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

Lecture – 16
Skeletal Muscles – Part 3

Welcome to this class on Neuroscience of Human Movement. So, this is part 3 of our discussion on Skeletal Muscles.

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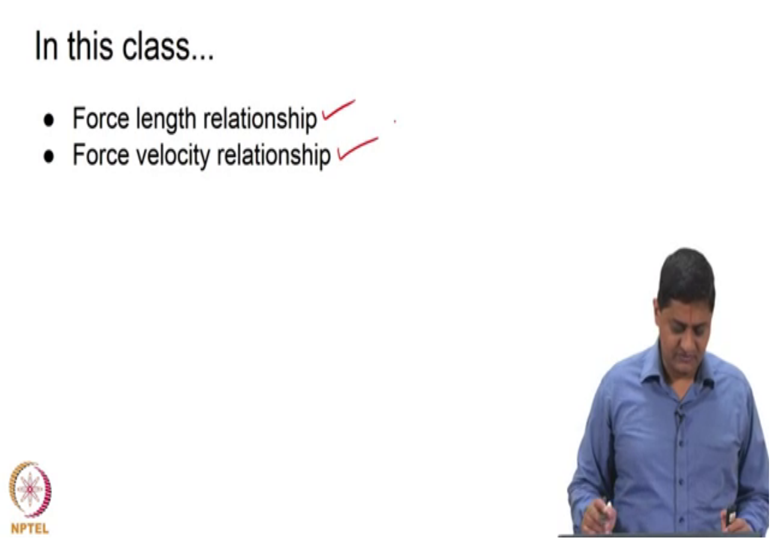

In this class we will be talking about how in a muscle force and length are related and force and velocity are related and in other words here when we say length we refer to the length of the muscle and when we say velocity we refer to the rate of change of muscle length. So, in general velocity means rate of change of displacement so, in human movements when we move there is actually observed displacement it I am making a movement that I am making a reaching movement for example, here when I do that.

There is a velocity of movement, but that is not a velocity that we will be discussing in today's class, in today's class we will be discussing the rate at which the muscle length changes that is what is called as velocity of shortening for a muscle. And, how this velocity of shortening of a muscle interacts with force is the other point that we will discuss. So, we will be discussing force length relationships and force velocity relationship

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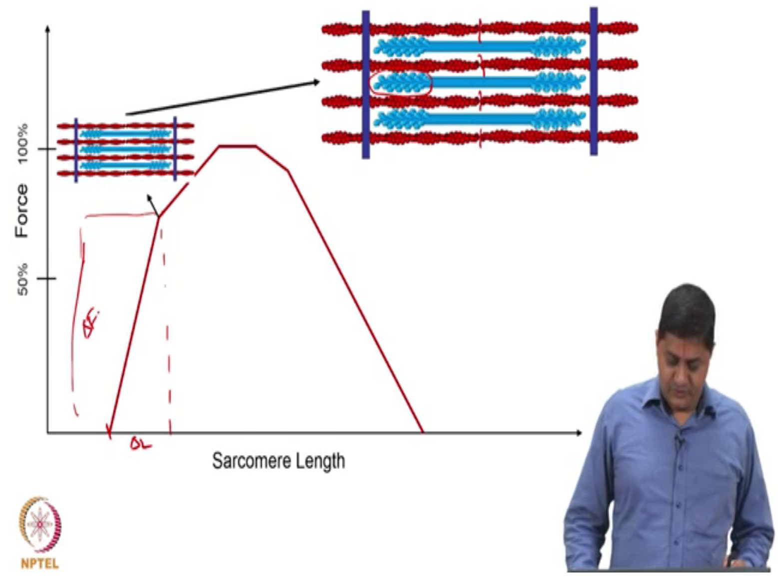

Essentially this is the curve of length. So, say this is in microns and this is force as a function of the maximum force that can be produced which is why it is a percentage. So, there is no unit which is force that is a function of the maximum force that can be produced how are the two related, this is how they should be related like that right.

Now, it makes sense for us to think about as the length increases the force increases that make some sense it is not clear why that happens for example, as the length increase the force should decrease we will discuss all the consequences of this in today's class right. So, what happens at this stage of the or in this regime of the force length curve right. So, we are talking about that regime what happens in that regime, that is what happens.

So, to zoom in what you see is that, the blue colored once filaments here are of course, myosin, the red colored ones are actin in the classic model of the sliding filament theory or the cross bridge theory we saw that actin is hanging in from one end and hanging in from the other end they do not actually touch, but then the length becomes too close to each other then what happens, actin starts overlapping with each other.

So, yeah approximately here this is end of one actin filament and the other actin filament, but they both start overlapping producing and overlap here. This causes a situation in which the myosin cannot bind with the maximum number of actin sites right. So, this reduces the force that can be produced, now if the sarcomere length increases what you would expect the actin filaments to move farther away from each other right like that so, here is the tip of the actin filaments right.

Now here, the force increases as the length increases so, the length has increased from that point to that point that is the change in length whereas, the change in force is that much alright. So, now, again now there is greater possibility that myosin gets access to actin binding sites.

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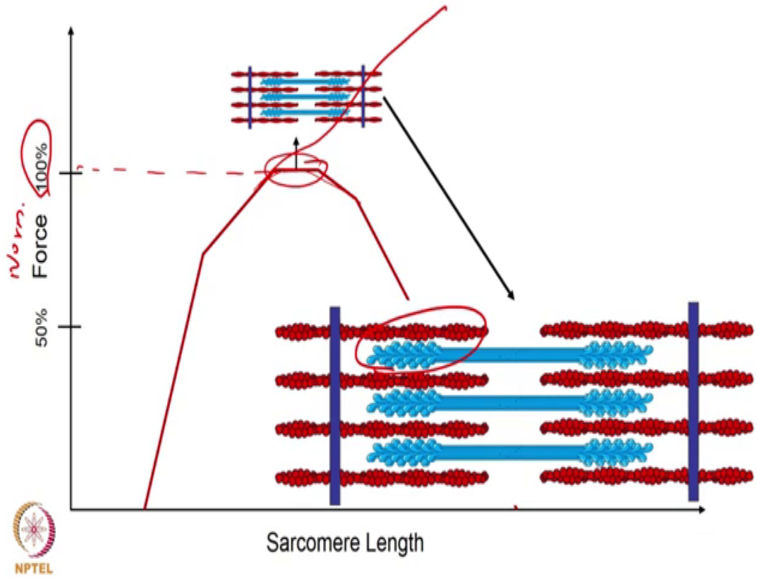

Now, I can further do this increase the length then what happens at around that point, I am going to have a situation where there is maximum actin myosin overlap. Let us remember that it is the interaction of myosin with actin that causes force production in the sarcomere and in the muscle right.

So, for us to have a large amount of force for us to have maximum force you have to have an optimum length at which myosin is able to interact with the largest number of actin filaments, but not just that it is also that at shorter levels the amount of effort that myosin will have to put to re cock attach, detach is higher because there is very little space available usually it also takes more time.

So, some other phenomenon other than just actin overlap are involved, but then at maximum force level what happens is that there is maximum overlap of actin and myosin filaments, this causes maximum interaction of actin and myosin thus also producing maximal force that is the 100 percent force as I said earlier this is the normalized force, how is this normalized?

This is the force produced divided by the maximum possible force produced right, that reaches 100 percent are the maximum force is actually being produced when there is maximum interaction between actin and myosin right. If that is a case you would expect (Refer Time:06:16) maybe a I can keep increasing the length then I can have instead of this I can keep increasing the length I can keep increasing the force too well; obviously, force cannot go above 100 percent.

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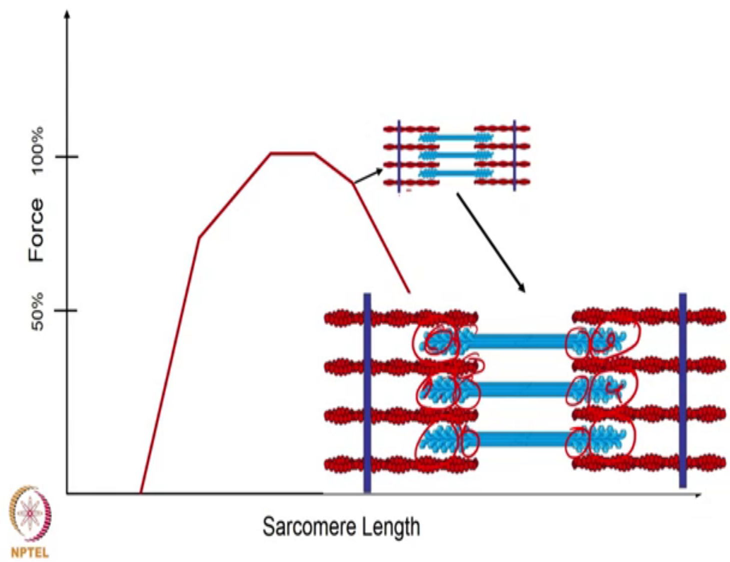

What happens at this stage or at that regime is this right, see here some myosin molecules do not have interaction sites. So, these are not able to interact with actin why, because the length has increased further the length has increased more than the optimum length because of this reason whatever the because of this reason whatever actin molecules that can actually interact with myosin these only are responsible for a force right. So, this reduces the amount of force that can be produced then what happens if I further increase the length right.

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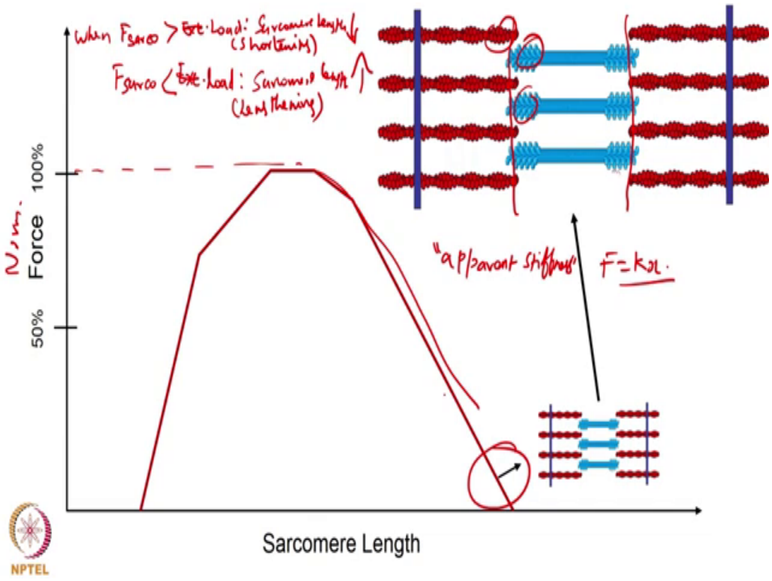

So, the question is what happens at that regime, at that regime what happens is that there is very little if any overlap between myosin and actin, actin again is in red and myosin in blue you see that there is very little overlap; that means, at the force that we will produce will be very small.

So, there is a particular point at which actin and myosin are overlapping at an optimum level, this is the point at which the sarcomere is going to produce it is maximum force right which is 100 percent of it is this 100 percent of the absolute right so, in this case right. So, this is the reason why you have a non monotonic relationship between force and length in sarcomere, as the length increases the force increases until some point like it happens in a spring right like you have stiffness the slope of this relationship right indicates some form of stiffness right.

So, except let us remember that for a spring for a spring F is equal to kx right where F is the force and x is the displacement k is the proportional de constant of the stiffness right. Here this is a linear relationship; however, in the muscle this is not going to be linear, but it is not just that muscle is not just a non-linear spring it is much more than that, because you are having that so, there is other things that come into the picture.

In general though many times in biomechanics people use the slope of the force length as some form of stiffness, sometimes it is called as apparent stiffness and this stiffness also has multiple names variations of this stiffness has various names etcetera. So, we will not go into those details for this class, question is what is the relationship between sarcomere length and force produced by the sarcomere?

So, suppose when the force produced by the sarcomere when it is greater than the external load on the muscle what will happen? Sarcomere is pulling together the external load is pulling on the opposite direction, but the sarcomere force is greater then what will happened to sarcomere length? Sarcomere length will reduce is it not why because it is sarcomere force that is greater.

Suppose the force produced by the sarcomere is less than the external load and this is not exactly uncommon sometimes the external load is higher than the force that can be produced by the sarcomere. It need not just be the external load for the purpose of this discussion when you are looking at one sarcomere that the force produced by another sarcomere can be acting as a load for this sarcomere for the first sarcomere.

So, some load that is if the force produced by the sarcomere it is less than the load on that sarcomere, then what happens the sarcomere length it increases right. So, you can produce force both when the sarcomere is contracting or when the sarcomere is undergoing contraction and it produces a force, you can also produce a force then the sarcomere is lengthening or extending right and it produces a force.

These two forms of a contractions and also called as concentric contraction or shortening contraction in the first case. And in the second case when the sarcomere is lengthening and it is producing a force it is called as lengthening contractions or sometimes also called as eccentric contractions we will discuss that in a future class in some detail.

So, let us what limits the velocity right the maximum rate of change of sarcomere length is limited by this biochemical process right by the interaction of myosin with actin the speed at which cross bridges can form. So, there is attachment of myosin to the actin and there is a pull there is power stroke and then there is a detachment and then there is re caulking.

There are bunch of steps in the cross bridge cycle are in the sliding filament theory that will have to be repeated this. The speed at which the steps can happen right, the rate at which the cross bridges can be formed limits to what extent the muscle can contract to what rate the muscle can contract right. So, the velocity of contraction is limited by the rate of cross bridge formation.

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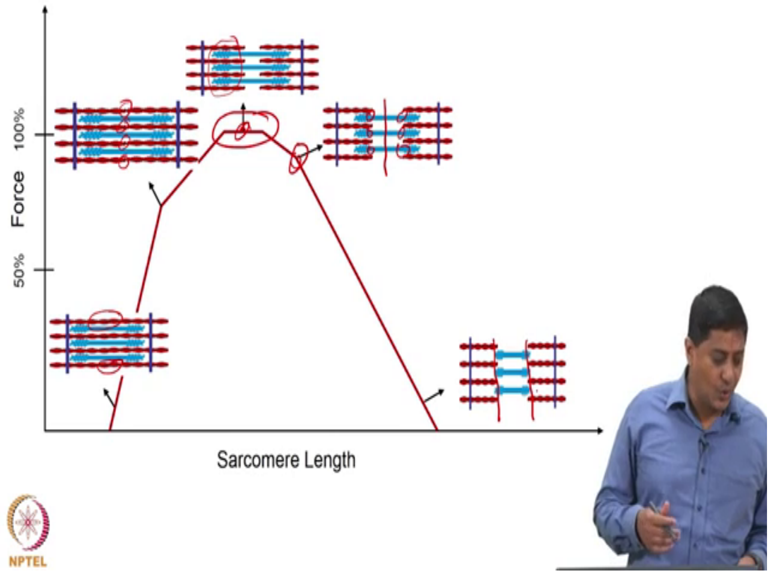

Now, let us take a look at that situation right and also in summary what happens, in summary what happens at various lengths at very at 100 percent force are at an at the optimum length. This is also usually the resting length of the muscle, but not always often this length is the resting length of the muscle, but when I say often it is not always there are exceptions.

At maximum force you are going to have maximal overlap between and myosin at length that is smaller they actin starts touching each other and some force is compromised because of the inability of myosin to find a attaching sites or there are just the displacement is just not possible and that becomes worse when the length reduces to a very small number because the overlap of the actin molecule.

So, when the length increases what happens is that sum myosin molecules close to the middle of the sarcomere are not able to find binding sides on actin. So, they are not able to form cross bridges and produce force. So, the force reduces at this point from here, from here to here and then ask the length continuous to increase that is very little are no overlap between actin myosin thus resulting in a steep drop of force.

So, deviations from the optimal length cause deviations in force and this deviation in force is relatively small, at small deviations in length, but as the length deviation increases the force deviation increases much more than one would expect. So, this is minimal for small deviations, but the tension drops of much rapidly so, high much higher slope much rapidly as the length deviates further from the optimal length.

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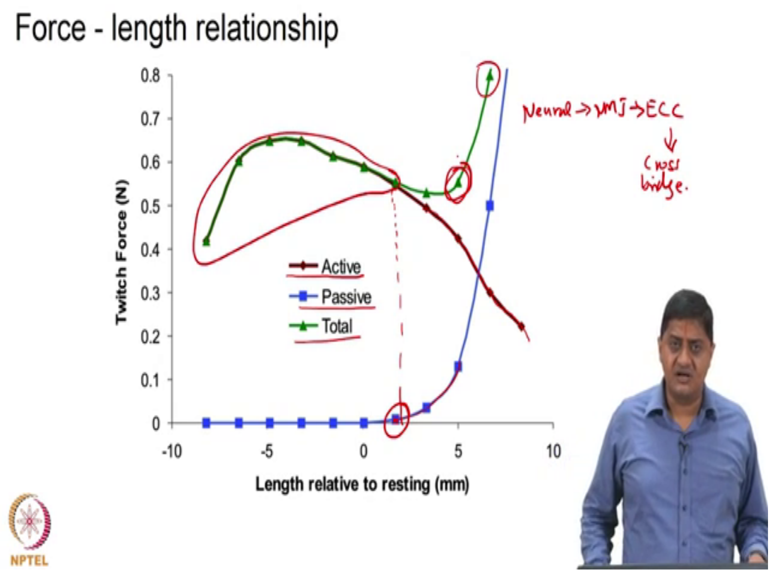

The active force is shown here in brown, the passive force is shown in blue, the total force is in green until some point until about that point right until that point the brown and green overlap here, in this region brown and green overlap or in other words the total force is basically the active force. So, at that point there is a development of a passive force, why is this passive force getting developed because, it turns out that muscles are composed of contractile proteins like for example, a rubber band type of a situation right.

If you have a rubber band when the rubber band is slack and you are trying to increase the length, as I keep increasing that is going to be a particular point after which if I increase the rubber bands length, it is going to start resisting changes in length right. The length at which it starts to resist changes in length are produced passive resistance that is called as a resting length of this rubber band, likewise you are having contractile proteins in muscle that start resisting the force and that is shown here as approximately that value at the (Refer Time: 17:12) that value the muscle also start resisting passively so, there is passive response.

There is also active response, but then the active response seems to drop of after sometime, then the passive response starts increasing, combine together basically there is a relatively strong resistance beyond a particular length right beyond an acceptable length there is going to be a great resistance basically a combination of both active and passive resistant.

What do you mean by active resistance? Active resistance is resistance that is produced by cross bridge formation by neural controls so, basically neural control to neuromuscular junction to excitation contraction coupling to cross bridge formation. It is this that causes the active force passive force, on the other hand is caused purely by the passive properties are the contractile proteins that form the muscle.

Now, let us remember at any given point in time if I only can measure the total force it may not be possible for me to estimate. So, at any given point in time if I am measuring the total force it is not possible for me to estimate, how much of this is coming from active force and how much of this is coming from passive force. Many times this is of importance in by mechanics this is a to be estimated in some cases with this, this varies as function of several factors. Now, the question is what happens to velocity?

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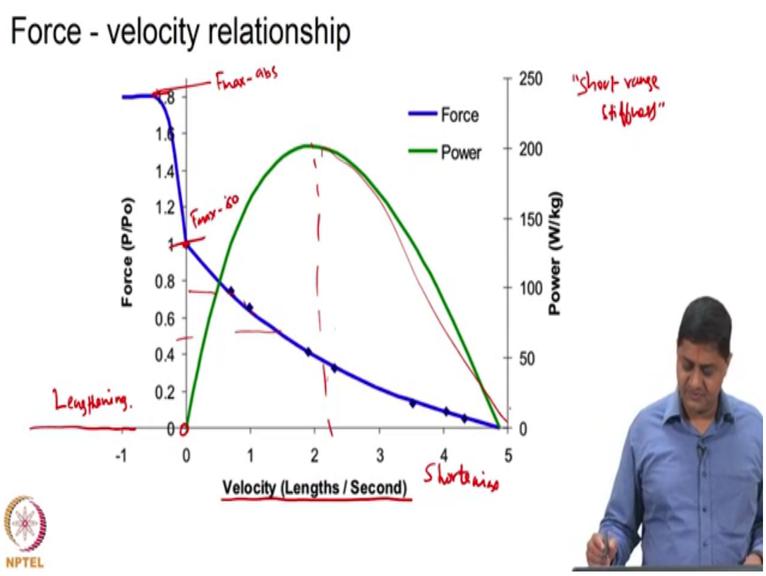

Well what happens, we can discuss this before we discuss the plots we can discuss the situation, I am having a relatively light object in my hand. So, what you would expect is that it is going to be possible for me to lift this with very high velocity is it not I can do this. Suppose I had a very big mass one question is whether I will be able to lift it, suppose I am able to lift it, it is immediately obvious that I will not be able to lift it at that very high velocities.

So, basically the force that can be produced and the velocity are in general in an inverse relationship so; that means what? That means, as the velocity of contraction. Once again here please note here I am talking about velocity of movement not velocity of contractions, but I am speaking as if these two are the same they are not the same acknowledging that they are not the same, let us also note that this velocity is produced by the velocity of contraction. So, I am assuming that they as related in the linear way for the purpose of illustration right.

But in general here we are talking about velocity of contraction what is meant by that, velocity of contraction means change in the sarcomere length and as a function of time right or time rate of change of sarcomere length is what is called as velocity of shortening of a sarcomere. So, that is also inversely related to the force like it happens here that is also inversely related. So, what happens is the velocity is practically 0 at the particular value of force this is also called as the maximum isometric force that can be produced right. Let us remember what is the isometric force, isometric force is the force at which the length remains the constant is it not.

So, beyond this level so, this is the shortening regime and here what happens what is this. So, can the velocity be negative the answer is yes, because it can also be lengthened by external forces or stretched it right when that happens a different maximum force is produced. So, this is I am going to call that force as the F max isometric and this is the F max absolute. This is the absolute maximum force that can be produced that happens as the lengthening increases, but then as I want to change the velocity, as I want to increase the velocity the force that can be produce drop down quite quickly right.

So, why does the force reduce, as I said the speed at which cross bridges can be formed reduces basically that is reduction in cross bridge displacement and there is also reduction in the ability of myosin to find active actin binding sites right. An important point to note is that the preceding activity effects how the muscle behaves right.

In other words if before this experiment the person has done some exercise right then the muscle will behave in some manner, if the person has not done any exercise or he is at rest the muscle will behave in a different manner right. In general if there is an activation before the experiment there is going to be in increased ability of the muscle to show stiffness there is an enhanced stiffness, but this does not last for a long time after the exercise.

So, this increase that is temporary transient post exercise is called as short range stiffness right. So, also what happens with power, what is a relationship between power and force, basically power is the product of force and velocity is not so, that increases until some velocity and then it decreases. So, essentially these two relationships, what are these two relationships?

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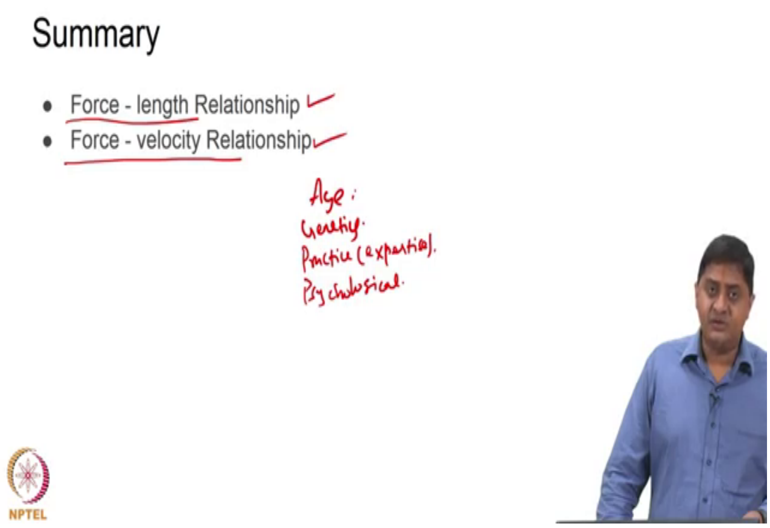

Force length relationship and force velocity relationship dictate to a large how forces are produced within a muscle within a condition depending on the situation. They have very important implications and consequences in biomechanics, examples are limiting the running speed say at Olympic level there are limits to how fast the person can run.

So, limits of running speed are limits of strength, how long you can jump, how much you can jump or how far can you will jump and to what extent you can jump and with what velocity you can run, all this things are to a great extent limited by force velocity and force length relationships. These can be modified of course, these can be modified the hypothesis is that they can be improved, but only till the physical and physiological limits is it not.

The question is in Olympic level athletes to how much you can improve this and are there genetic influences that is other question. So, basically it is possible that given person can only improve so much, it is a function of age, genetics, practice level or expertise level and of course, it is probably function of the psychological state also many of these things have been studied this data suggesting that specific ages so; obviously, one would expect that a younger person would run faster than an older person etcetera.

Especially of this age gap increases the difference in velocities are also going to probably increase, there are exceptions to every rule because there are old people who are relatively fit when compared with a young people who are relatively unfit. So, there is exception to every rule I am speaking about, but these are some of the factors that affect this. So, with this we come to the end of this discussion we will continue our discussion in a future class.

Thank you very much for your attention.