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

Lecture – 20
Motor Units - Part 2

So, welcome to this class on a Motor Units. This is part 2 of few parts about 3-4 parts as part of the Neuroscience of Human Movement course.

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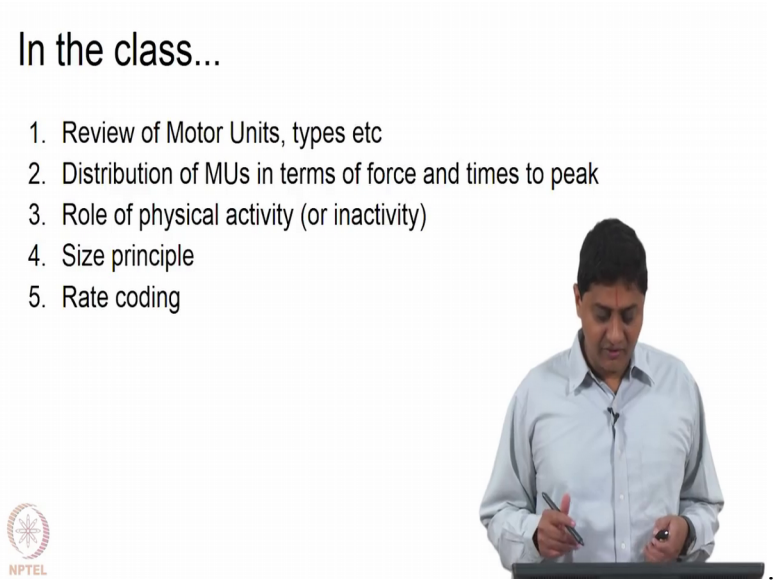

So, what we saw yesterday was motor units its types and their properties. So, in today's class we will talk about we will review what we saw in the previous class first, and then we will talk about how these motor units are distributed in terms of forces and times to peak etcetera. And, what role if any does the physical activity or inactivity have in the properties of motor units. And some principles based on which motor units are recruited size principle and rate coding. So, said relatively deep concepts these two ok.

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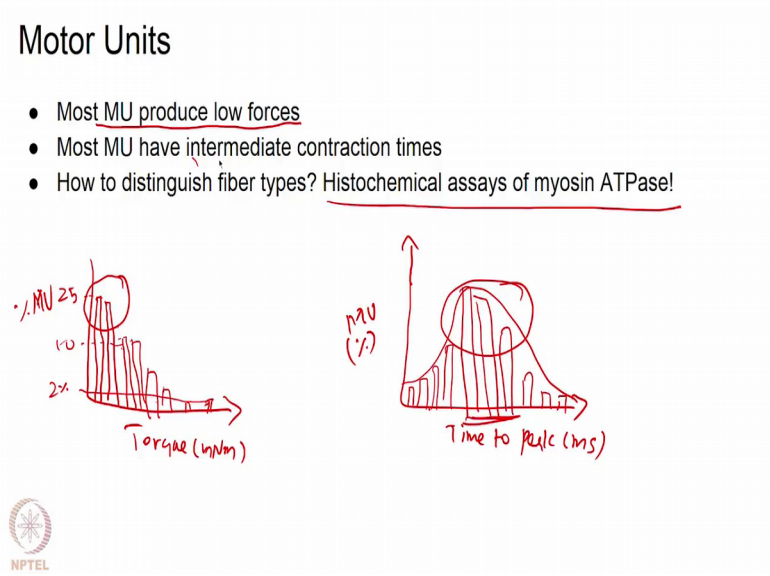

So, what we saw yesterday was that, motor units are divided into a few types those that are slow and less fatigable, those that are fast and more fatigable, those that are with intermediate speed of contraction and have intermediate fatigability this is what we saw yesterday. So, we divided this into a few type. A few types and we said these are oxidative and glycolytic or purely glycolytic. A question is how to distinguish the fiber types, what is how we have distinguished fiber types I have already said this is type 1 type 2 etcetera, how are this distinguished how is this done you there are there are a few methods. One popular method is this histochemical assays of a myosin adenosine triphosphate or myosin ATPase histochemical assays we will show different responses for the different types of fibers.

So, that is what the other types not discussed in this class are genetic methods. So, what has been found is that most, motor units produce relatively low forces and most motor units have intermediate contraction types. What you will see is that suppose I were to draw a response between a function of say a Torque in milli Newton meter and the percentage of motor units recruited.

Suppose what relatively small amounts of Toque it is produced by relatively large amounts of a large sets of what is about 25 percent. 25 percent of the total number of motor is pretty small amount of a Torque, and about a little less than 25 produce a slightly larger amount of Torque and so on so forth right.

So, then say if this is 10 for example, there is going to be one that is this and this reduces after some time; that means, there is a very small amount of a there is a very small number of motor units, that produce very large amount of force most motor units produce low forces. And then suppose I was to have a similar curve for contraction types ok. Suppose I am having contractions m is basically the time taken to reach the peak it is not it is not. So, if I have a similar plot for time to peak with the what number of motor units will have.

You will see that there are some smaller numbers of motor units with small times to peak, then that increases and so on and so forth this is approximately a normal curve if I favored about this I am going to get something like that. So, what you get again is that and most motor units are located here and they have intermediate contraction times. So, most motor units have low forces, most motor units produce low forces and they have intermediate contraction terms.

So, these are 2 important lessons that we need to learn in terms of motor unit properties and their distribution; how motor units are distributed in terms of their properties. If I had 100 motor units a large number of this more 100 are going to produce low forces and a large number of this 100 are going to have intermediate contraction types ok. So, this is the general truth in a cross spread across muscles this is going to vary between individuals this is going to vary between muscles is going to vary between groups of individuals and so on and so forth. I am talking about the general case then what else? Suppose if this were the case can I influence this somehow the answer is yes.

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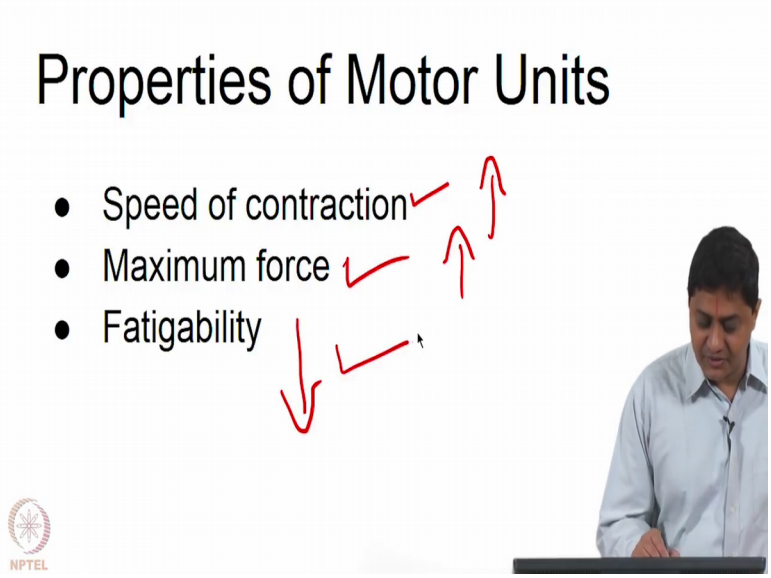

I am interested in changing the following properties we said these are the three important properties of motor units speed of contraction. What is desirable in this case a, higher speed of contraction is desirable I want to control these things quickly a higher speed more is good maximum force again what is desirable? A higher force is desirable in general. In general a higher force is desirable again more is good fatigability. In fatigability I want to have least fatigue while I am doing tasks. So, here more is not good whereas, less fatigability is good.

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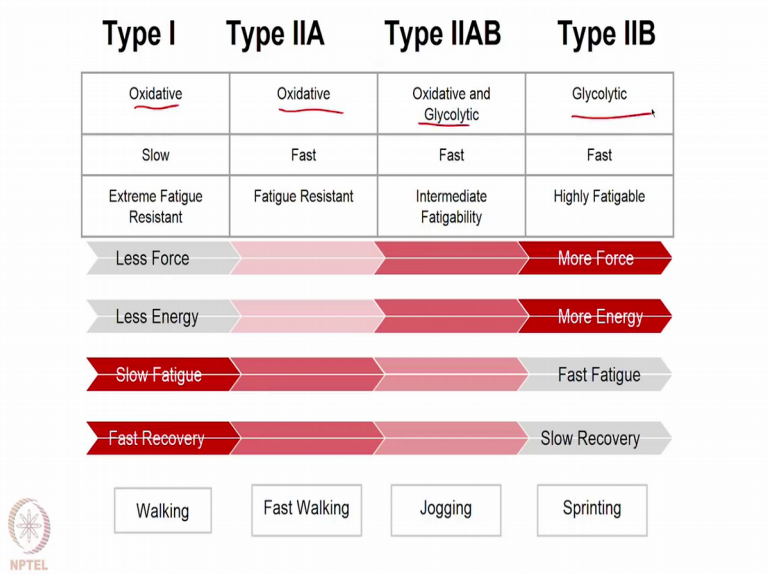

One method and we saw these are the types and we discussed this. So, there is it changes between oxidative and oxidative and glycolytic and glycolytic.

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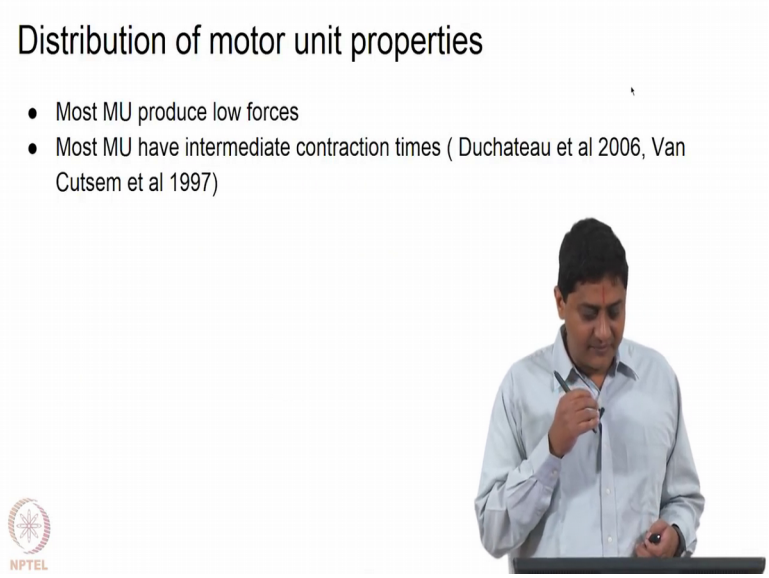

One method to change this is a physical activity or exercise.

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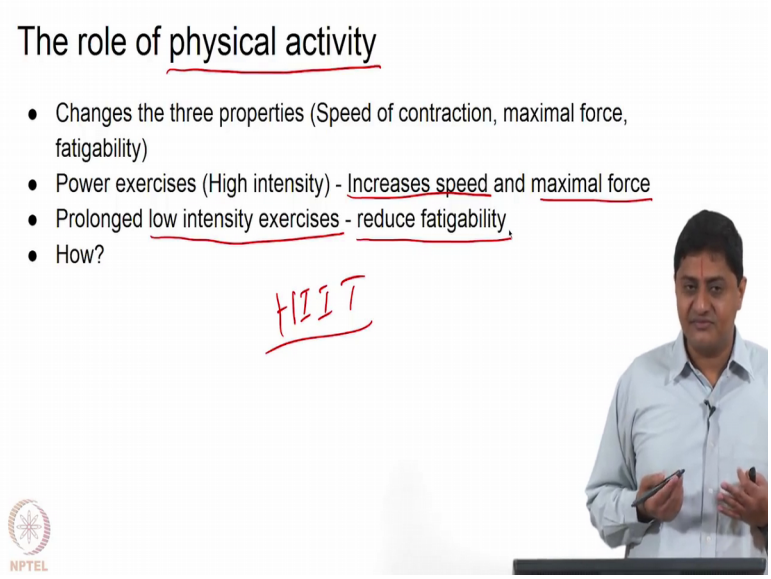

So, what would one expect as, one would expect power exercises those that involve high intensity this would be weightlifting are what are called as High Intensity Interval Training HIIT High Intensity Interval Training are weightlifting increases the speed of contraction and maximal force. So, I am interested as I said what are my interests? My

interest is in increasing the speed of contraction and in increasing the maximum force that can be produced that is possible I can achieve both by doing power exercises by doing weight lifting or by doing what are called as high intensity interval exercises, either way their intensity has to be very high that is the point.

If I need to reduce fatigability, I said fatigability is desirable if it is less fatigability is desirable right. If you want to reduce fatigability I need to perform prolong the low intensity exercises. So, it is known that if I perform prolonged, but low intensity exercises for relatively long periods of time, this is going to engage the aerobic portion of the spectrum that pixels, this is the spectrum that we saw. I am interested in reducing fatigue, I am interested in you know training this part it is not I am interested in doing the aerobic exercises more. If I am doing weight lifting this is glycolytic anaerobic, I am interested in engaging the aerobic portion more for a relatively long period this will reduce fatigability. How does this do that, that is the question how is that some sort of magic that does this the answer is no that is a reason why.

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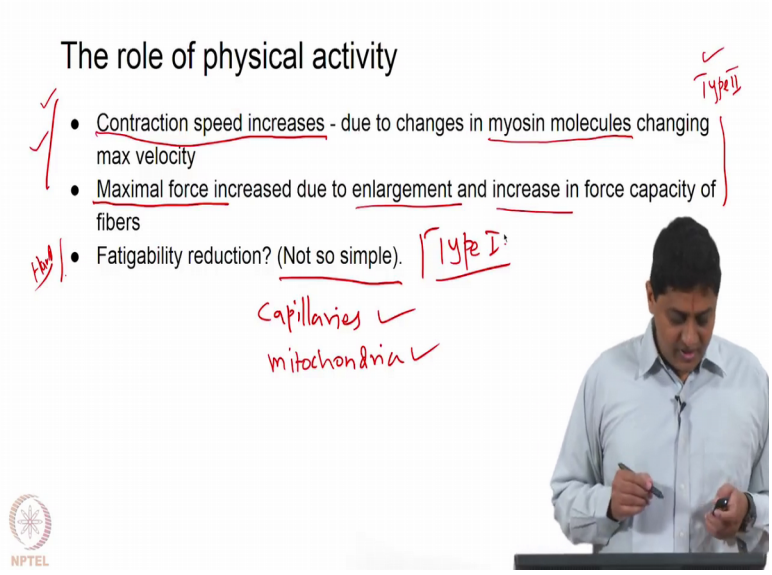

There are physiological reasons why this happens we said contraction speed increases with weight lifting why? What is the process that costs us is, what is the mechanism what is the physiological mechanism that causes? This actually happens due to changes in the properties of myosin molecules thus changing the maximum velocity.

So, the myosin molecules have an enhanced response causing a change in the maximum velocity, thus causing an increase or a desirable increase in the contraction speed. Of course, this is not going to keep on increasing forever until some level and how is maximal force produced it increased? Well due to enlargement of the fiber. So, the fiber itself becomes bigger and that that causes our concomitantly simultaneously, that is an increase in the force producing capability of these fibers.

So, the fibers become bigger as in bulkier and also become stronger in terms of its ability to produce more force, causing an increase in the maximal force that can be produced. Fatigability reduction is actually not so, simple, it is accompanied by changes in several levels of control several levels of control these can be capillaries changes in the properties of the capillaries, because we said this is an oxidative process more oxygen is needed right.

So, changes in the capillaries properties and the changes in the distribution of mitochondria etcetera, and a combination of several other things causes reduction in fatigability. Usually these 2 are easier to achieve relatively easier to achieve in comparison with this, this is hard it requires everything requires practice this is hard why? Because usually these 2 involve changes in type 2 fibers is it not? This one involves changes in type 1 fibers.

Usually type 1 fibers less adaptive are more difficult to change in their properties we see that there are the individuals who are difficult to change or who find it difficult to change themselves, and then there are individuals who find it easier to change themselves likewise these guys are relatively more adaptable in comparison with type 1.

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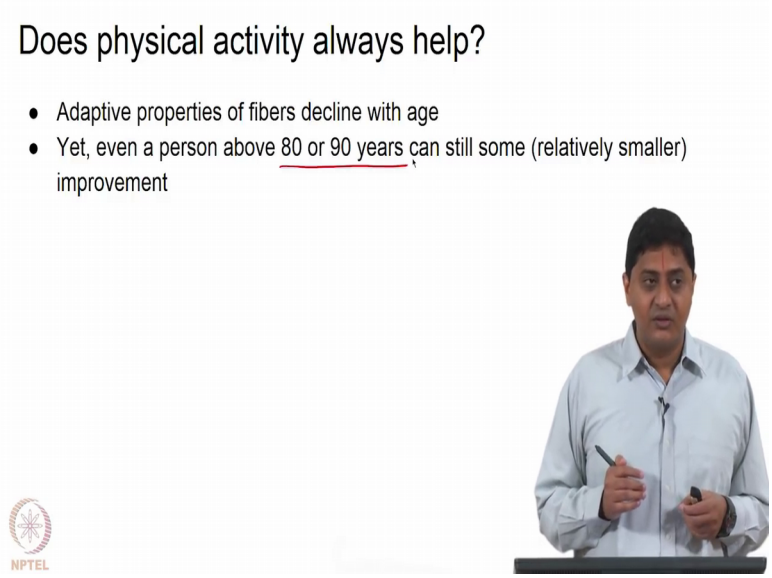

So, a question is does it always help? Does it help if your older physical activity, it turns out that adaptive properties of fibers decline with the age. So, the response is going to be greatest when you are. So, exercise has the greatest benefit when you are young, as you get older the response of the fibers the response of the physiological response of the body is going to decline when you get older, yet it turns out that muscles are still adaptive still dynamic that even a person above 80 years even 90 years can still see some improvement, relatively smaller improvement this in comparison. So, exercise has the greatest benefit when you are young and the benefit reduces as a function of age.

So, as you become older the benefit reduces, but there is still some residual benefit. You still get some benefit of exercise even after 80 years even after 90 even in cases of 90 years and so on. Even at 90 years muscle tissues and these properties the fiber properties change even at 90 years of age, which is surprising what would you expect at that age. So, exercise is good, but it is less beneficial when you are older ok.

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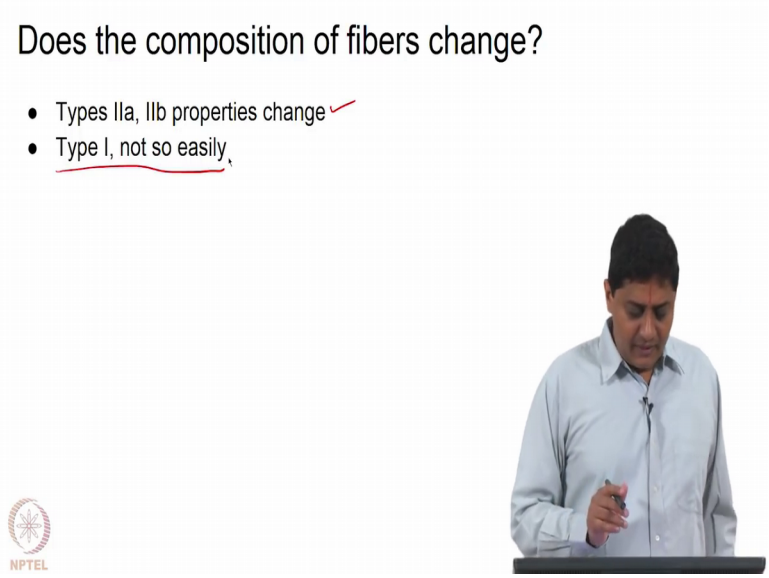

And we said does the composition of fibers change, I told you already type II a and II b etcetera their properties change whereas, a type I properties also changes, but not. So, easily what could cause a change in the type I properties?

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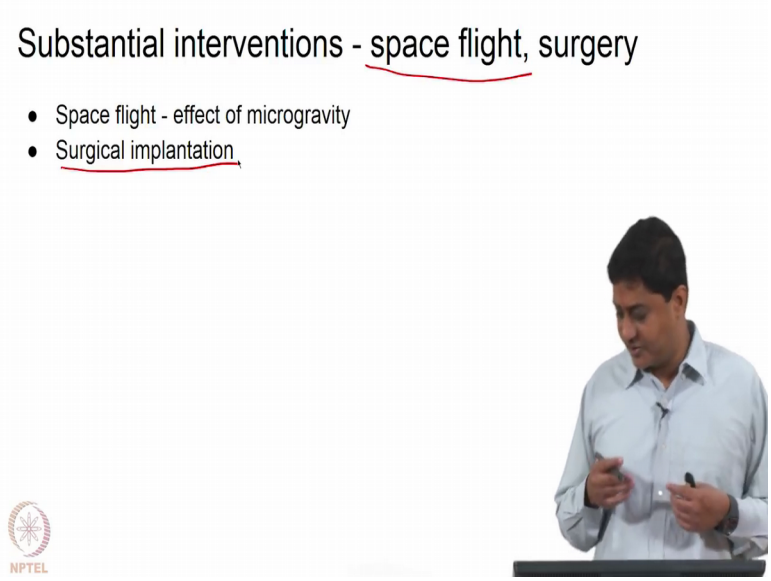

Well substantial interventions such as spaceflight. In spaceflight what happens is that there is no gravity or there is a microgravity, that causes the person to lose muscle mass. So, that is a reduction in muscle mass, there is a reduction in muscle mass fiber mass in all the three types of fibers even type I fibers are reduced to some extent. Of course, so

how would you increase this? Prolonged stimulation at relatively low frequencies for a relatively long period of time, can bring back the last muscle mass after some time. So, which is why astronauts after they return back say from a space station, it cannot immediately walk take some time to adapt to this world they will take time sometimes.

So, they are brought back, there that is a rehab program for them and then they get to you know merge with the rest of the society. The other case is the case of a surgical implantation. Suppose we do a surgery where a muscle nerve that is innervating a relatively fast muscle is attached to a relatively snow slow muscles. So, this happens from time to time there are there are situations, when this is required to be done. In such cases a nerve is transplanted from a fast muscle to a slow muscle, in that case what happens this slow muscle adapts itself and tries and behaves more like the fast muscles.

So, these two are obviously, substantial interventions right. So, these two involved in as in spaceflight is a relatively rare phenomenon not everybody goes through that and surgery it is also relatively rare surgery moving there were no transplant like moving the nerve from one muscle tone other muscles, it is also a relatively rare phenomena. So, these are substantial in interventions that could cause a change in type I properties and so on and so forth ok.

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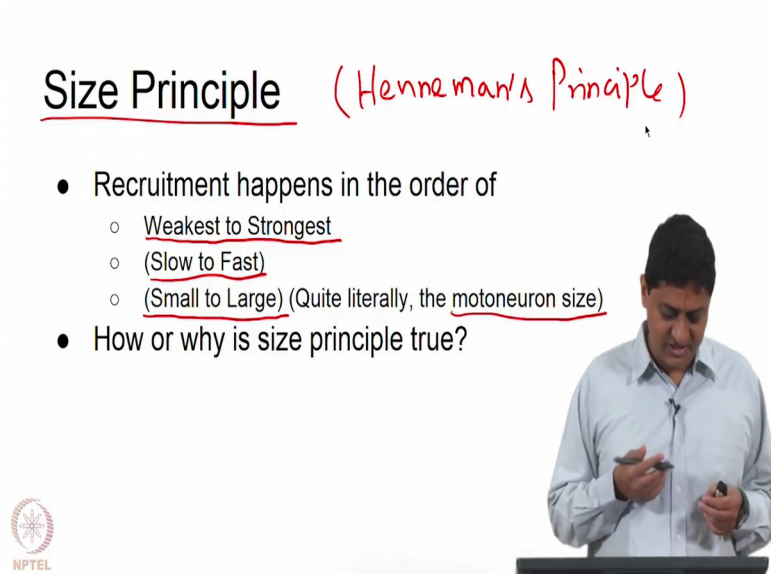

What happens how do I, how are these units recruited? It turns out that a recruitment itself happens in the order of weakest to the strongest, that produces a smallest amount of

force in a in a muscle is the weakest, the motor unit that produces the largest amount of force is the strongest. So, that is suppose I order this, in the order of their strength are in the order of their ability to produce maximal force, then recruitment happens in an orderly fashion from the weakest to the strongest. First the weakest motor units are recruited and then the next stronger one is recruited and then the next stronger one is recruited and so, on and so, forth.

This also means that the recruitment proceeds from slow to fast are from I put them in brackets, because this is not exactly are always true, but this is mostly true are from small to large. So, materials are recruited in this is in the order of their size we said what is motor unit size. Motor unit size is defined by the innovation number is it not the number of a muscle fibers innervated by a motor neuron.

If it is small, then that is a small motor unit the number that is a if it is large if the motor innovation number is large we call it as a large motor unit actually. Quite literally the motor neuron size also correlates very well with the motor unit size, in other words the large motor units usually are innervated by large motor neurons. These motor neurons have larger diameters, they are literally big a question is we said we said that this recruitment happens in the order of size from the smallest to the largest, this principle is called a size principle are also called as Hennemans principle proposed by Elwood Hennemann in the 1950s

Why is this true? Why should this happen this way? Why not? Suppose I want to produce say a given Newton of force why not directly you know recruit the motor unit that produces that amount of force and leaving all the others out why do I have to do this? Why does this principle hold true that is one how what is the mechanism that causes this to be true? These are the 2 questions that are then we will answer them.

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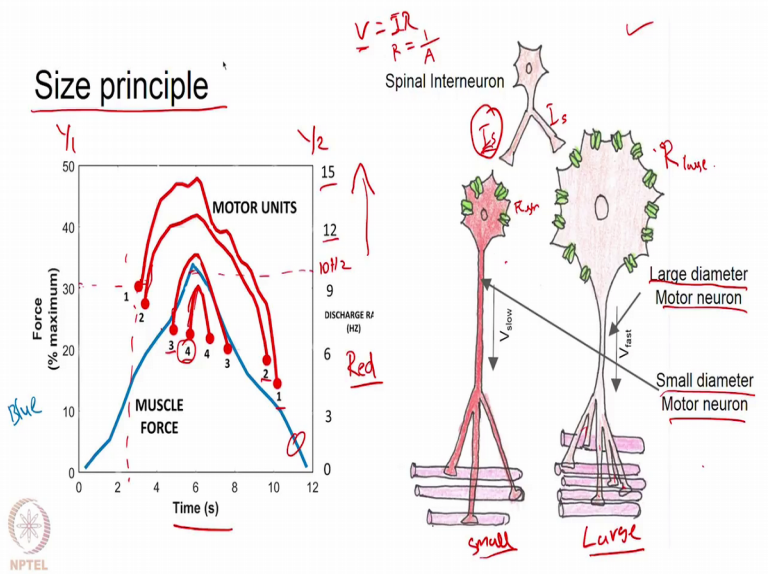

First let us take a look at this as in this part of the picture right. Suppose spinal inter neurons since a particular amount of synaptic current, we am going to call the synaptic current as is ok. Is amount of current synaptic current is sent in a motor neuronal pool; motor neuronal pool means there are several motor neuron cell bodies lying in this area of the spinal cord right. So, these are located in the ventral ganglion is it not ventral root ganglion.

So, several of these neurons are present in the motor neuronal pool, they come in multiple size as they are there are multiple sizes let us take two extreme cases one that is relatively small I am going to call this as small, and one that is relatively large it is already there. So, this is large and this is small. And also note the small motor unit; small motor neuron is innovating three fibers and the large motor neuron is innervating a relatively larger number of other say 5 say for example.

Assuming that all the muscle fibers produce equal amount of first, though this one will produce smaller amount of force and that one will produce a larger amount of force is it not. So, suppose the same current is sent to both of this a question is which one will achieve threshold first that is the question. And sending the same synaptic current which one of these two will achieve depolarization or will achieve threshold first? It turns out that a principle similar to Ohms law holds true in this case.

So, the voltage and the membrane potential is a product of the current which is the synaptic current and the surface resistance and under resistance, and we know that the resistance itself is inversely proportional to area. What happens is that a given synaptic current first depolarizes the smallest motor neuron, and then depolarize is a next larger motor neuron and then depolarize is the next larger motor neuron and so on and so forth. Thus, creating an orderly recruitment of motor neurons, and it turns out that you know the smaller motor neuron do not generate a smaller number of fibers, the larger motor neurons innervate a larger number of fibers; that means, the this motor neuron is going to produce a smaller amount of force.

So, a given synaptic current depending on it is; so, that obviously, this changes as a function of the synaptic current without doubt. So, given synaptic current may recruit these, this and some more motor neurons, but not the larger ones and so on and so forth. So that means, that I can change the order of recruitment by depending on the size, this is due to this property of the motor neurons. Because of the distribution of the sizes, the resistance distribution varies because, of the change in the distribution of the resistances the smaller motor neurons reach threshold earlier or smaller motor neurons reach threshold with smaller currents in comparison with the larger motor neurons, which require relatively larger currents to which they would not threshold.

Action potential will be produced only when they reach threshold. When they reach threshold, then action potential is producing these motor neurons producing an action potential in these fibers and causing excitation contraction coupling and force and so, on and so, forth right. So, is that the only mechanism in which I can change force that is the question. Can I just are there other things that come into the picture it turns out that there are other things.

So,, but before we talk about the other things, this principle where there is an orderly recruitment of motor neurons in the order of increasing size from smaller to the motor is called smaller to the larger is called as size principle or Hennemans principle. It turns out that this is not the only mechanism by which this can happen there are other mechanisms. Let us consider a case where I have to produce a particular amount of force say that force that amount of force. The one that is you know indicated in the blue line that is the amount of force that I have to produce. So, this there are please note there are 2 y axis y 1 axis and the y 2 axis, y 1 axis the plot is in blue, this is the blue plot and that

is the red plot just. So, you know to read this properly. So, you see I want I want to produce this force I want to produce that force the one that is shown by the blue plot the one that is shown by the blue plot is what I want to produce, and let us say I have recorded activity discharge rates of a some motor units.

Actually there are multiple motor units that are recruited to produce this force, let us say that I have measured the activity of a four different motor units these motor units, I am going to call that as the motor neurons I am going to call this as m 1 m 2 m 3 m 4 what is the method in which you could measure their activity we will have to see. How to measure their activity I am saying I have measured the motor activity of these motor units how? We have not discussed that so, far we will discuss it in future class.

So, somehow for the purpose of this class, let us assume that this has somehow been recorded I have somehow been able to measure the activity of these motor units individually ok. The first motor unit is recruited at that time when the value at a frequency of about 10 hertz. I keep increasing I keep increasing this value right and that causes an increase in force and they recruit one more motor unit and I keep increasing the discharge rate.

So, for the red we will have to see this right hand side scale why to scale is it not? So, the discharge rate keeps increasing for these 2 motor units, as these 2 motor units discharge rates keeps increasing the force seems to increase this is the output blue line is the output, which is a force red lines are the input for the case considered right. So, as the red lines increasing the blue line also keeps increasing right. Then at some point I am recruiting a new motor unit, as I recruit this motor unit and change its discharge activity change its firing rate it causes a further increase in force.

Then a particular point in force is reached, where this guy is going to be recruited and it is its firing rate also keeps increasing and at some point a maximum force is reached and then I keep reducing, and there and also note the guy who was recruited last the motor unit who was recruited last is relieved first. Fourth motor unit is first relief, then 3 then 2 then 1. Recruitment happens in the order of increasing size there is be recruitment happens in the order of decreasing size.

So, the largest motor unit is functional for a brief amount of time. So, this is a smaller amount of time the x axis is time here. So, this fourth motor unit is active only for a brief

amount of time whereas, one is active for a larger amount of time. So, from this conversation, what are we able to say? We will be able to say that one is a smaller motor unit, 2 is relatively larger three is relatively larger and 4 is the largest in these four motor units at least under consideration.

And as I keep increasing the discharge rate as these increases it seems that the force is increasing; that means, the following. That means, I can increase the force either by recruiting the stronger motor unit which is the force in this case or by increasing the discharge rate. If I increase the discharge rate at the firing rate of a motor neuron, then the force is going to increase. So, there are not just there is not just one way, one way that we have seen is size principle the other way in which I can increase the force is by increasing the rate of firing of the motor neurons. So, I can keep increasing the rate of firing of the motor neuron and increase the force.

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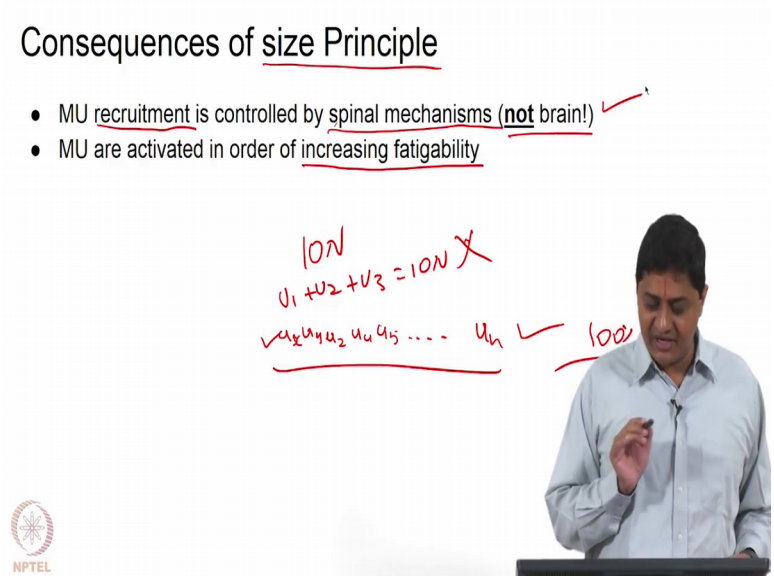

So, there are two ways in which this can happen, one is size principle, two is a rate coding or a rate of firing of motor neurons. What are the important consequences of size principle what causes? What are the most important consequences? First and foremost motor unit recruitment is controlled by spinal mechanism spinal processes not brain related processes.

The brain cannot choose. Excuse me please recruit motor unit number 1345 or whatever. It cannot say that you can only specify something else, it can only specify a synaptic

current, it can only say specify a particular amount of activity, it cannot choose which particular motor unit to be recruited. Suppose I have 2 motor units right suppose I have 2 motor needs of equal size of equal force producing capability, for example, which one of the 2 will get recruited is a question.

When the threshold is reached for that to be this, both of them will reach threshold simultaneously right, but if both of them are recruited it is possible that the force will be over shooter which is undesirable. So, at a particular point in time only one of them is recruited the others are not recruited, how is this happening? Not through brain processes through spinal control mechanisms. So, brain is not the only controller in this case the spinal cord plays an important crucial role in function of in this function especially in motor unit recruitment.

In particular brain is excluded from choosing which motor units to recruit and at what times? Brain can only say what is I sing here right? I s specified from some somewhere in the top; so, this is the bus actually this boss is receiving inputs from other bosses right. It can only specify I s, it cannot say which of the 2 to recruit no that, is the spinal cords role.

What is not discussed you will soon see what is not discussed something else is not discussed, toward the end of the class I will talk about that. Importantly brain does not participate in choosing which particular motor unit is to be recruited and also motor units are activated in the order of increasing fatigability why is this important. Suppose I want to produce a particular amount of force, that force say 50 Newton of force needs to be produced for example, I need to produce 50 Newton of force.

I am having a motor unit that could produce let us let us take a simpler example let us say I want to produce 10 Newton of force for example, and I am having say 2 or 3 motor units together that can produce 10 Newton's, I am going to call this as you know unit 1 plus unit 2 plus unit 3 equal to 10 Newton’s can be produced. These are relatively large motor units each of them can produce approximately several Newton’s several units of Newton's. I am having you know small youth this is mu actually u one r let us call this as ux ui r ux 1 or ux and several small of u 4 u 5 lots of this until un a very large number of small motor units are there, which one will be chosen that is the question, it turns out that this one will be chosen against this one this one will not be chosen.

If there are smaller number of motor units producing the same force in comparison with a larger number of motor units. Suppose 10 Newton force is produced by 100 motor units. The same 10 Newton force is produced by a combination of three motor units right I mean the chances are that the 100 100 motor units are going to be recruited why? Because these are smaller motor units; that means, they are also slower and less fatigable.

So, to produce the 10 Newton force, I am going to have the least amount of fatigability whereas, to produce if I use these guys they are larger motor units, that are more fatigable. So, I will still be able to produce 10 Newton's you might ask like. Well your aim is to produce 10 Newton's what does it matter whether it comes from three motor units or from 100 motor units.

It does not matter; however, I am also I am not just interested in producing 10 Newton force I am also interested in not getting fatigued that is not an explicit control variable, you are not stating that as the part of the task, but you are not just humans all organisms are interested in not becoming fatigued. So, I am not interested in becoming tired or becoming fatigued. So, the chances are I am going to recruit this not just the chances this is 100 percent chance I am going to almost always recruit a large number of motor units to achieve a particular amount of force. This is again a consequence of size principle; motor units are activated in the order of increasing fatigability.

So, I am I am in I am first recruiting smaller ones and then the larger ones smaller ones are having you know less fatigability. So, by default I am using a strategy that is going to reduce the probability that I am going to be fatigued. However, if I have to produce a very large amount of force right more than you know say more than 70 percent of my maximum more than 80 percent of my maximum, let us say that I can lift 100 kg's for the sake of discussion.

Let's say that I can lift 100 kg's I am asked to lift 85 cages right? It is impossible that they can achieve 85 kg is just with the small motor units, I will still have to recruit the larger motor units at that time that what are the odds that I am going to become fatigued? Very high, why I have already recruited the larger motor units; so, then the question comes why then how this motor units larger motor units.

If you are going to use them less in general there were; that means, these larger motor units are going to be used only when there is an absolute need to produce that amount of large amount of force. So, you have a very simple principle that that is followed the body has this principle, either you use it or you lose it.

So, if you are not using it, it turns out that if you are if you are continuously leading a sedentary life state if you are a person who is say leading a sedentary lifestyle not much exercise, the chance is not that you know your muscles are not going to be strong enough for you to suddenly lift you know a 50 kg bag of rice one fine day at your home that is not going to be possible. Because, you have not really trained yourself to do that it is expensive to maintain muscle mass and bone mass it is expensive metabolically expensive.

So, the body prefers to not store the you know muscles are fibers that are not being utilized not have them, they are you know they are disposed of in favor of smaller motor units. But still there are some of them that are retained that are going to be used in terms of emergencies in terms in times of emergency when you need them the most ok. So, we said that there is a consequence we have the two important consequences of a size principle, this is most important that the brain cannot control specifically which motor unit to be fired, the brain cannot do that it is a spinal process ok

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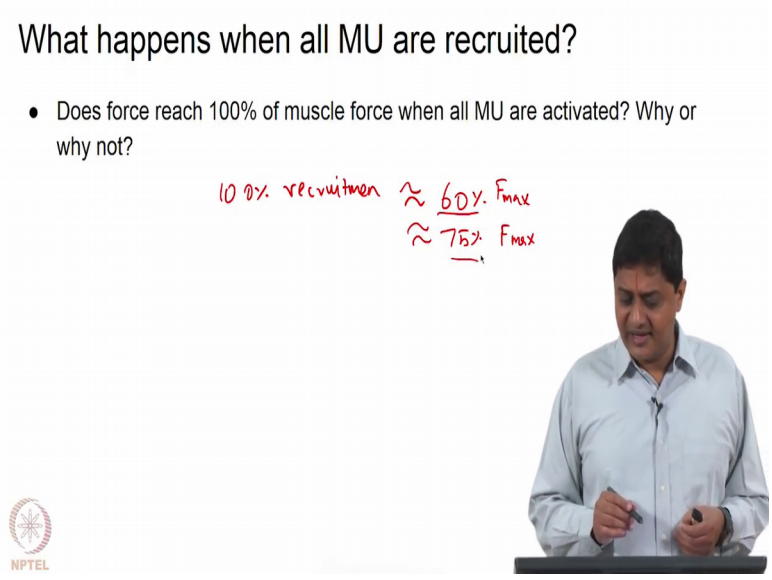

Suppose I recruit all the 100 percent, suppose I have 100 motor neurons or 100 motor units, I have reached I have activated all 100 of them will they reach 100 percent of the force? The answer is no why not? I have recruited I said there are 100 motor units all of them are active, all the 100 are active I should be reaching 100 percent of my maximal ability rate, that is what one would think the answer is no because it turns out that it turns out that I am able to increase force by also by another mechanism, I said that I can increase force not just by motor unit recruitment but also by the rate of firing.

I have only said that I have recruited all 100, but I have not said at what rate they are firing. It is possible that all the motor units after they are recruited if they are firing at relatively slow firing frequencies, then the force that may be produced after 100 percent recruitment. It could cause sometimes in some muscles as less as 60 percent force, 60 percent of the maximum force sometimes 75 percent.

Then how is the other 40 percent achieved? In this case in this case how is the other 40 percent achieved in this case how this other 25 percent achieved. By increasing the firing rate of the already recruited motor neurons, I have already recruited these motor neurons I increase their firing rates; from 60 it become 65 if I increase the firing rate, I increase the firing rate further it becomes 70 75 85 95 whatever 100 at some point right. So, it is possible for me to do that by 2 processes by size principle and increasing the rate of firing.

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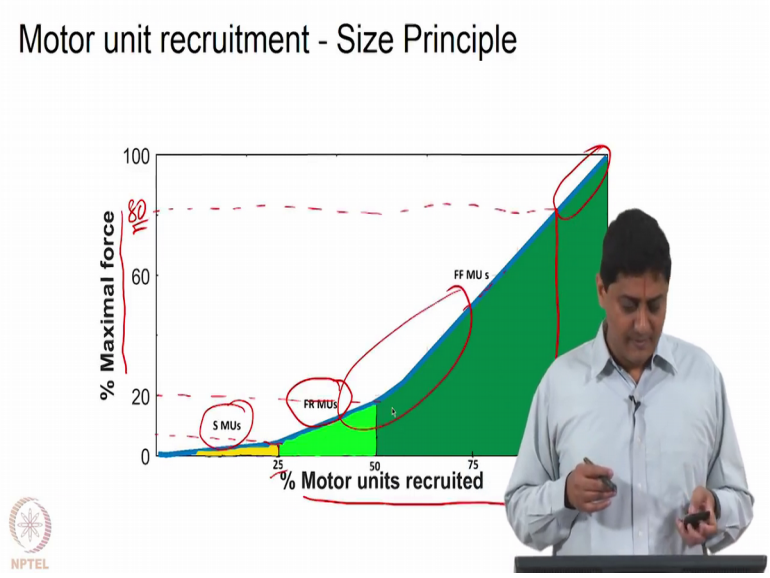

So, what happens is usually first the small motor units are recruited. So, about 25 percent and what is the mode, what is a force maximal force the destitute is about less than 10 percentage of the maximum force, this is percentage of the maximum force that can be produced say if the maximum force is 100. So, this is about 10 less than 10 Newton's is produced by 25 of the 100 motor units that are available.

Suppose there are 100 motor units that are available, and the force that is produces 100 Newton's for the sake of discussion right. 25 motor units together produce less than 10 Newton force this is comparison to you know the case that the discussion that you see always on media that you know, 2 percent or one percent of the wealthy people have 60 percent of the worlds wealth or something like that right. So, there is a disproportionate distribution of wealth.

Likewise there is a disproportionate number of a motor units that are recruited to produce a small amount of force is it not. So, disproportionately large amount of a motor units need to be produced, then fatigue resistant motor units are recruited. So, that in that cars has an increase about 20 percent of the maximum force can be produced, and then I keep increasing and then and then what happens? At some point I have pretty I have recruited all 100 of my water units.

And what is the force at that level? Approximately 80; so, after I recruit all the 100 motor units after all of them are recruited, I am able to produce about 80 percent of the force then how is this increase happening? This increase is happening by increasing the firing rate of the motor neurons right. Just illustrating the important principle that firing rate increasing the firing rate of motor neurons can and will increase the force, but note it is not when in this discussions it might appear to you as if you know I am saying that the firing rate is increased only after all the motor units are already recruited.

But what actually happens is that, even here even in these regimes right some motor units are recruited at slower firing rates and their you know their firing rates are increased even in these regimes. This is a this is a theoretical concept just to explain that you know after 100 percent motor unit recruitment, I can increase the force for that for that I am using this principle, but it turns out that even at below 100 percent recruitment, below even at 50 percent or 60 percent or 70 percent of the motor units are recruited. Even at that range force can be increased by increasing the firing rate of the motor

neurons in now at all times force can be increased by increasing the firing rate of the motor neurons that is the principle.

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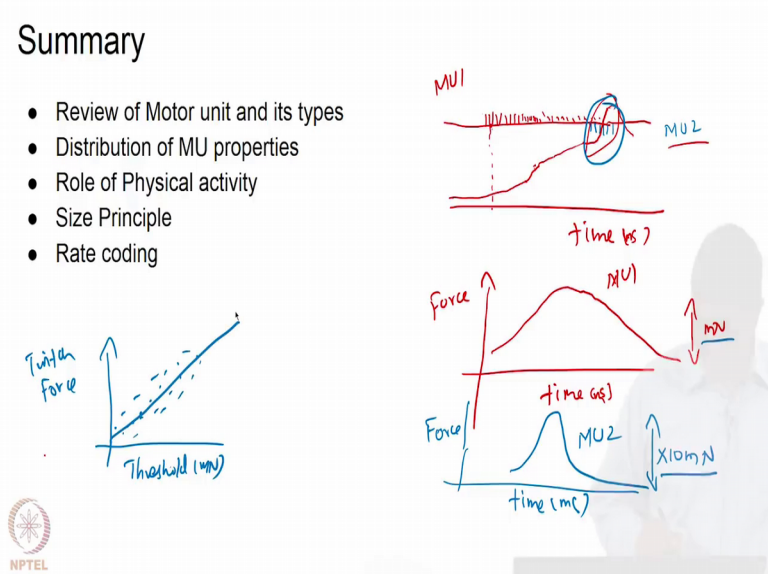

So, to review one important principle before we before we summarize this and talk about the next class an important principle. Suppose let us take a 2 cases. So, to illustrate to review what happened, let us draw the activity of motor unit one here and I am going to draw a force. Let us say that you know this motor unit starts firing at some frequency right what happens at around that point the motor unit starts firing, then the force that was relatively small or nonexistent or close to 0 starts to increase at that point, slowly increase not like that a little slow increase slowly increase like that.

Then I suddenly increase the frequency, then the increase is happening at a greater slope and then sustained frequency, then the increase is happening like that. Then let us say another guy comes into the picture let us say. There is a different motor unit I am going to call this guy as motor unit 2 and that guy starts firing at around that point at say at a sustained frequency. It is possible then what will happen is the force increases like that say for example, sudden there is a sudden increase in force like that and then and then this guy is d recruiter and then there is a decrease in force.

What could you say about the properties of these 2 motor units? It is immediately obvious that you know this MU 2 causes a relatively strong increase in force; that means, it must be a larger motor unit; that means, it must produce a larger force that must; that

means, it must be the faster motor unit is it not? This is MU 2 that response this is time. So, the x axis is time.

So, if suppose I were to draw the responses of these 2 motor units I am going to draw the response of the MU 1 time in milliseconds not seconds. For example, the response of the motor unit one right this is a slow motor unit, that increases that reaches peak and then you know based only for example, the order of force the scale of. So, the y axis here is force say the absolute force is in units of milli Newton's for MU 1.

For the motor unit 2 though suppose I were drawing the same force versus time curve right. I am going to have something like that with the scale being different this will be in order of several 10's of million Newton's. So that means, if I recruit MU 2 if I recruit the motor unit 2, I am going to see this done development this increase in slope why? Because this guy can produce a greater amount of force note the difference in scales this is in units of motor this is in units of million Newton's this is in several tens of million units.

So, from this we can also what is known is that suppose what is also known is the following. Suppose threshold in milli Newton's is on the x axis and force which force that is produced is on the y axis, what you see is that there is relatively linear response. So, as the threshold increases that which was produced also increased a relatively linear response is also found. So, this means that you know I could recruit depending on the situation these choices are made by the central nervous system by the spinal cord. So, what are the 2 principles that control this size principle under rate coding; and we also saw review reviewed units we reviewed how the material properties are distributed this, and we discussed the critical role of physical activity in day to day functioning.

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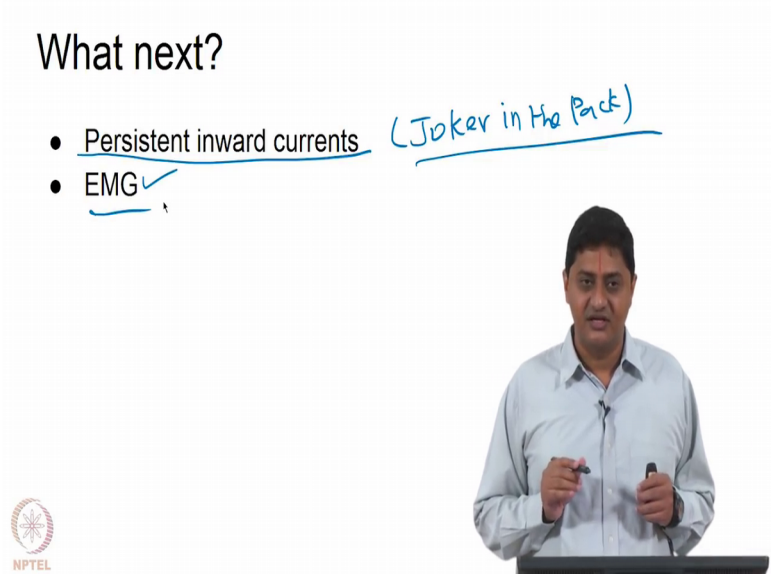

The joker in the pack is what is called as persistent inward currents and EMG, this is in the next class. Persistent inward current I am calling as the joker in the pack because this changes everything. So, we have so, far seen I have now said where I have now described the system as if it is an engineering system, I am giving a greater current bigger motor unit is recruited a greater force is produced that seems too simple for the biological system.

For the biological system it seems like I am giving. So, this is like you know changing a response with a greater amplitude of the input, something that we would do analytical engine is, something that we would do in engineering systems. I am keeping and I am increasing some input the output is also increasing as you would expect, that is what I have now described. Also I am increasing the frequency of firing the force is increasing so, far so, good. But what is not discussed is this role important role of a mono I mean energy input from elsewhere in the system.

So, this is the joker in the back, persistent inward currents we need to discuss it is critical crucial role in adjusting the sensitivity or gain of the motor neuronal push or excitability of the motor neuronal pool tomorrow in future classes. And we will also discuss EMG. So, with this we come to the end of a today's class.

Thank you very much.