Neuroscience of Human Movement
Department of Multidisciplinary
Indian Institute of Technology, Madras

Lecture – 17
Skeletal Muscles - Part 4

Welcome to this class on a Neuroscience of Human Movement.

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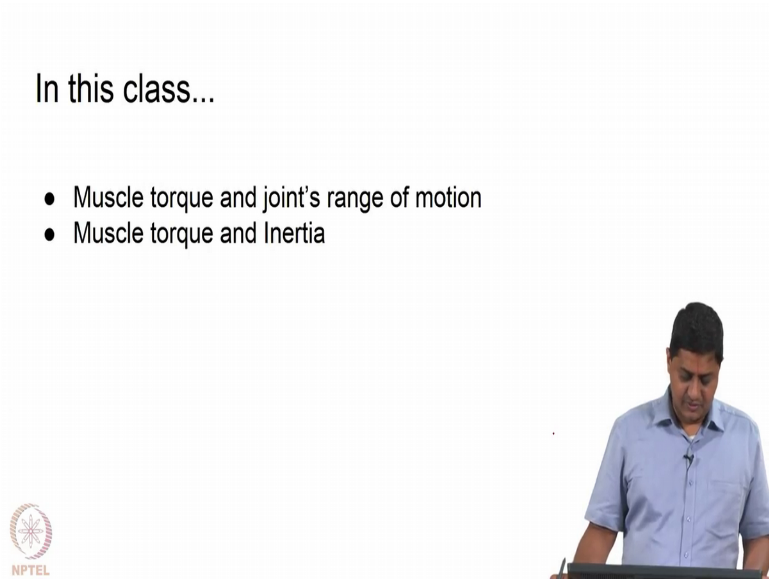

We have been talking about skeletal muscles. Today's class will be part 4 of our discussion on skeletal muscles. So, in this class we will be talking about muscle torque and joint range of motion and how muscle torque and inertia are related.

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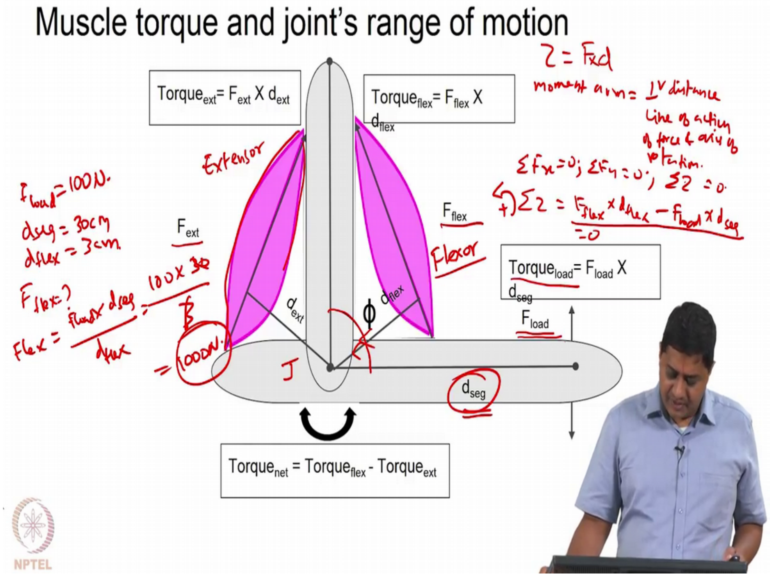

The situation is how are even human movements produced, what is considered moment. What is presented here is in this simplified version of the actual situation obviously, the actual situation is way more complicated and we have taken a very simple version to understand the concept to understand the principle ok. Let us consider a case where there is a flexion action being performed right.

So, that maybe similar to that action for the purpose of this course and class we will define flexion are a movement that reduces the angle between two segments. Two neighboring segments if the angle between them is reduced, we will call that as flexion. Actually there are several definitions I am not going into the details, but far now suppose I have the elbow joint right that is the elbow. And as of now this is approximately at right angle, approximately this is at 90 degrees I am doing that.

Now, that angle is slowly reducing right slowly reducing that is called flexion, that movement which reduces this angle is called flexion. When you do the opposite it is called extension you note I can extend that at up to 180 degrees, that is approximately 180 degrees. Whereas, I cannot flex to 0 degrees actually because there is a tissues that prevent these two bones to actually become a parallel to each other so, that is not possible right. So, it cannot be 0, but it is a small value there is the minimum say 20 degrees or whatever. So, the angle between these two joints may be 20-30 degrees at this level and its 180 degree this is called as range of motion alright.

How is this movement happening? Actually, this particular movement is happening through the interaction of multiple muscles, but we will consider a simple case. Let us suppose this is the joint of around which the moment is happening ok, this is the joint J about which the moment is happening alright. Now, if I have to reduce this phi, phi is the joint angle which is approximately 90 degrees in this case. I would like to flex or reduce phi in that case what should happen.

Let us consider that this joint is (Refer Time: 03:22) only by two muscles for the purpose of discussion there only two muscles, one muscle is this which I am going to call as flexor. And the force produced by this flexor is F flex the other muscle is this which is called as extensor. And the force produced by that muscle is a F ext, if the flexor contracts then what it will do is essentially this will reduce or that will happen, is it not something like this situation will happen. So, earlier this was the configuration earlier the joint was at approximately 90 degrees.

Suppose when the flexor muscle is contracting then what happens is this right say for example, at the end I am supporting a load here some load that value I am going to call us F load. Let us assume that there are no other joints that are being spanned I am simplifying the situation, so we can understand the principle. So, a suppose there is no other joint involved here that perpendicular distance between the load and the joint is some distance d segment.

Now, I would like to hold the object an equilibrium, let us assume that this object is about 10 kilograms right. And I have to hold it in equilibrium if I have to hold it in equilibrium I have to produce an active force with the flexor muscle because otherwise if I did not produce this will draw. But, I want to keep it in equilibrium I want to keep it in that is configuration, I want to keep it in equilibrium in that configuration by the way it is also possible for me to keep it in at multiple configurations. For example, that configuration for example, that configuration or for example, that configuration I can do that in multiple configurations.

But, for now I am interested in this configuration where there is a right angle between the upper arm and the fore arm right. So, in that case I have to produce an active force with the flexor muscle such that the moment or the torque that is produced by the load is overcome by the torque that is produced by the muscle.

Let us analyze that situation a bit more deeply. So, the torque that is produced by the load is essentially the product of the load itself times the perpendicular distance between the load and the joint about which are the axis about which the movement is happening. The joint about which the movement is happening is here the load is here. In the case of the forearm that we just now discussed this d seg is about 25 or even 30 centimeters. So, if I had a 10 kg mass then I am talking about the load being 10 into 9.81 are essentially 98.1 Newton's times 30 centimeter.

That is the approximately 200 and 94 Newton centimeter note the unit its Newton meter Newton centimeter this case right ok. That is the load that is sorry that is the torque that is being produced by the load on this system whereas, note the muscle is attaching at that point it is not this distance that we care about let me erase this. So, things are a bit clear right this is where the muscle is attaching, but it is not this distance that we care about for the purpose of computing the torque. It is that distance what is the difference essentially the torque is the product of the force and the momentum (Refer Time: 07:59.) What is the momentum the momentum is the perpendicular distance shortest perpendicular distance between the line of action of force and axis of rotation.

So, essentially this means that that is what we care about. In this case it is immediately obvious that d segment is actually a constant at that angle. Actually at a different angle again since the load something to remember is since the load always acts down wards, and in this case it is convenient that d segment actually is the length of the forum. But, that is only in this case at different configurations d segments are the momentum of d segment will vary depending on what the joint angle is. Here I have chosen a convenient co ordinate system such that d segments is the length of the forum, but this may vary in other configurations as we will see in future slides.

So, at least one thing is clear that did this is d flex and this d flex is also a function of the angle phi at different angles you will have different momentums. Now that means, it is not clear for me: what is the force that I need to produce. Then how does the system learnt this that is one question that we will have to address in future classes, but far now we will assume that there is this d flex at the momentum. And there is this d seg are the momentum of the load d flex is the momentum of the flexor and the muscle force that is produced by the flexor is F flex and the torque that is are the and the force that is produced by the load is basically F load. Then essentially you are looking at equations of static equilibrium which is basically sigma F x equal to 0 sigma phi I equal to 0 sigma m is 0.

In this case if you choose convenient coordinate systems sigma m alone if you write you will essentially get for the purpose of this course I will use instead of m I will use tau for the moment or the torque (Refer Time: 10:51) m can sometimes be confused for muscle force. So, I will use that different notation, so this is essentially this is essentially F flux times d flex which is a counterclockwise moments. So, sigma tau where counterclockwise moment is considered pass it is.

So, that is essentially a counterclockwise moment minus F load times d segment and that is 0. Important to note here is d flex is usually a fraction of d segment d segment is of the order of 25 to 30 centimeters, best d flex is usually a few centimeters for convenience I am going to say that support 3 centimeters whereas, d segment is about 30 centimeters. Now, it makes my problem easier to solve and let us assume that the load that I am carrying is instead of 10 kg I am going to call that as 100 Newton's to simplify my problem. I am going to assume following values for the forces and momentums these are I will write here, F load is 100 Newton's d seg is 30 centimeters d flex is 3 centimeters.

The question is what is the muscle force that is produced that is the question using the equation I could compute F flex as you know F load times the d seg divided by d flex. And that is basically 100 times 30 divided by 3, which will essentially give me 1000 Newton's essentially realize that is a relatively large number 1000 Newton's is what needs to be produced to carry a 100 Newton pro why is this. Well obviously, this is because this distance are the point at which the muscle attaches are the insertion is closer to the axis of rotation are to the joint, when compared with the load in this case and this is usually the case in many such a systems.

So, usually the muscle force that needs to be produced as many times the actual load right. So, that is because of small momentums in this case the situation is at there is a small momentum are. Sometimes it turns out that they attached at inconvenient angles such that the rotation is not happening about the joint under consideration, but actually happening about multiple joints one of which is this joint. In that case what happens is you have to make the movement about this joint and prevent moments about others joints, those are other problems that come with the situation. But far now, it is enough for us to realize that that the muscle force can be many times the load in this case that is because of small momentum, in other cases it may be due to inconvenient angles of attachment right.

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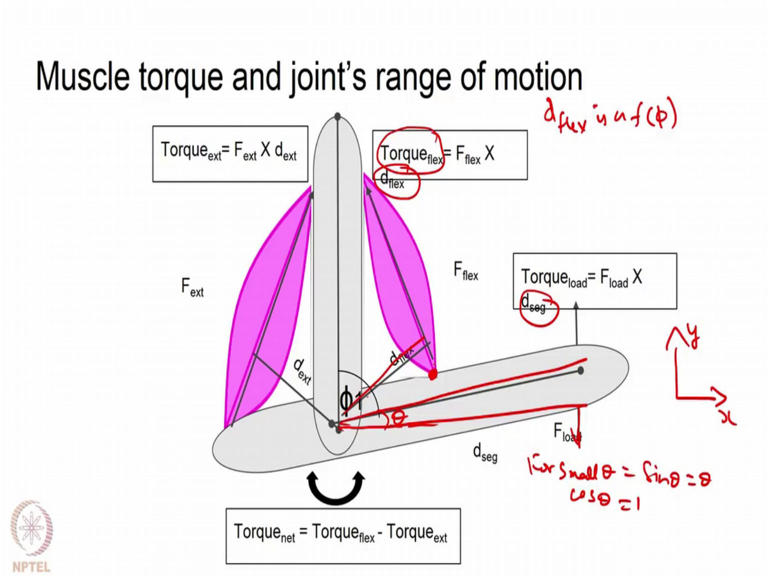

Now, what would happen if I were to do this at that level well the problem slightly changes right. Now, let us remember since the load is always acting in that direction right if I choose that as the x y axis as the frame of reference. I will have a theta this theta is actually small right. So, for small theta sin theta s theta and cos theta s phi again for relatively small theta that is the actual momentum and that is the length of the forum. So, here there is a slight change in the problem why because now you have an acute angle right.

Earlier I had a right angle now I have an acute angle accordingly the problem will change of course, it is possible for me to choose a different coordinate system, whichever coordinate system that you choose depending on that the problem will change. But it is not like the force that needs to be produced by the muscle has changed by a lot regardless of the situation d segment d flex is not going to vary by a lot. And by the way d flex which is the momentum of the muscle actually varies is as a function of the phi d flex is function of phi, and it reaches a maximum around the joints middle of the range of motion.

So, if the joint has a range of motion of say 100 degrees then at about 50 degrees you are going to have the maximum momentum ok. So, then the torque that is going to be produced is actually the product of this momentum and the force. So, you are going to produce the maximal force at around the same point it turns out that it a maximal force it is also produced at around at the same point at many cases, but there are exceptions.

So, the maximum torque is produced at around the center or the middle of the joints range of motion because of two reasons: the one is a maximal force is produced at that region, and the momentum is also maximal at around the same regions. So, which is why you are going to have a maximum tau at around that region, the relationship between d flex and d seg are not going to change greatly depending on whether the angle that is being considered as right angle or an a acute angle or an a obtuse angle because this is relatively small distance.

The point at which the muscle attaches to the distal bone is called as the insertion this is something that is not going to change what is going to change is phi and essentially the momentum, but this point itself that point does not change right. And essentially the relationship between d flex and d seg will remain such that the muscle force is usually a large number when compared with the load this is the usual case. Now, what happens if I have to produce an obtuse angle like that.

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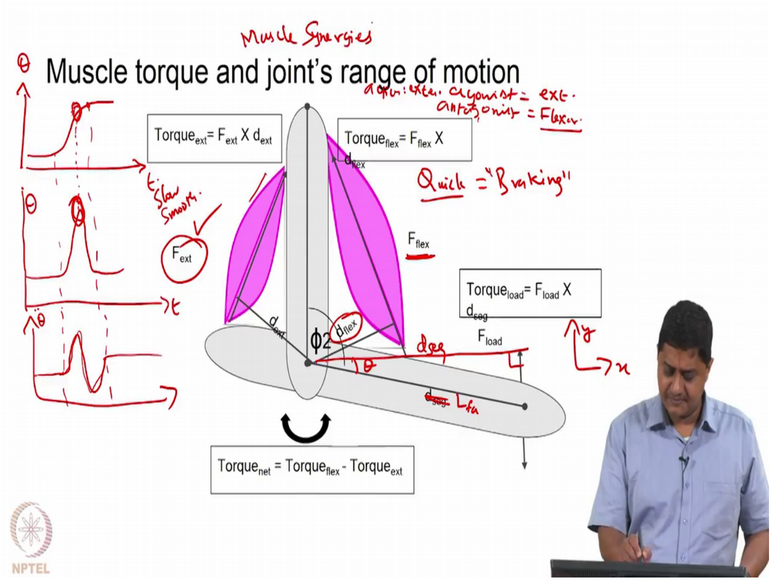

Now, again the situation is the same the situation is I am once again having a d seg, now I know you know if I use that coordinate system sorry that is the momentum right, that is the momentum and this is d seg. And this is going to be a relatively small theta in comparison with phi or in comparison with the. So, in once again d flex is going to be small in comparison with now that is d seg this is essentially forum linked or length of forum something about, but the situation is actually somewhat complicated more complicated than this. So, far I have only been discussing the case where there is only a single muscle. Actually what happens is there are two muscles that span at least two muscles that span this joints, now that is the joint under consideration if I want to flex if I want to reduce the angle

If I want to do something like that from the neutral position if I want to make the angle an acute right. If I want to do that that is basically flexing if I want to flex that action is done by that muscle if you want extent that action is done by that muscle or that force. Now, that seems like a in efficient arrangement I am having two torque motors to produce moments in two directions. A smart engineer would do the opposite they will have only one motor and essentially change the current. So, that the motor rotates in opposite direction.

So, there are only be one motor, but here there are two motors actually the situation is physiological situation is way more complicated than this. Actually there will be multiple muscles that spend the same joint, that is not been discussed here why does nature prefer this arrangement that is one question we will have to discuss that. So, I have two muscles one producing flexion and another producing extension in this simple case right, one is making that moment done the other is making that right.

And the net torque is basically the torque that is produced is basically the vector sum of all the torque that are involved right. Essentially, if there is no load or if you assume that the if you assume that the forum is mass less for the sake of discussion if there is no load, then what happens is that the net torque is basically the vector sum of these two torques right or the flexor torque and the extensor torque that is what is being written here.

Now, once again the net torque is basically the vector sum in the case where there is no load are the forum is considered mass less we will have to change the equation depending on the situation right. That is the situation with the joint torque case, now let us say that I am actually interested in producing a trajectory x axis here. Let us say time in the y axis this case is you know theta. Now, that theta say I am producing relatively smooth slow movements I am producing something like that. If it is a slow movement you are going to have activation if it is if increasing theta is considered extension say for example, right.

So, that is increasing theta in that case then only the extensor will be active if it is slow moment. What will the velocity look like the angular velocity will actually look, in angular velocity will look like that approximately there are somewhere earlier you are going to have the peak (Refer Time: 23:11) times t. How will the actual relation will look like that is how the actual relation is going to look like? So, essentially you want to reduce the velocity if you want to have minimal variability at the end point. Actually that is something that we desire we would like to reach the end point as planned with very little variability are small amount as variability.

Then I am interested in controlling my movement in such a way that I start where I want otherwise I will over shoot right. By the way those are deceases dissymmetry, over shooting, under shooting, these are deceases right, reaching the target approximately accurately most accurately is sign of heath right. So, that is possible if I start slowing down as I am getting closer to the target, so essentially that is what this means. So, the velocity peaks to a point and after that it reduces right and it is almost 0 when you reach you have reach that target right.

So, this means you will have that set of an acceleration curve this is for slow smooth movements which are usually produced by the action of a single sorry right the extensor mode. If you want to produce a quick movement right I am having the flexion like this, like that right like that and accurate movement like that If I want to produce quick movement, then I am interested in breaking as an like in driving you want to break you want apply the brakes. If you want to slow down you can reduce acceleration or you can reduce the velocity right of one motor of the engine in the case of driving for example. The better way if you are driving too fast right, the better way and the must thing to do is to have good breaks. I want to break I should stop accelerating of course, I should stop accelerating.

But I should also break if I want to come to a relatively abrupt stop right. Now, that is achieved in this case by the combined action of two muscles. In that case what happens is at around that area at around that time when the velocity peak is reached are sometime before or after the antagonist which in this case is the flexor muscle starts getting activated that starts applying a brake. So, there is co activation of the antagonist for a brief amount of time during the movement that essentially reduces the effect that the agonist has.

In this case the against is the extensor the antagonist agonist is the flexor for what action. The action is extension for extension the agonist is the extensor right, when I am doing that now if I want to come to an abrupt stop then I must apply brakes or activate the flexor at an appropriate time. Now, essentially this means that there is a synergy a coordination between muscles actually we have discussed only the simple case of two muscles.

Actually both the extension and flexion can be produced by multiple muscles that means, that there are many ways in which you could overcome, the forces or the loads, but that also means that you will have to control this availability of other options much better. So, that is the luxury that you have with the system having many degrees of freedom, but there is also the problem that you will have to control many more degrees of freedom. So, that is point the other case is preventing unwanted movements. Now, how is that achieved there are several things why do we care about this it turns out that many muscles have more than one action they are not pure flexors or pure extensors, they also cause a rotation about other joints.

This is because of attachment at the insertion at inconvenient angles at other angles that you don't want. Since essentially, the muscle force is produced along its tendon it is going to cause rotation about multiple axis some of which may not be wanted, quick example is the case of supination right. Now when my arm is pronated like that this is called pronation this is called supination right.

How do we know that this is supination how do you remember that this supination well supination is when you can hold soup right, now here I can hold a soup this is called supination this is the other one is pronation so this is pronation. If you would like to supinate right there are two muscles that are responsible for this one is called as the supinator muscle the other is called biceps, but biceps also responsible for flexion. Now the question is depending on whether you want to produce supination you activate biceps and you activate the antagonist of the other action what is means is the following what this means is. If I would like to say supinate, but not flex if I would like to supinate, but not flex I would like to supinate that angle.

So, my hand is pronated I would like to supinate without flexing. In that case I will use biceps to supinate right I will do that, but when biceps is active it will also cause of a flexion action it also produce a force in the direction of flexion, but there is no flexion I am supinating without fluxion right how is that happening. Because the antagonist of the flexion action what is antagonist of the flexion action in this case that is the triceps the triceps is activated simultaneously when I am going to supinate at a relatively equivalent level of activity are you equivalent level of force that will overcome the flexion force.

So, biceps actually produces a flexion force and that force is overcome by the triceps force. So, that flexion does not happen, but supination does happen this is a relatively common phenomenon this happens all the time. The question is that means, we will have to activate several muscles for producing one movement the answer is yes. So that means, it that is also energetically expensive, also the other reason why you want to avoid unwanted movements is when I am moving say the proximal part of the body.

So, usually the part of the body that is close to the center of the body is called proximal, those that are away from the center of the body are called distal right. So that means, the fingers and the hand are distal parts of the body whereas, the upper arm and the fore arm are relatively proximal right. Now, if I am making a relatively fast movement of the elbow my wrist position remains approximately the same like that relative to the fore arm wrist position remains approximately same when I produce fast movement of the elbow joint, how is this happening.

Usually what will happen if there is no activity at the wrist joint what will happen is the following let me try to do that right. See what happens what happens is there will be flailing of the distal joints there will be flailing of the distal joints when the proximal joints make movements if there is no compensation active compensation that is happening at the distal joints. Why? Because these are distal to this week they are attached to this segment right, when there is movement in this joint in the proximal joint that movement is going to produce a force produced some action on the distal joints which must be actively overcome by the distal segments. If that is not happening they will be flailing right which is undesirable.

To avoid this flailing what is usually done is there is co activation of wrist flexors and extensors and objectors and adaptors depending on the actual action intended action depending on that. There will be simultaneous activation of muscles into different directions thus increasing the apparent stiffness of the joint, then this joint becomes stiff it is like a I have lock this joint in place.

Now then when I make the fast movement this joint is already locked in place, but there is no physical lock. Essentially I am supplying energy to lock this in place now that means, I have to spend energy for overcoming unwanted movements in this case, this is the this is again a very common phenomena the same. Similar thing can be said about how if I would like to flex the wrist without updating it. So, usually restriction is made possible by the radial flexor right, but this also causes an abduction.

Let us say that I am not interested in abducting the risk I am only interested in flexing it, then I will have to activate another muscle that is producing the abduction action. Thus producing only the fluxion the advantage of having a multiple muscles spanning a joint is at the same movement can be produced by different muscles, the disadvantage is that you need to have a very good control right.

There must be good neural control timed control of this also the advantage of having one muscle having multiple actions is that you do not have to have too many muscles. The disadvantage is that every time you want to produce one action, but not the other it should also activate the antagonist of the other action, so this is a problem. So, essentially these results in coordination between multiple muscles that are also sometimes called as synergy are or precisely muscle synergies.

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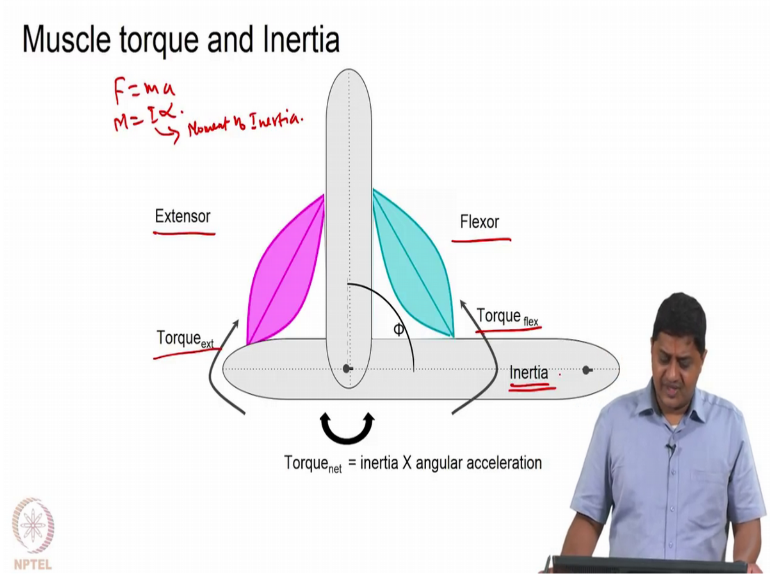

Now, let us discuss the case when inertia and torque and angular acceleration interact right. So, just like you have Newton's law F is equal to m a you also have M is equal to I alpha where I is the moment of inertia right. Now, this means to produce the particular acceleration I have to produce torque that is influenced by moment of inertia right. Now in the case of the so let us take the same case of flexion and an extension.

So, that is extensor flexor here the torque produces to by the flexor is flexor torque and (Refer Time: 36:47) right. So, essentially a the joint angular acceleration that we discussed is the. So, that is that alpha (Refer Time: 36:56) that is influenced are affected to a large extent by the movement of inertia of this right.

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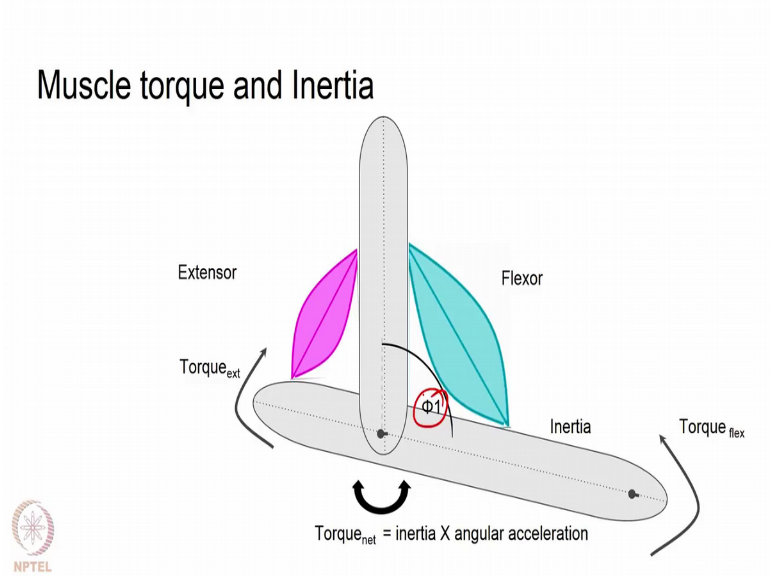

So, that is another thing that contributes to the situation once again the same these changes depending on the joint configuration. So, as in the details will change depending on the joint configuration one more thing before we move before we finish the class one more thing.

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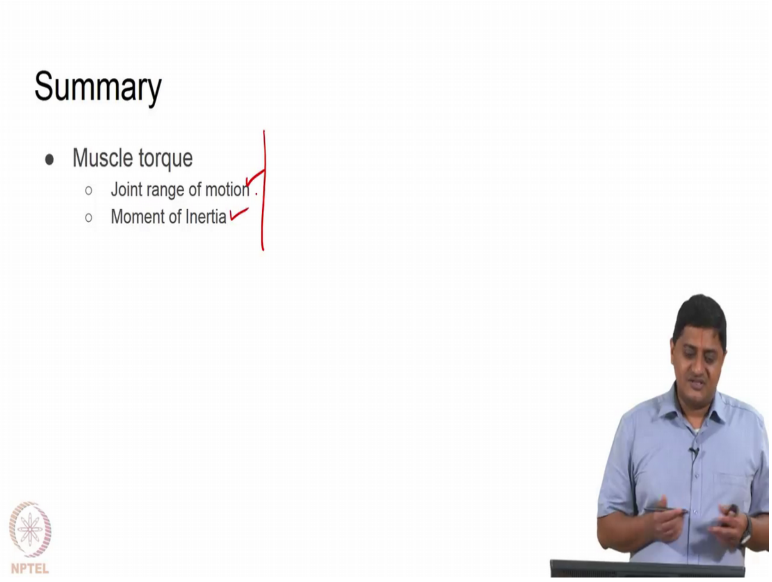

We said that there are muscles synergies coordination between multiple muscles that produce an action. Essentially what you see in healthy people who have learnt to produce the movement you see there is fine coordination. In such a way that only the minimally required muscles are active minimally to produce a given moment this is because they have learnt this multiple times and they know what amount of force in which muscle at what point in time will produce success at the task.

However, if you are a beginner in a given motor task that is a game there is some task that is given and you have no clue or you have never done that before in your life. Then it is not expected that the energy that is expanded will be minimal right. You will be is producing more forces then required and there will be a larger amount of co activation right than required so that means, that will be energetically inefficient. So, essentially the amount of co-activation are the amount of energy that is expanded in performing at ask is a measure of skill that is there. So, if you are highly skilled you will produce a smooth movement with minimal energy expenditure.

Whereas, if you are a beginner the same movement will require a larger amount of energy to be produced because many more muscles than required will be activated to a higher level than required. This is something that you can see you are trying to learn the task say you want to learn punching an a keyboard right. Initially you will be like pressing one two three discrete disconnected movements.

Whereas your practice a lot and you want to produce the same keyboard for producing the movement you practiced a lot. After that you will make moments that are smoother in such a way that are well timed and the muscle activations are appropriately timed and the activation levels are appropriately controlled to such an extent that the energy expenses should avoid this is a hallmark of skilled or well learnt movements ok.

So, in this class we have discussed how joint range of motion effects muscle torque that is produced and how moment of inertia of a muscle torque is produced, we have also discussed learning and skill level and other such things with this we come to the end of this lecture.

Thank you very much for your attention.