Virtual Reality Engineering

Dr. M. Manivanan
Department of Biomedical Engineering
Indian Institute of Technology, Madras

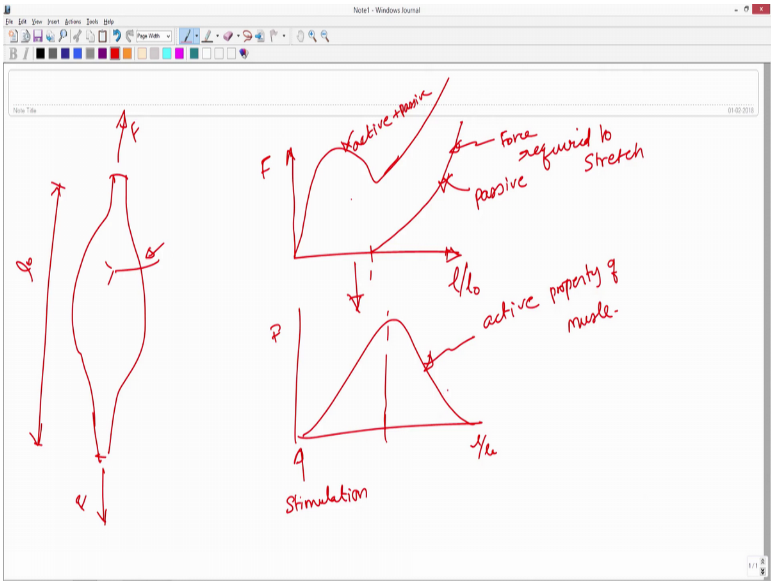
Lecture – 70
Motor System

So welcome back in the last class we saw kinesthesia the sensing mechanism of a our movements, sense of position proprioception sense of position and then it is a sense of balance also we saw. So, in this class we will look at how muscles are generating forces ok. So, how movements are initiated muscles are integral part of the movement generation. In a haptics we need to apply force, we need to move our hands, we need to explore objects.

So, the hands have to move and then generate force. So, the integral part of a haptics is, is understanding how muscle is generating force; that is what we will focus in today's class. There is a lot of biomechanics involved in understanding the muscle force generation we will not get into the biomechanical aspect of it very important things, that is necessary for understanding the haptics part of it alone, I am going to focus on it much more details I cover in a biomechanics course which I used to offer in a other semesters ok.

So, only that is required for haptics course, I am going to touch upon it, but there are much more details probably you know you can look at the in a textbook specifically the Eric Kandel chapter 33, 34 and 35 for getting more details on a what we are going to talk about today ok.

(Refer Slide Time: 02:15)



So, we will start with ye muscle let us say it is going to generate a force, let us say we are trying to apply force over here ok. So, what will happen; I am going to draw a graph, let us say this is the length, let us say this is the force it is generating right.

So, let me say it has some original length, this is a starting length initial length l naught, and any longer stretch is going to be you know l naught plus something right. So, let me let me normalize this one with a l naught and let us say one means it is at a resting length. I am starting to apply force, what is going to happen is; as I increase the length it is going to be more and more tougher is going to be exponentially increasing right.

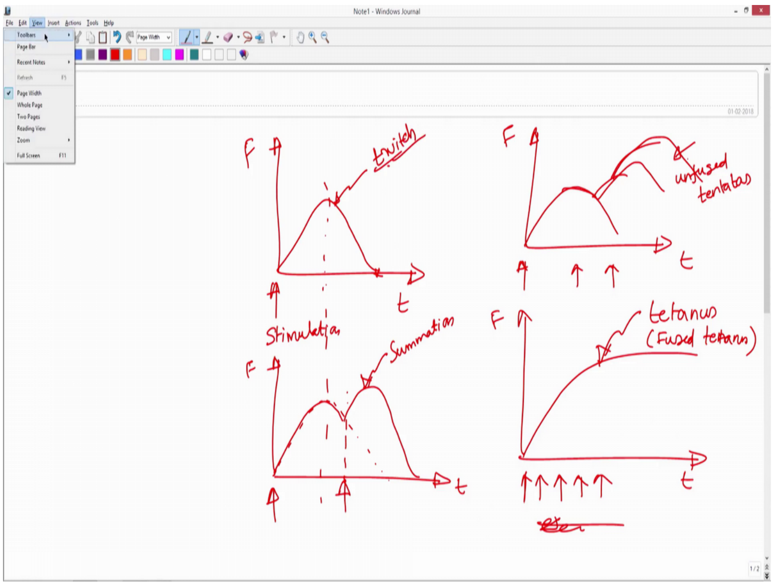
So, this is of force required to length right force required to stretch. Now, you have to see that this is without any addition of electrical stimulations it is just a you know, ye we have taken a muscle out of the body, and then put it in a your our stress strain or you know force application or even with the hands you are trying to stretch it and this is going to be your force resisted by the muscle.

Now, suppose if we apply electrical stimulation. So, you remember in the last class we saw there, but alpha motor neuron and gamma motor neurons, let us say this is the intrafugal muscle, which is innovated by one of the motor neurons. Let us say it is a electrical stimulation, let us say when you stimulate the muscle, what is going to happen is; it is going to generate force and it is the force profile generated by the muscle when you are holding it.

What happens is whenever there is the electrical impulse it is going to shorten it, when it is shortening your hands are going to feel the full force and that force is, what I have plotted over here. So, this is plus I call this profile as active and this profile called a passive, in the sense there is no electrical stimulation here this graph not only active it also passive active plus passive, because the passive properties also is there right it is not the just the active property.

So, from this I can easily find out what is the active property alone l naught that is going to be this is the active property of property of muscle. This is a force generated by the muscle, when it is stimulated with a electrical impulse. So, where are we generating we are just generating here electrical stimulation, when you start over here the muscles start generating force and it would reaches some maximum and then falls down. So, what how did I do this I have taken this curve active plus passive I have subtracted the passive I got the active alone ok.

(Refer Slide Time: 06:45)



So, the same graph I can put it in another view just for understanding instead of a x axis on length I am going to plot it in t time, I want to look at a how the muscle is generating force over the time ok. So, y axis I am again going to keep the same F and, if you look at the time again it is going to look at look similar to what we have seen it over here, but it is the x axis this is t this is called the tetanus in the literature tetanus, tetanus in the literature.

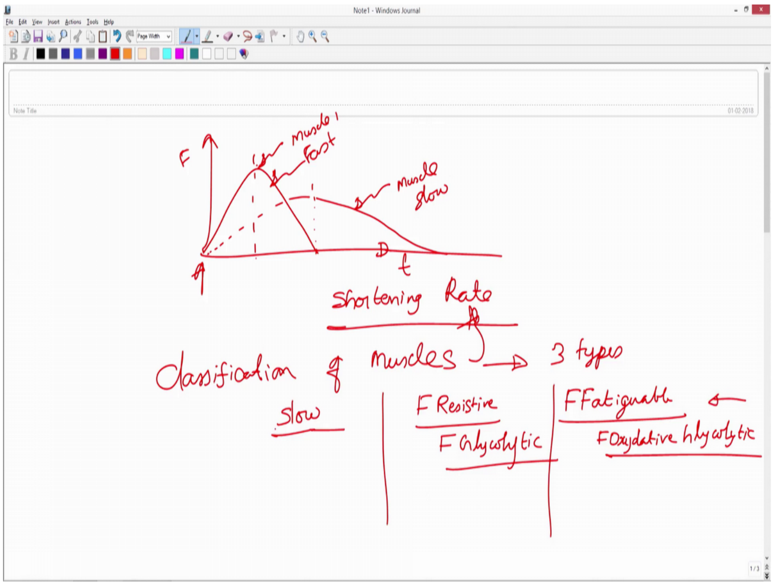
So, what is that I have done I have started the stimulation over here and the muscles started developing the force over time reach some maximum and then fallen down and then attend some zero over here. Now, the same thing, suppose the same muscle I am again plotting F and t. So, before the muscle reaches 0. Suppose, if I put stimulation, what will happen and started stimulating over here the same muscle it is going to reach this way, but before it reaches zero, what I am going to do is I am going to put another stimulation.

So, what will happen? It is going to build up force from the place where it left it is going to submit ok. So, it is going to the force it is the summation of the force ok. Now, now this will go on as long as the stimulation is on here also I am simulating you let us say here also I am stimulating [noise so, it is going to it is going to keep building on it ok. Let us call this as a unfused ok, this is you know here ok. So, unfused to tetanus oh yea.

So, this is not this tetanus this is called the twitch and this is actually a tetanus tetanus is the saturated force value. So, if I continuously apply stimulation, what happens again I can put a store. So, I am not continuously very frequently, I am applying stimulations. So, what is going to happen is; is that is not going to be you know discontinuity it is going to be continuously and reach a force over here this is called the tetanus not the other one or in a some textbook; you will see fused tetanus tetanus this one is the unfused tetanus it is keep building it up this is called the fused tetanus.

So, this is for one muscle we have seen how electrical stimulation is actually you know is used to generate a force. Now, there are different type of the force the type of the muscles which has different and twitching properties twitch properties ok. So, understanding different type of the muscle is important.

(Refer Slide Time: 10:50)



So, the one type of the twitch we have seen it is over here right; for the same stimulation different muscle will have a different twitch for example, another muscle will have a much slower response ok.

So, the peak occurs over here whereas, this muscle let us say this is muscle one this is the muscle two. Muscle two has a slower response and this is the faster response fast muscle whereas, this is the slow muscle depends upon how twitch is developing we can classify muscles ok. So, why do the muscles have different rate this is called a the shortening rate of the muscles shortening rate. The muscles are generating force during shortening, it can generate force only during shortening and then there are different rates for each of the muscles and it has a in a purpose, why; different muscles have different shortening rate there are different reasons we are going to see 1 by 1.

But, for the time being you have to understand that the shortening rate are there for different muscles. Now, according to how are different muscles are shortening people have classified the muscles ok. So, a classification of the muscles is important muscles based on the shortening range ok. So, there are slow muscles, that is; one type slow muscles most of the literatures classify the muscles into three types; slow muscle and then and there is a another muscle called fast resistive FR for fast resistive.

Another third type is called the Fast Fatigable; these are the three different type of the muscles fast resistive this fast fatigable. So, the fast fatigable muscles they are very fast, but they are quickly fatigable, they can and generate force only for very short time, they cannot generate force for a very long time those are fast fatigable slow muscles or they are slow to generate force, but they can generate force for longer time they are less prone to fatigable ok.

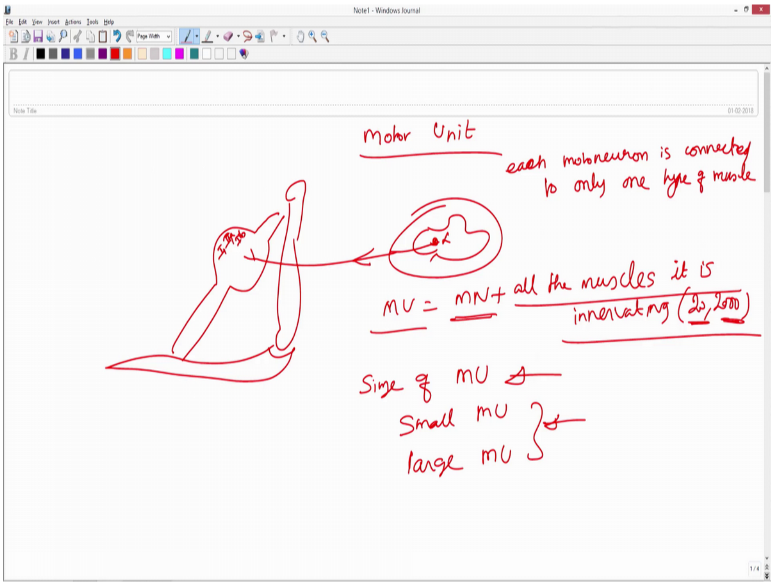
Fast resistive is the embedment in some of the literatures or in the textbooks you also see something like fast glycolytic FG is called the fast ; this is a fast resistive is also called fast glycolytic glycolytic fast fatigable is also called the fast oxidative, glycolytic oxidative glycolytic pharmacologically people have you know a named different type of it.

In fact, in the a recent time as of now there are many type of a muscles people have identified even subcategories of all this muscles maybe some 10 different type of the muscles people have identified, but for our understanding if you if you differentiate between these three muscles it is good enough ok. So, one way to identify each of those muscle is by looking at the color ok.

So, the slow muscles are you know red in color whereas, a fast fatigable muscles are you know pink in color or this is you know white in color whereas, this one is in a pink in color kind of things, because slow has you know lot of a oxygen in it has a lot of you know a lot of you know energy in it looks very you know red reddish.

Whereas this one it does not have much power in it looks white whereas, this one is the medium of it ok. So, again so, to we have to still to answer the question why our muscle systems have different type of the muscles, why should this be; you know differentiated using the shortening rate ok.

(Refer Slide Time: 16:46)



For this I need to explain a concept of a motor unit this is one of the important concept we have to understand. So, in the earlier class we looked at a muscle connected to the spinal cord motor neuron. Let us say this is the you know alpha motor neuron this is the efferent.

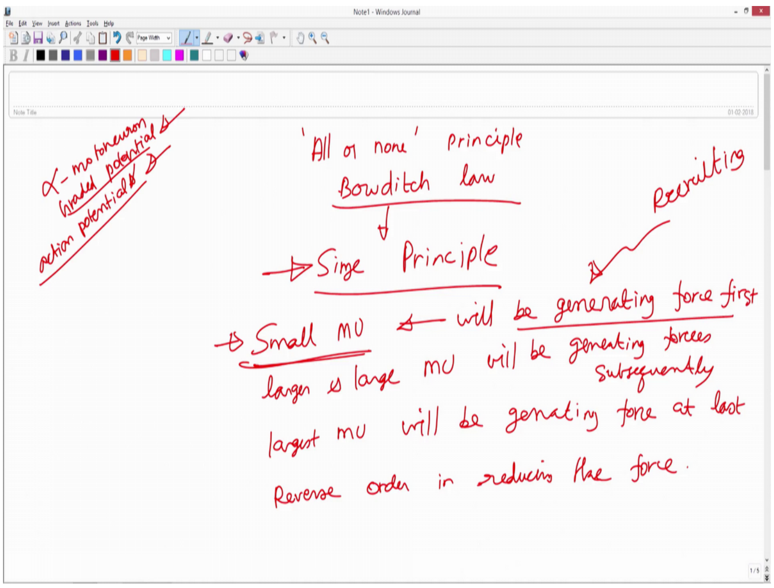
Now, we are it is getting connected over here now in the in any of this muscles there are this three type of muscles or all the type of muscles are there ok. So, there are type one type two this all called the Type 2 a or 2 b this what the classification is all the type of muscles are there, but this alpha motor neuron one of any one of the motor neuron is connected to only one type. So, each motor each motor neuron is connected to connected to only one type of muscle it is not connected to a different types.

So, as many types of muscle there will be as many type of motor neurons ok. So, depending upon the force required, there are different type of the muscles are going to be in action ok. So, we are going to see this. So, the motor neuron is the a motor unit is nothing, but motor neuron plus all the muscles muscles it is it is innervating innervating. So, this motor neuron may be connected to some 20 muscles or 2000 muscles, but it is all going to be the same type ok. So, when the motor neuron is firing all the 20 muscles. So, all the muscles it is innovating are going to be fired all are going to generate force. So, together motor neuron and all the muscles it is innervating is called the motor unit ok.

So, we can we can find out what is the size of the motor unit it depends upon, how many muscles each motor unit is innervating. So, the motor unit it depending upon, how many muscles it is connecting; it can be you know 20 or 2000 there are many a different sizes of the motor units small motor unit small motor unit or a large motor unit it depends upon, how many motor how many muscles it is actually innovating ok.

Now, comes to answer this question of why our muscle systems have different type of the type of the shortening rate it has to generate force at a different level at different time ok. So, before explaining this let me explain the principle called the, where a motor unit related principles called the all or none principle or law this is also called the you know Bowditch law in the literature.

(Refer Slide Time: 21:14)



So, this principle says that all the muscles connected to the motor neuron will be firing or none will fire, that is what the principle is, that is a concept of the motor unit ok. So, this is important to understand that um all the muscles are either active or not active ok. Now, this is important because this is going to help us in a understanding another principle called the size principle. This principle says that small motor neuron motor units will be in action first, why is that; we will be generating force we will be generating force first why is that the slow motor neuron, sorry; small motor units they are all you know made up of a slow muscles they can stay there for a long time ok.

So, a small motor units it is it is going to generate smaller force first large motor neurons units are going to generate larger force. So, what we want is we want to gradually increase the force. So, first you know small motor unit has to be generated. So, how is it going to generate, the alpha motor alpha motor neuron is going to is going to send the send them, what we called a graded potential alpha motor neuron is generating the graded potential to all the muscles, but only this only the small motor units will have a action potential action potential which is equivalent to the corresponding graded potential.

Whenever our, this motor units action potential is. So, you know equal to the graded potential it starts firing it is starts generating force. Now the motor neuron is going to increase the graded potential, then what is going to happen is next smaller motor neuron will come into picture. So, larger and larger larger and larger motor units will be generating forces generating forces subsequently ok, but the first small motor neuron is going to still be active, because it is action potential is lesser than the greater potential ok.

So, this has to be fatigue resistant it has to be there in action for longer time therefore, this has to be a fatigue resistant ok. So, the largest motor unit will be generating force at lost right generating force at lost ok. So, this is called the size principle depending upon the size the muscles are generating force, suppose if you are reducing the force what happened; then the reverse order will happen a reverse order in reducing the force reducing the force the largest motor unit will be dropped first.

The smallest motor unit will be dropped lost ok. So, the generating the muscle generating force is actually called a Recruiting. Recruiting it is like the muscles are recruited for generating the force. So, while increasing the force more and more are bigger motor units are recruited while reducing the force the largest motor unit are dropped first, and then smallest to you motor unit is dropped last this is called the size principle.

Student: How to know the muscle is larger or a smaller.

So, the number the number of muscles number of muscles attached to it.

Student: (Refer Time: 26:43) specific number.

Say there are 20 is smaller 1000 is big ok; 20 number of muscle fibers there are or each muscle is made up of muscle fibers muscle fibers is the one which is generating the force. So, 20 muscle fibers generating force compared to 100 muscle fibers compacting force is a larger ok. So, a number of a muscle fibers it is innervating can directly tell you whether what is the size of the motor unit.

Student: Sir if the force becomes steady in the smaller motor unit like if you are dropping at last. So, the force will become steady is it.

If you are dropping the force at last what is the question.

Student: It is like a smaller motor unit we are dropping at last.

Correct.

Student: So, is it like at like closely becomes steady or certain kind like.

It depends upon, what is the force requirement; if we have to maintain the force constant, then and all the motor units recruited will be in the action for during the time, whenever it is reducing or increasing there will be a change in the you know recruitment. So, if you want to maintain the force the largest motor unit, which is recruited last will be still in action it depends upon how much fatigue it can be it can withhold so, one way to find out. So, whenever you go to you know your sports center or other any athletes syntheses audience right, you are a athletes ok. So, ye when you go to the any training camps for any a type of the sports each type requires different type of the muscles ok.

So, as soon as we go the training is going to find out, what is your composition of the force muscles ok. So, for this sport sports this is a composition required, but your body has this is a composition. So, how much what is the target, which what are the different type of the muscles, which has to be developed for this development, what are the different exercises needed and that is what the drilling master is going to sit and decide, and then he will give you a course; if you do this course this is the muscles will get developed either the fast or slow for example, sprint needs a.

Student: (Refer Time: 29:27).

Yea, but whether it is a slow or fast.

Student: Fast (Refer Time: 29:32).

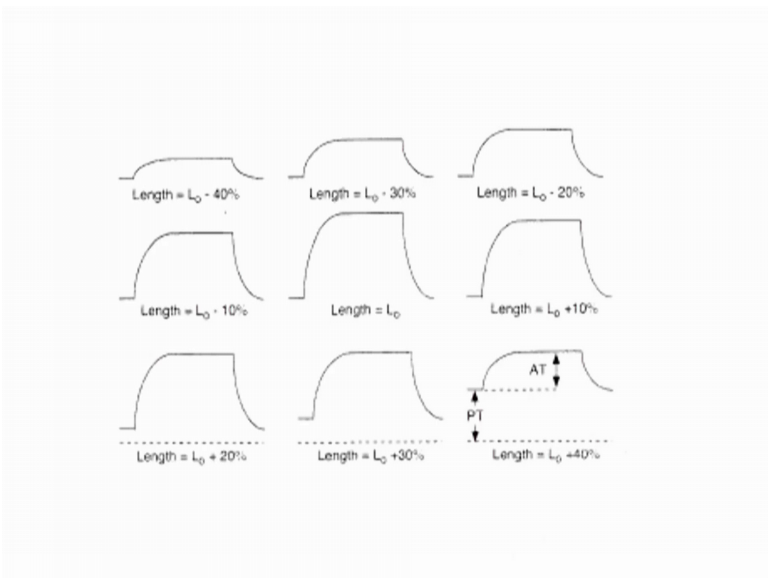
Fast whereas, a marathon requires.

Student: Slow

Slow. So, they will find out how much percentage of the muscles are slow or for marathon we need lot of slow muscles powerful muscles. So, what are the; you know different exercise needed to develop these slow muscles every every sports will have this kind of analysis in. In fact, you know invasively they find out muscles. For example, you know biceps they put a micro needle and then take a small biopsy of the muscles, and then look at that analyze it what is the and a composition of the muscles without invasively finding it out non invasively can we find out the; what is a composition of the muscles, there is still a research question you know you can find out an answer, and then it is million dollar or million dollar you know ideas ok.

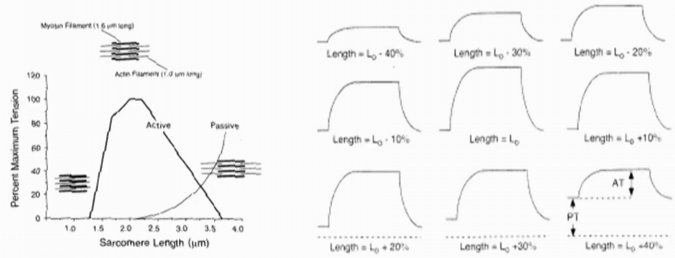
Now, I hope the size principle is clear the next ok.

(Refer Slide Time: 30:46)



Let me show you a couple of you know slides to make it make it more clear.

(Refer Slide Time: 30:51)



These are the different type of the muscles I talked about a motor unit properties type one type 2 a, type 2 b, you know slow and a fast resistive fast fatigable you know contraction speed is slow this is fast and the fast there are you know depending upon the composition cellular compositions.

(Refer Slide Time: 31:54)

Motor unit properties (Maughan et al. 1997) *Powerpoint*

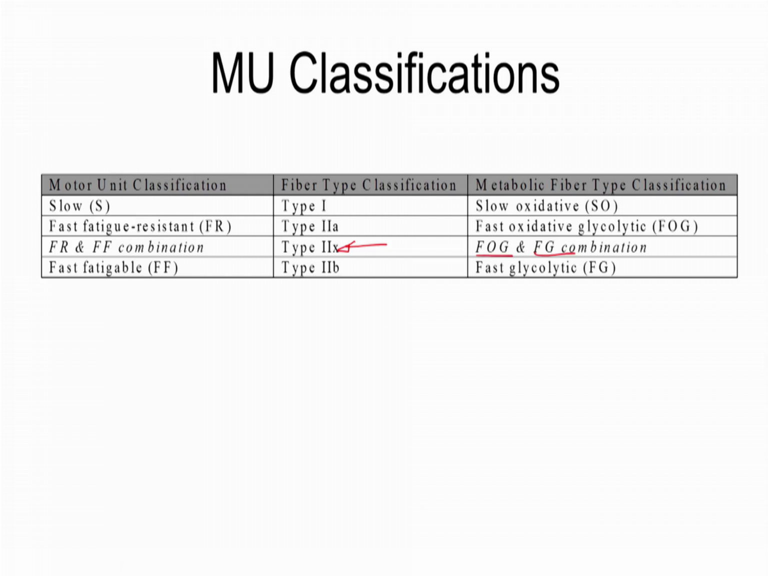
Motor unit type	Type I S	Type IIa FR	Type IIb FF
Contraction speed	Slow	Fast	Fast
Myosin ATPase activity	Low	High	High
Metabolic type	Oxidative	Intermediate	Glycolytic
Mitochondrial density	High	Medium	Low
Fatigability	Low	Medium	High
Motoneuron size	Small	Large	Large
Motor unit size	Small	Large	Large

FF- Fast Resistant or Fast Oxitative Glycolytic (FOG),
FF- Fast Fatiguable or Fast Glycolytic(FG)

If you look up at look at the fatigability this is low, low fatigability it means it can stay there for a longer time, this is a medium fatigability this is how high very highly fatigable motor in neuron size, this is small motor neuron a motor units is also is small.

So, this is a large motor unit, it means and there are more number of a muscles attached to it.

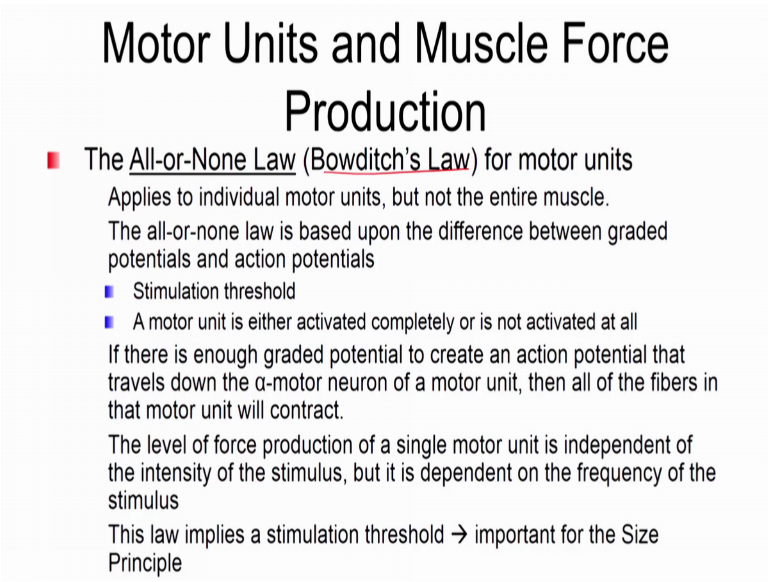
(Refer Slide Time: 31:50)



Motor Unit Classification	Fiber Type Classification	Metabolic Fiber Type Classification
Slow (S)	Type I	Slow oxidative (SO)
Fast fatigue-resistant (FR)	Type IIa	Fast oxidative glycolytic (FOG)
FR & FF combination	Type IIx	*FOG & FG combination*
Fast fatigable (FF)	Type IIb	Fast glycolytic (FG)

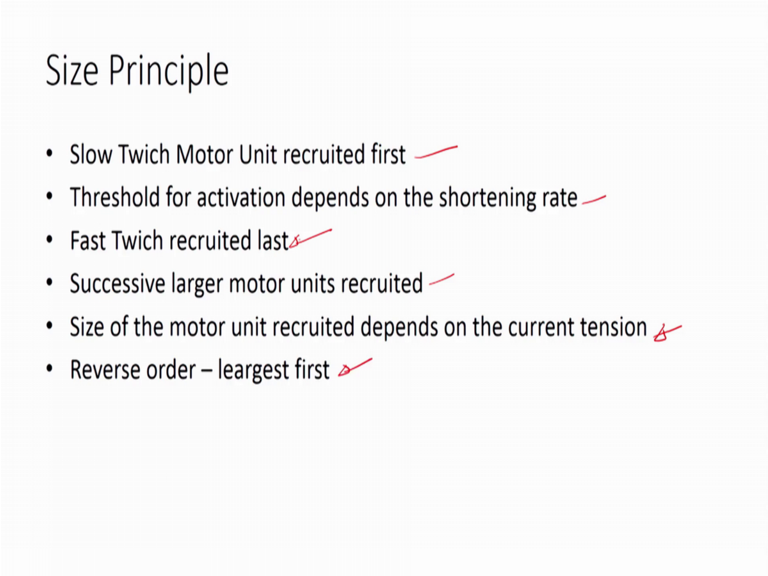
There are more and more types being identified for example, the recently people have come up with there are 2 x; 2 x is nothing, but the fog and FG combination combination of this also people have found out and. In fact, there are much more a types recently found out.

(Refer Slide Time: 32:12)



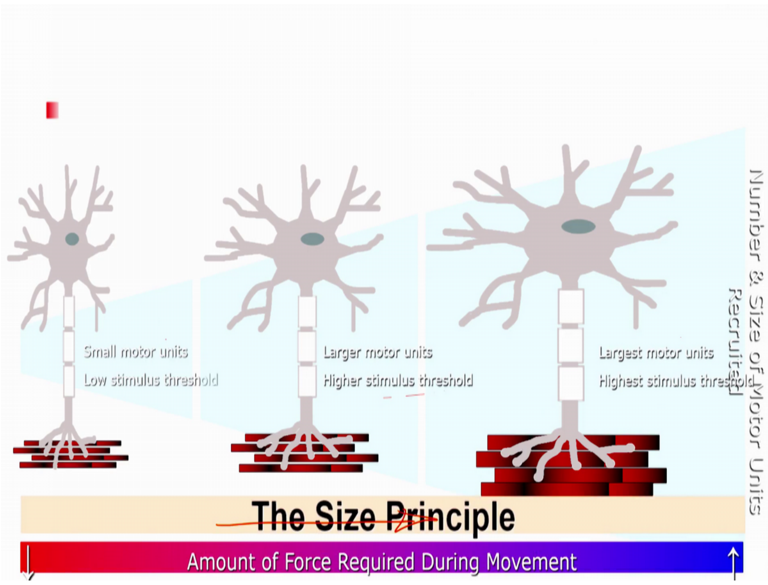
So, this is the you know all are none Bowditch law it depends upon the graded potential are equal to the action potential ok; this law is very important for the size principle.

(Refer Slide Time: 32:24)



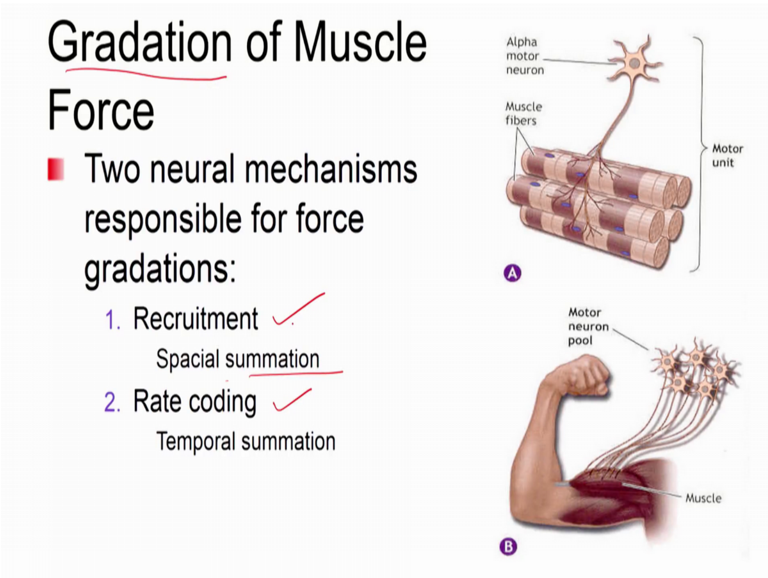
Size principle slow twich motor are recruited first, threshold for activation depends on the shortening rate, fast twich recruited lost, essentially it is nothing, but the you know small motor unit or large motor unit successive motor units are recruited later, size of the motor units recruited it depends upon the current tension, depends upon the requirement if you require more force than, the next level of a motor unit is recruited.

(Refer Slide Time: 33:00)



And then the reverse order the largest one this is to show that you know the small motor units. Suppose, if this is the amount of required force it is increasing first a small motor unit low stimulation threshold is required, and then the larger motor unit higher stimulation threshold, and then largest later highest stimulation requirement ok.

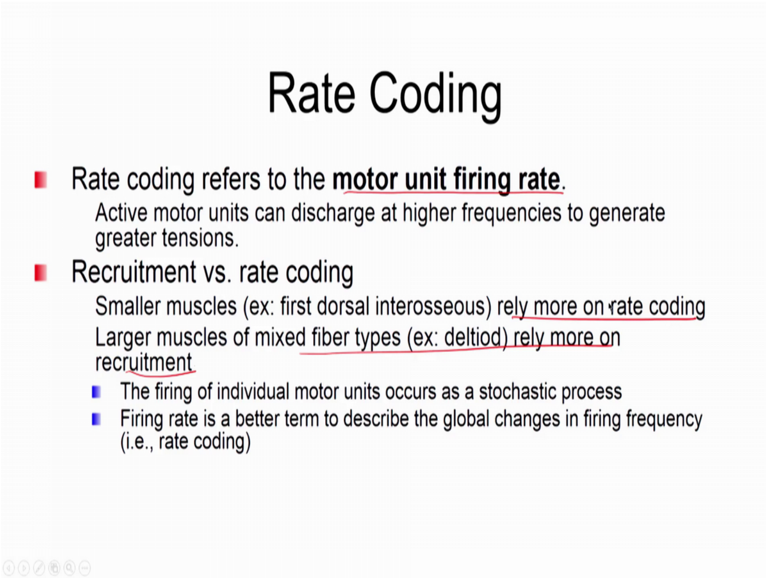
(Refer Slide Time: 33:24)



This is called the size principle we saw. So, what we have seen is the only the recruitment there is one more way of controlling the force. So, the that is called as a rate coding in the initial, when we started this lecture we saw that the frequency of the stimulation can also change the force that is called the rate coding. So, how frequently you are going to simulate a force. So, I will stimulate the muscle that can change the force developed by the muscle ok; while recruitment is the spatial summation many muscles are adding the force rate coding is going to you know temporarily submit the forces.

So, muscle can change it is force by two ways by recruitment and rate coding this two things is very important to remember.

(Refer Slide Time: 34:26)



Rate coding refers to the motor unit firing rate. Active motor reader can discharge at a higher frequency to generate greater tensions. Recruitment versus rate coding; smaller muscles rely more on the rate coding larger muscles of mixed fiber types rely on more recruitments, I am going to show you. So, this is what I mentioned over here larger motor a larger muscles of mixed fiber types rely more on recruitment, there rather than the rate coding smaller muscles rely more on rate coding rather than the recruitment ok.

The firing of individual motor units occurs as a stochastic process as it is not the you know (Refer Time: 35:12) what as what we have seen it a firing rate is a better term to describe the global changes in the firing frequency that is the a rate coding.

So, this point is very important that you know motor units which larger motor units are using the a recruitment more of recruitment smaller motor units are relying on the rate coding I wanted to highlight it is very important to understand. Now you have an idea about how muscle is generating the force we have taken only you know the muscle alone. So, in the earlier class, we saw the sensors measuring the length the velocity and the force.

Now we have we have looked at only the development of the force haptics is nothing, but a control system right movement, and then you know really making an and interaction with the objects generating the force. So, in the next class what we are going to do is that, we are going to use the sensors and the motor force developments together and then see how these muscles are controlling the forces using the information coming from the sensors ok.

We have the muscle spindles we have the Golgi channel organs which is measuring for both the length and velocity and force right, what information is going to use for generating the for controlling the force generated by the muscle is, what we are going to see is; it going to use a length based control or is it going to use a velocity based control or the force based control in the robotic literature, if you look at it there are you know position based control system right the robo end effecter is controlled for the position or the force or the mixture of anything, but what is that our human hand, what control system is; it actually using it we will see it in the next class.