass, plus using the parallel axis theorem m B r 1 square ok. This is rotating with omega B ok. In addition, I have the arms; I am approximating them as wheels. So, I am saying or rings as the centre of mass is at the shoulder ok. So, I have m A r 1 plus r 2 square into omega B, again that the whole it is rotating with the body. In addition, I have I A omega A angular momentum due to the arms rotating about the shoulder joint ok. So, these are the 3 components of this ok. Omega B I do not have control over, because? Yes.

Student: (Refer Time: 15:55) this omega B which will be introduce this after the (Refer Time: 15:58) in this situation (Refer Time: 15:59).

At that instant.

Student: Yeah.

The body is toppling.

Student: So, in that case (Refer Time: 16:06) body there is no external moment that will generate that right. So, then we are including (Refer Time: 16:12).

There is an external moment, the external moment is because.

Student: Yeah.

The weight has come out of the base of support. And now the body is tipping over the edge of the foot.

Student: We observe the, but the movement generated due to the arm that, when we an (Refer Time: 16:29) equal and opposite movement on the body the (Refer Time: 16:31) of the body part the entire body separated (Refer Time: 16:34).

We are not looking; we are looking at angular momentum.

Student: Yeah.

Right?

Student: So, there should be an equal and an opposite angular momentum generated at the hinge at the ends are generated.

That would be an internal you are talking about; you are saying the angular momentum generated by this arm.

Student: Yeah.

Yes, would be.

Student: With the arm is generating some x momentum.

Right.

Student: That then the place where (Refer Time: 17:09).

So, let us, let us be clear about the movement will be counteracted by a reaction movement.

Student: Yeah.

The momentum is due to the motion; we are looking at angular momentum. Is the difference clear? Ok, a force would be counteracted by an internal force of the same acting on the other body. The most we are talking about the angular momentum, which is because of the motion ok, which is equal to I A omega A.

Student: When we are taking angular momentum will taking (Refer Time: 18:01).

Yes.

Student: So, for parallel axis tell me if it will not be arm generator B, something else I approximately (Refer Time: 18:08).

I am taking r 1 as the perpendicular distance from that point to that.

Student: We should taking from the point A to (Refer Time: 18:20).

Point I am taking the perpendicular, I am taking this. So, this is, I am taking about an axis that is passing through point A.

Student: (Refer Time: 18:33) axis is basically (Refer time: 18:34).

Oh you are saying it should be this distance?

Student: Yeah (Refer Time: 18:38), line joining line joining m B.

Line joining m B and A.

Student: (Refer Time: 18:44).

Ok, I see what you are I see what you are saying. So, if this were directly below m B, then the r 1 would be the same as that distance ok, fine, it would be r 1 should actually be this. You are right ok, but let us just approximate it here to be this distance.

Student: (Refer Time: 19:21) (Refer Time: 19:22)

This one? No, omega A is the angular velocity about.

Student: The wheel.

The wheel is the arms are rotating about that center, but the arms are also part of the whole body and that is what this contribution is. And that part is rotating with omega B ok, the wheels themselves. So, it is like this if you just think of a rod with a wheel attached to it ok. The wheel is rotating at omega A, but the rod is rotating at omega B about this point so, that is. So now, this angular momentum of the system is because of W d ok.

So, this is equal to so, if this is the final angular momentum. Let us say it starts this is integral W d dt if this is the at a particular 0 to t W d dt. Then what happens is now you do not have control over omega B, but you do have control over omega A ok.

So, this if I start increasing omega so, this is sort of the same ok, this is one quantity ; which is influenced only by w and d ok. If I take a snapshot, then this is going to remain the same. But I can play with the contribution. So, if I start increasing omega A, then omega B has to start reducing to keep this total instantaneous angular momentum the same. And in fact, I have to keep increasing omega A such that because d is constantly increasing. So, I have to if I have to write myself, then I actually have to increase omega A so that A omega B will become 0 when all the angular momentum goes to omega A. But even then there is a moment and actually now have to increase it even further to sort of go back.

It is a very instantaneous, you know, we are talking about something where you have to do it very quickly but if you see even when you know push someone right, instinctively your arms go up. Instinctively you start rotating your arms in that direction. And that is kind of the way we try to regain that balance. There are other strategies, because your body has multiple segments.

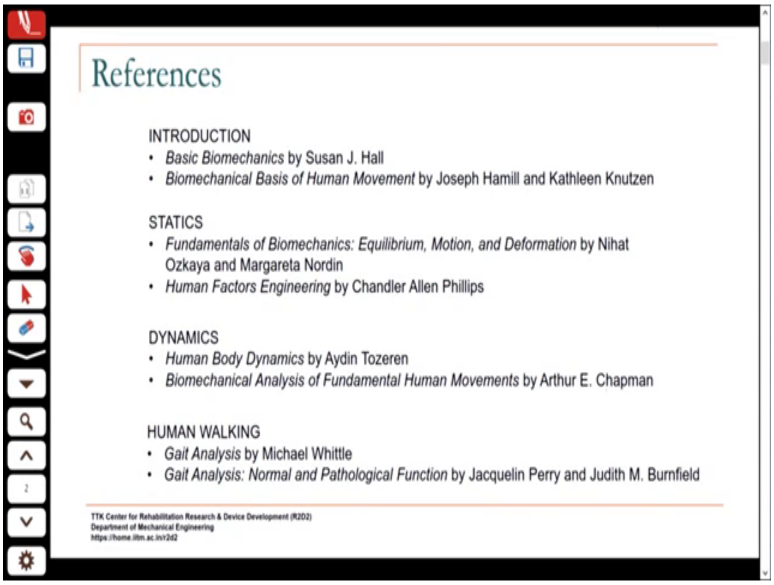
Another thing that we do is at the hip. Someone pushes you immediately flex your trunk, right? If you push somebody suddenly, right and they are to going to fall forward the instinctive reaction is try to flex at the hip. So, that you are transferring that momentum to another segment that could actually help you, right.

So, when you do that now I am actually moving my CG, I start moving my CG backwards. So, the chances of my writing myself you know preventing myself from falling increase. So, that is what we are you know with this because of the multi segmented nature of the body, we are able to do that.

This is a very simple model that kind of explains how we can do that. But so, essentially what you are do what you are doing is this external moment is increasing the rotational kinetic energy of the system. And you are doing internal muscle work, muscular work to counteract that increase. So, you have to start doing more work in order to be able to straighten yourself back up, ok.

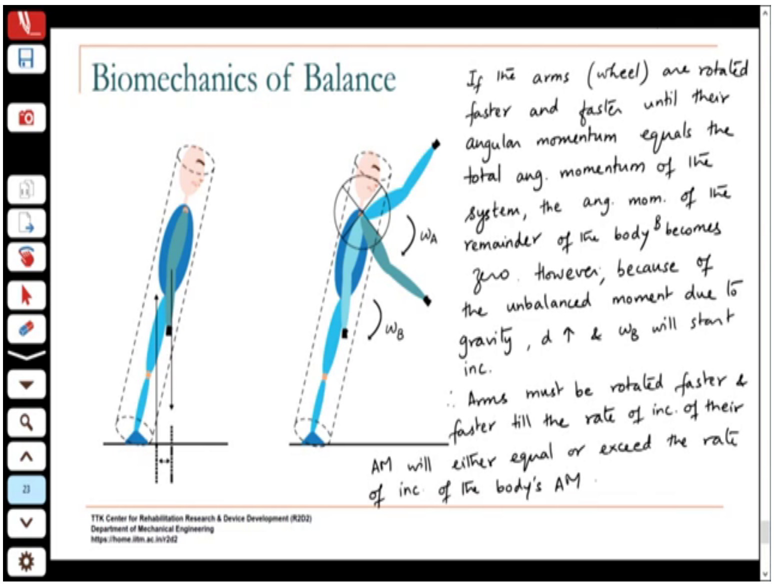
So, that is this I mentioned in the references right, this book by Arthur Chapman has some interesting examples like this. But I like to do a few of these. So, you get an idea of, I think it is called biomechanical analysis of fundamental human movements. I think I mentioned it in the, I had the references that day.

(Refer Slide Time: 24:25)



This book, Arthur Chapman's book has this sense of other interesting examples of ok.

(Refer Slide Time: 24:35)



Same analysis applies to you can do it for the losing balance in the sagittal plane as well; so, here again.

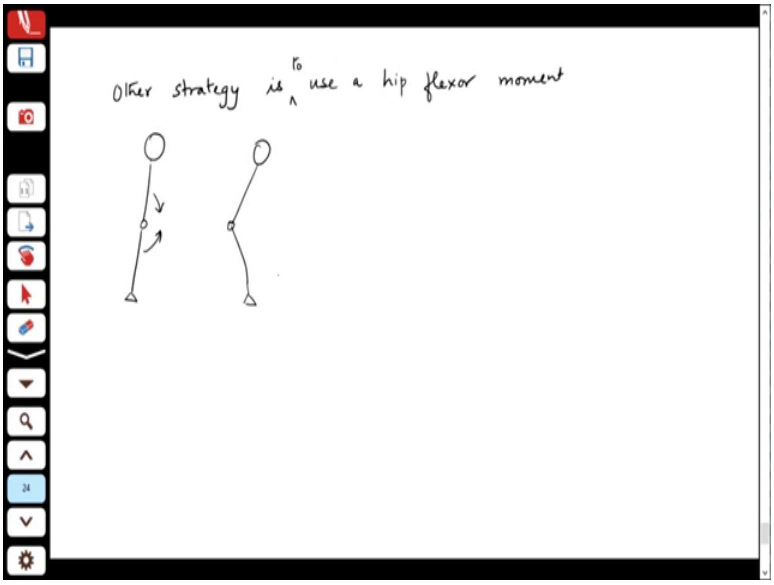
So, the lesson from this is, if you start to fall forward, then you start rotating it is sort of counterintuitive; you think that you are going to try to you know rotate your arms in the opposite direction to try to go back. But what you are actually doing is not trying to provide a reactor, but you are trying to basically take the, that angular momentum into some other part.

So, you start rotating in the same direction. You rotate your arms in the same direction as the direction in which you are falling. You are going to fall, because now that term actually becomes negative, you will probably just fall faster. You are may right.

So, this is of course, a simple an analysis of this, but it gives you some insight into how we do this. So, if the arms the wheels are rotated faster and faster until their angular momentum equals the total angular momentum of the system, the angular momentum of the remainder of the body becomes 0, but because the body is still leaning and that instant you have to that is not enough, just making it 0 is not enough because it will just start falling forward, because you still have that unbalanced moment. So, omega will B will be instantaneously 0, but you have to prevent it from increasing further.

Therefore the arms must be rotated faster and faster, till the rate of increase of their angular momentum will either equal or exceed the rate of increase of the. So, essentially your shoulder muscles have to do the work to counteract the work done by gravity to do this. And if that work the work of the shoulder muscles exceeds the work done by gravity, then you start straightening up ok. Body starts rotating in the so, the other strategy of course is to use a hip flexor.

(Refer Slide Time: 29:53)

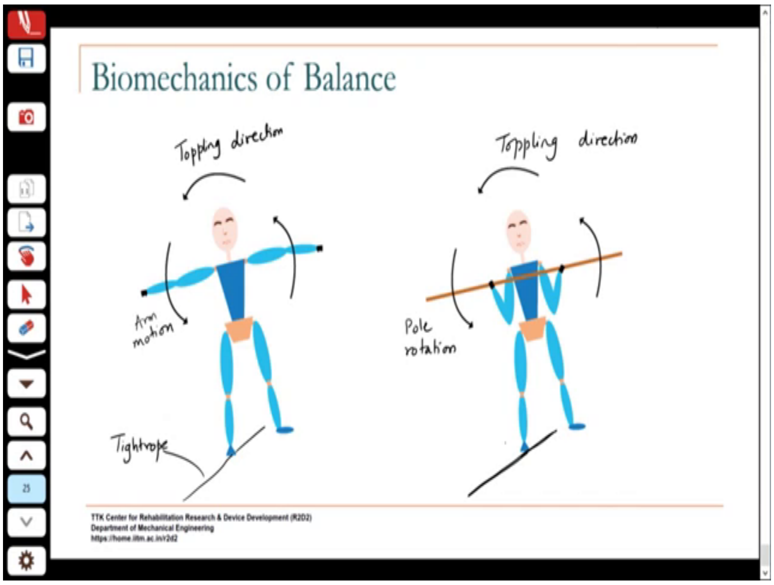


Student: Moment.

So, if you have this guy falling; so, assuming the rest of it is you know you are only assuming it has 2 segments, then if you start falling he start bending ok. And then you kind of assume a posture like this, and that will help you regain your balance. And the COM may actually become positioned within the base of support, when you do that.

If you combine this and the arms, then the chances increase a few. So, if without the person knowing you push somebody, you will see instinctively that is the kind of writing mechanism we adopt. Be careful if you try it on [laughing] somebody and if somebody is maybe you can do it, you know now that you are aware of it you can do it on one another, but yeah do not do it on unsuspecting people in case, then I will get into trouble [laughing].

(Refer Slide Time: 31:37)



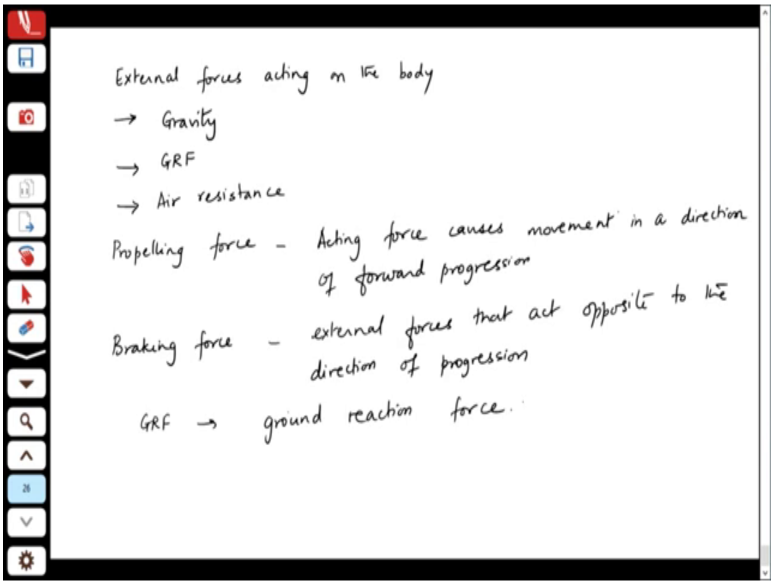
So, similar kind of strategy, when somebody is walking on a tightrope right. So, this is let us say they are walking on a tightrope. Say, the person starts toppling in this direction, they start falling that way, then they should start rotating their arms in the same direction, ok; this would be the arm motion.

Now, challenges here you have a very small base ok, takes a lot of skill to walk on a tightrope. So, what they do is many of them carry a heavy pole ok, what that does is this pole has a high moment of inertia. So, even with a little omega so, with the arms you know there is only you would have to start rotating them very fast to kind of absorb the angular momentum, to transfer the angular momentum to the arms. With the pole because it has a high moment of inertia, you can give it a small angular velocity. And that will help to maintain your balance, same principle that you do.

So, then there the important thing is the motion is, in the same direction. Because what you are doing is transferring the angular momentum to the other moving segments. Now in many cases so, in the body we have this multi, we have the ability to use our muscles is actuators to apply forces and moments about the various joints.

Now we want to look at in many cases we are also subject as we have seen, we are subjected to a lot of external forces and moments. You know, for instance how are we able to move our center of mass from one place to another, like you know there is some interplay of external and internal forces happening that enables us to do this ok.

(Refer Slide Time: 34:35)



So, in most cases the external forces that act on the body what are they? What are the most common external forces that act on the body? As human beings, what are the external forces that we normally experience? In most of our daily in most of the activities that you do walking running you know, sorry?

Student: Gravity.

Gravity; so, you have ground you have gravity, gravity is something that is acting on us all the time.

Student: Friction.

Friction or what I mean what can you? Friction comes from what? It comes from it is essentially a?

Student: Ground reaction.

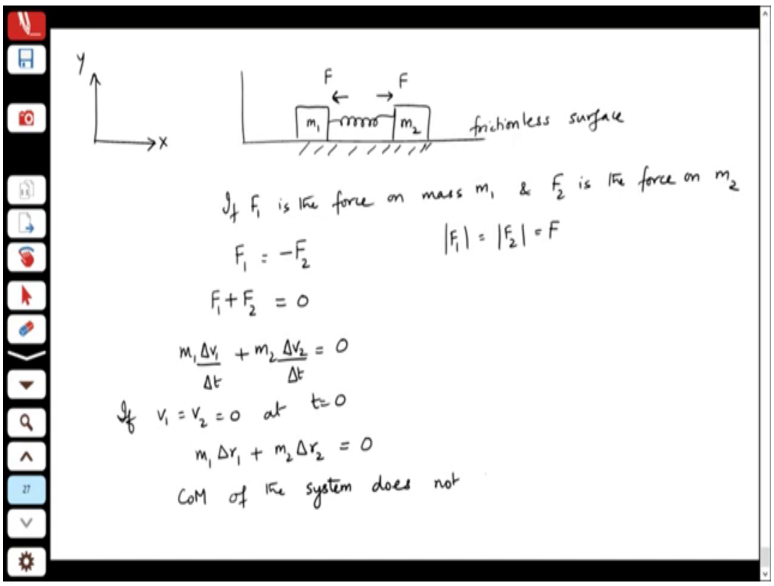
It is a ground reaction force. So, we also are subject to ground reaction forces, you have normal forces as well as frictional forces. Ground reaction forces are a very common external force acting on the body. Then due to fluids you can say air resistance, but in most cases we tend to ignore air resistance, because as compared to the other forces, unless it is in special situations where this is significant we tend to ignore the effects of air resistance because the other 2 are more dominant in the body. So, we want to look at what kind of forces. So, we in many cases we want to be either propelled forward or we want something to break our motion ok.

So, those are the sort of and that is where these forces play a role. Like the air resistance is more of a braking force ok. It is a resisting force whereas, gravity may be more of a propelling depends on the situation it depends on the activity, but let us we will look at how these internal forces and the external forces kind of work together to make movements happen ok. So, when you say when do you say it is a propelling force, when you want to move in a certain direction, and the force is aiding that motion. Propelling force is when the movement happens in the same or sorry when the forces same direction as the force.

And the braking forces a propelling force they acting force causes movement not necessarily in the same, but in the direction of in the direction in which you want to go ok. In a, let us it is typically referred to as forward progression, direction of forward progression.

So, if I am walking from point A to point B, then that is my forward progression is from A to B, a braking force these are external forces that act opposite to the direction of progression. The ground reaction force as it is name implies is a reaction force ok. There has to be some action that causes that reaction. So, the GRF is basically a reaction force of the ground.

(Refer Slide Time: 39:51)



So, let us look at a simple case where you take let us call this a frictionless surface. I have 2 masses connected by something ok that can apply a force on these 2 masses. So, some actuator in between ok, which can. So, this would be like similar to your muscles. I have one segment another segment and you have a muscle that is capable of applying a force to each segment. Now I can say that so, these are both internal forces right. So, if I let us say I say F 1 is the force on mass m 1, and F 2 is the force on m 2, then I have F 1 equal to minus F 2 ok. And the magnitude of F 1 equal to the magnitude of F 2 equal to F, ok.

So, I have F 1 plus F 2 equal to 0 this is my Newton's third law right, because those 2. So, if I write this in terms of the change in linear momentum of these 2 bodies, I can write it as m 1 delta v 1 by delta t plus m 2 delta v 2 by delta t equal to 0. If v 1 equal to v 2 equal to 0 at t equal to 0, I start from rest ok. And then I can write it in terms of displacement. I can write it as m 1 delta r 1 ok, whatever the change plus m 2 delta r 2 equal to 0. So, what is this tell me? This tells me that the center of mass of the system does not move. Applying only internal forces cannot make me change the center of mass of my system.

So, if I was not acted on by any external force, I can move my limbs all I want; say, I am suspended in a gravity less environment unconnected to anything else. I can move my arms any which you know I can move my limbs any which way I want, but I cannot change my center of mass. This is that is what this is telling me right. So, we will continue with this you know, so, then how do we move? Because walking running a lot of the things that we do involves moving our center of mass from one place to another. So, how do we manage to do it, ok? How do we use the external forces to help us move the center of mass?