Virtual Reality Engineering
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Lecture - 69
Kinesthetic System

Let us, take a hypothetical situation where we have our bone.

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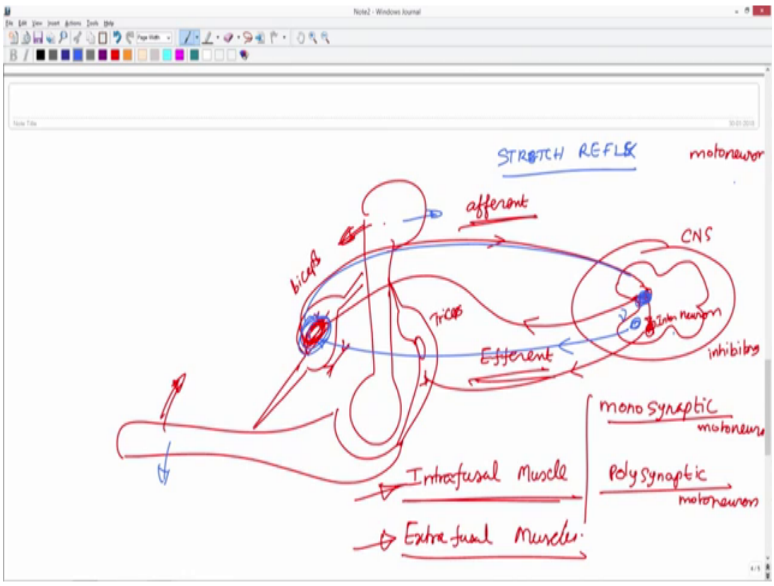

Let us say, we are taking an object in our hand. This is a, the femur bone, this is the, forearm bone, bone. We have this, muscle, which is connecting this bone to the femur bone and, for a every bone sorry. Every muscle, there is a antagonist muscle. So, in this case is, this is let us say, this is a biceps, biceps. Here is the triceps, excuse me for my poor drawing.

Now, this muscle is connected to our spinal cord, which we have seen it in the earlier class. Let us say, it is connecting to their spinal cord. Let us say that is a spinal cord. In the spinal cord, this muscle is connected to a motor neuron, the last class we saw that, motor neuron right. Motor neuron and is, what? It is going to let us say, it is connecting this.

So, muscle needs electrical impulses from the motor neuron, whenever the motor neurons fires then the muscle contracts. Muscle can only contract it, cannot along it, it cannot generate force when it is elongating right. So, this, connection from motor neuron to the muscle is called the Efferent, Efferent pathway.

Now, the muscle when it is contracting, then the, the two bones comes together. The length of the muscle changes, if you want to control. These forces generated by the muscle then there should be some way of. Now, monitoring the muscle length and force right then only the closed circuit, your control circuit will be established.

So, some of we need some mechanism to monitor the length of the muscle and the force of the muscle. Let us say, we have some sensors over here, and the sensor is attached to the motor neuron ok. This is called the Afferent. Afferent is anything that sensor is going to the, the central nervous system. This is a CNS part of the CNS. We saw it right; afferent does anything from CNS to the effectors outside. There is the afferent and afferent, this again over terminology may have to now, get used to it.

Now, the question is, now, how is, what kind of sensors will be here in the muscle, which is measuring the length and we are going to see that, it is not just measuring the length, but also many other things. So, with an engineering background we have seen, lot of sensors right. So, what sensor will measure the length, can you name some length?, sensors that measures the length change LVDT very good, any other sensors change in length potentiometer. There is the rotation linear potentiometers also there here, very good ok.

Student: Strain gauge.

Strain gauges very good.

Student: Capacitors

Capacitors senses ok, all right. So, we have so many sensors that can measure the, the length changes so, but what changes? What sensor is in our muscle?

Student: (Refer Time: 04:43).

Can you imagine a LVDT in the muscle or capacitor or potentiometers are there, what sensor is there in the muscle.

Student: (Refer Time: 04:50).

Which one?

Student: Piezoresistive.

Piezoresistive is there ok, very good, all right. Let us see what kind of sensor? What nature has you know, design the sensor in our muscle and how it is working is, what we are going to talk about it.

So, before we talk about, there is one more concept, I need to, you know clarify, it is. So, this muscle is, with only one motor neuron in between. It is called monosynaptic synaptic motor neuron right. There is only one motor neuron connecting the receptors to the muscle.

When this muscle is contracting, imagine this muscle also is contracting. What happens that is a triceps. This is a triceps right, triceps also is contracting then what will happen, you know the hand will not move at all. So, when this is contracting, this has to relax, then only eventually you can contract it.

So, somehow this muscle has to be told, that you know just relax. So, how will that happen is there is, you know a polysynaptic muscle. Polysynaptic neurons are there from here. There is a inter neuron that is inhibitory nature, inhibitory nature. From here, it will go to this, this is again efferent.

So, because there is a inter neuron, which is inhibitory nature, whenever this motor neuron is firing, this will stop this motor neuron firing. Therefore, this muscle is in relaxing condition. So, that this muscle bicep is actually contracting the entire, musculoskeletal system is actually reducing the, the length. This is reducing length ok. So, polys, the monosynaptic motor neuron and polysynaptic motor neuron is very important in understanding, how the muscle is working.

Now, how is this system tells the triceps in this case to relax ok, that is a question then, before we see that, more details, there is one more set of, terminologies, I wanted to introduce, it is called the intrafus fusal, intrafusal muscles. The, the muscle is, usually called the intrafusal muscle oh sorry, intrafusal muscle and the extrafusal muscles, muscles.

The sensors we are talking about, which is measuring the length itself is made up of muscles ok. It is not made up of piezoelectric or. Now, potentiometer it is made up of muscles. So, the muscle is embedded inside the muscle, the embedded muscle is called the intrafusal muscle. The, the outside muscle is called the extrafusal muscles, this distinction also is very important.

So, again to recap, we have seen many terminologies I want. This terminology is a very important to understand the rest of the things afferent, efferent, afferent is going from receptors to CNS. Efferent is from, CNS to the effectors and then monosynaptic and polysynaptics. Monosynaptic is one and, single motor neuron, which is a reflexive actions. Polysynaptics is usually multiple motor neurons in may be inhibitory or in intrafusal extrafusal. Intrafusal is the muscle embedded inside. The muscle extrafusal is the outside muscle and then we saw kinesthesia and the proprioceptions.

Now, let us see, how this intrafusal muscle is helping to, helping to get the, the length sensed.

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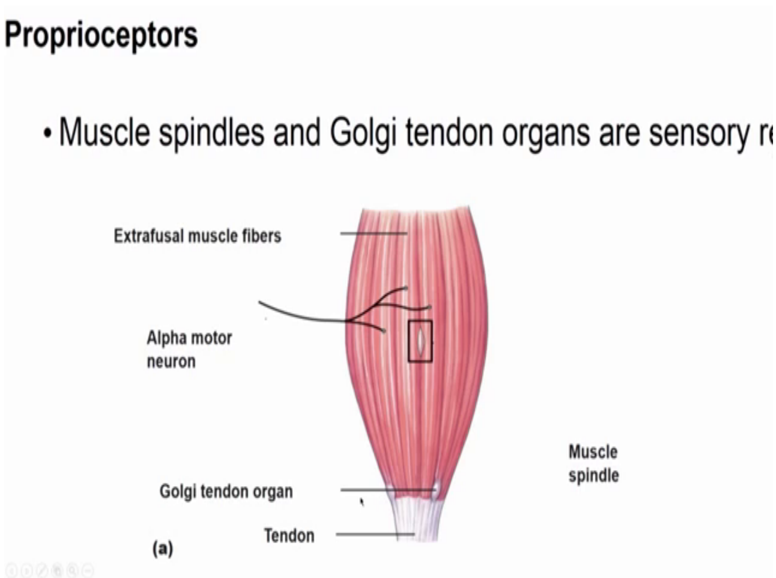

So, this muscle, what you are seeing is the, the extrafusal muscle, inside. You can see the small, rectangle drawn over here, you can see the small muscle in there, shown in white, that itself is a muscle and it is a different muscles. There are different kinds of the muscles, which we will see it, later you will not see the different kinds of muscles in this, course in detail whereas, in the biomechanics course. We study the different type of the muscles, in detail, but we will just, you know, quickly overview different kinds of muscle.

So, inside the muscle, it is a intrafusal muscle that is going to act as a sensor for us and that is measuring the length whereas, whereas, another organ, you can see that this is the, Golgi tendon organ, is called the GTO, that is measuring the force, the tension, which is felt by the muscle. Whereas, this, muscle spindle, which is highlighted in a rectangle that is measuring the length. How it is measuring the length, how Golgi tendon organ is measuring the, force is what we are going to see.

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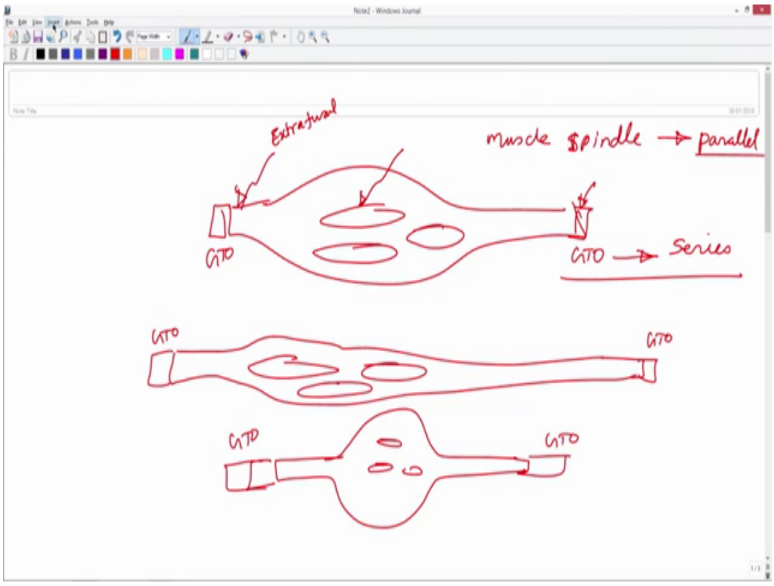

Now, let us say, that I have, this is a muscle, our, spindle organ. This is called the muscle spindle right. Muscle spindle is embedded in the bigger muscle, this is the (Refer Time: 11:00) extrafusal muscle, fusal muscle and this is the spindle organ, which is itself is a intrafusal muscle, we saw.

So, this muscle spindle, there may be more than you know one spindle, in the, in the muscle here, at the end. This is v Golgi tendon organ, this also, this side also. So, you know that tendon is what is connecting, the muscle to the bone ok, in between the bone and muscle. This is the GTO, which is connected. This is measuring the tension.

If you see this, muscle spindle are connected to the muscle in parallel whereas, GTO is connected to the muscle in series ok. So, when the muscle is elongated. Let us say, I am, let us say, this is a elongated muscle. You can see that this, spindle organs also gets elongated ok.

So, in a parallel arrangement, when the muscle is getting elongated, the spindle also get elongated. Whereas, the, the GTO, GTO gets shrunken whereas, when the muscles get shrunken, the same muscle whereas, the GTO gets elongated. So, you can see that in this, the GTO, which is in series, gets opposite of what the muscle is actually doing. The GTO gets elongated when the muscle is shrinking, shrinking whereas, the muscle spindle get say elongated, when the, main muscle is a elongating.

This arrangement is again is very important. I am going to show you, how it is now, how is this muscle spindle helping is to, measure the length.

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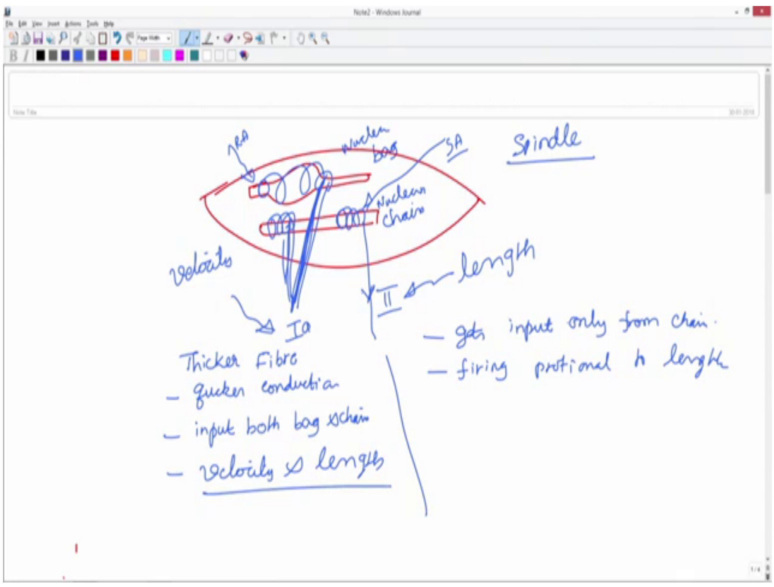

So, I am going to focus only on the muscle spindle. This is a muscle spindle alone, which is embedded in the mains, main inside the muscle spindle. There are two, organs. This is called the again, let me put a oops, oh yea, this color is there, ye, ye.

So, this is, the muscle spindle has bag, nuclear bag it is called. This is the nuclear chain, nuclear bag, nuclear chain and, the nuclear bag. Let us say this; nuclear chain is connected to the CNS. This is the afferent is not it; afferent it is a one particular type of, fiber called 2, and the nuclear, chain also. Nuclear bag also is connected to a ok, nuclear bag that is also a, is connected to, it is called the 1 a. The 1 a, which is, slightly thicker, I am going to write it as thicker one and there is also connection from the nuclear bag.

So, 1 a has connection from, this is thicker actually first of all thicker or, tickle thicker, fiber nerve, fiber thicker nuve. Nerve fiber means quicker conduction, conduction when compared to the number 2 two type of, nerve fiber. So, this one a gets input from input, from both bag and chain, bag and chain and whereas, the two gets input, input only from, only from chain.

So, this nuclear bag and the nuclear chain, these are all receptors like, just like the receptors, what we have seen in the tactile like pacinian or ruffini? Four type of, receptors we have seen. So, this is again like a receptors, the nuclear chain is like a you know rapidly adapting receptors ok. So, I am going to say this is a, where is this one, the nuclear chain is like a.

Student: Slow.

Slow adaptive receptor. As you know the, rapidly adaptive, receptors, they will, they will, give input or, they will give neural firing only. When there is a change right, whereas, the slow adaptive will give firing, firing proportional to.

Student: (Refer Time: 17:25).

Proportional to, length. So, even if it is constant. It will continue firing whereas, nuclear bag will fire only, when there is a change and when there is no change, it will not fire there is a you know rapidly adaptive, receptors.

We have seen earlier, but if you look at this 1 a, which is getting input from both a bag as well as the chain. So, suppose, if you measure this as a, if you take this as a length measure, this can be considered as measuring the velocity.

So, the nuclear chain and bag together measures, the velocity of the, the stretch. So, the spindle itself, spindle measures, not only velocity, not only length, but also velocity that is a you know take home message. I am driving it. Let me write it as velocity and length, it is what measuring it. These are all going to the CNS.

Now, the question is why does it require velocity and length, why not just a length is good enough ok, that we will take it up later. Now, we will finish off, how it is actually measuring it. So, I hope, this spot muscle, spindle is, is, is clear. Let me go to the other part of the muscle. It is here in this slide, I want you to be now, familiar with all the terminologies used extrafusal muscle fibers right. Alpha motor neuron, alpha motor neuron and is the motor neuron coming from the motor neuron.

So, essentially, let me go back ok. This motor neurons can be alpha motor neuron or gamma motor neuron or we are going to talk about two different things. I will, explain in, why we need a gamma motor neuron and in a few moment ok. Golgi tendon organs, you have seen it.

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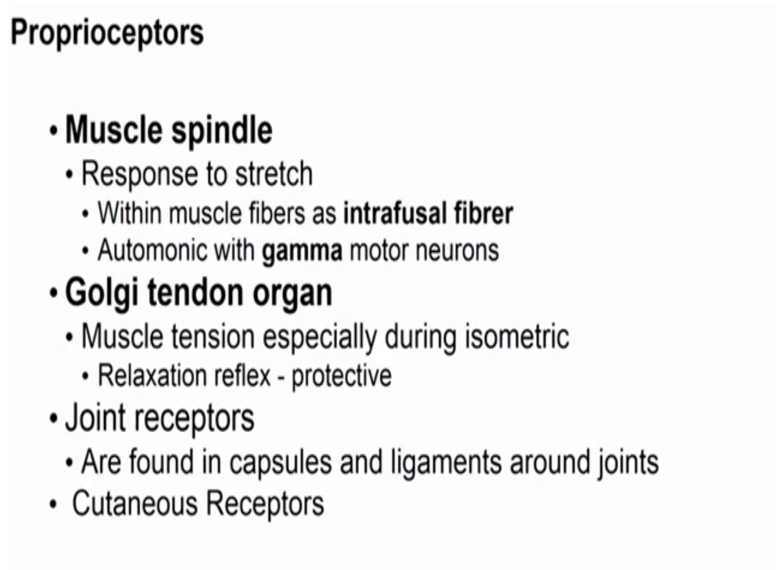

So, the proprioceptors or the kinesthesia is coming from the response to their, Muscle spindles, Golgi tendon organs and there are joint receptors also. There are joint receptors as, which are found in the ligaments and the capsule; capsule salts all the, the membranes, which is around the joints, around the joints and then couturiers receptors. So, the tactile receptors, which we have studied earlier, that also gives input to the proprioception ok. Do you remember which receptor is responsible for stretch?

Student: Pacinian.

Not pacinian ruffini, ruffini endings are actually you know responsible for stretch. So, when you move the hands, the skin, some part of the skin is getting stretched and that could be actually, you know useful for our proprioception ok. So, not only muscle spindle, but also, Golgi tendon organs and the joint receptors cutaneous, receptor, receptors ok.

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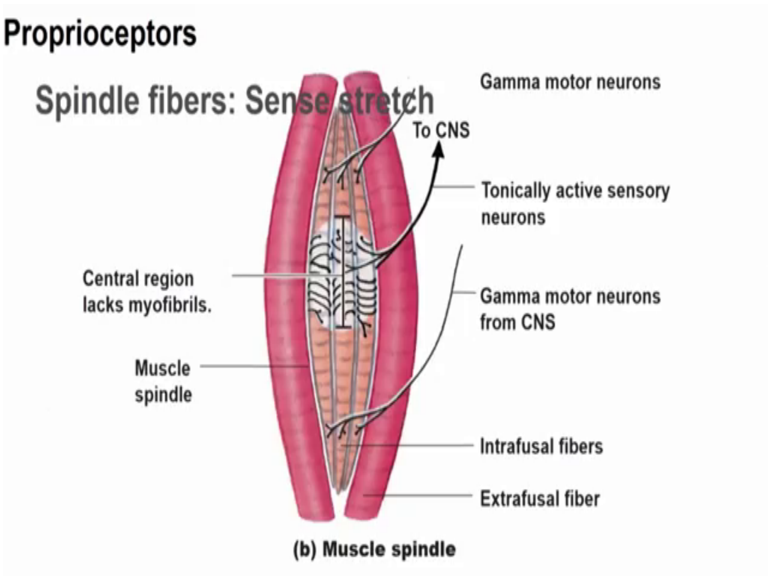

So, this is a spindle organs. We are looking at, ye.

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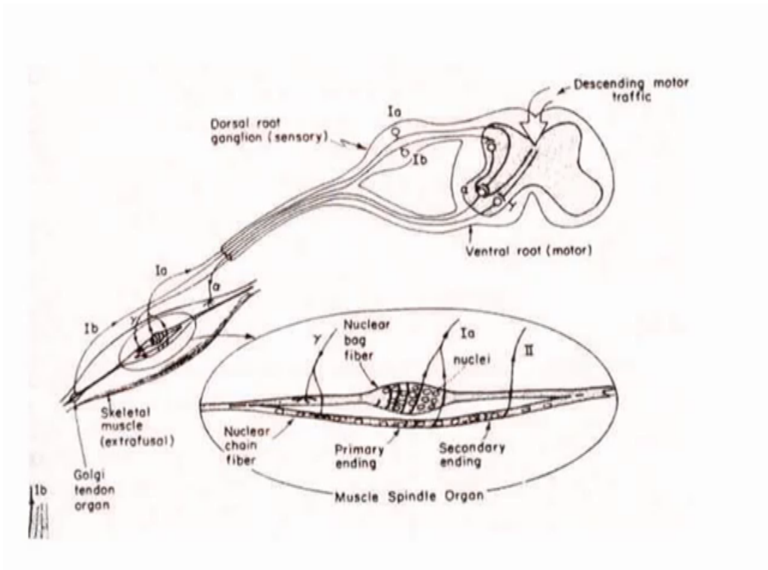

Intrafusal muscles I am going to, yes. So, in this picture, this is a muscle. We are talking about, let me ye. So, it can, you see the mouse cursor movie. Ye, this is a muscle, we are talking about in this, there is a, spindle and that in the spindle. You can see that, there is a nuclear bag and then nuclear chain, nuclear bag and nuclear chain. You can see that, it is a 1 a, is coming out 1 a is going to the CNS that is a afferent, 1 a is afferent, which is coming from both nuclear chain and the nuclear bag whereas, 2 ok.

So, this is actually, zoomed in over here in the zoomed version, you can see that this is a nuclear bag and this is a nuclear chain and 1 a is coming from both, nuclear bag and nuclear chain. 2 is coming from only the nuclear chain and here, you can see that there are monosynaptic, motor neurons, there are polysynaptic motor neurons and this is a Golgi tendon, organ from Golgi tendon organ that is 1 b going, that is again 1 b is a, naming of the, the fiber nerves, nerves fiber, depending upon the size, depending upon how fast it can conduct the, the signals. It is all named 1 a 1 b right and this alpha is coming from motor neuron, which is the afferent. Afferent is, is stimulating the, the extrafusal muscles and this is gamma, the gamma stimulating this. The nuclear bag and nuclear chain, I told you that these sensors themselves are made up of muscles right.

So, the muscle means, we can stimulate it and then we can contract it, why do we need to contract? I will tell you where, it is needed, but you can imagine that there is a requirement and, that is coming as a gamma and this is a alpha. This is a gamma. Similarly, the, the, the motor neurons can be either for alpha or gamma ok. There is a recovery. Now, let me go back and then, emphasis on why we need a gamma.

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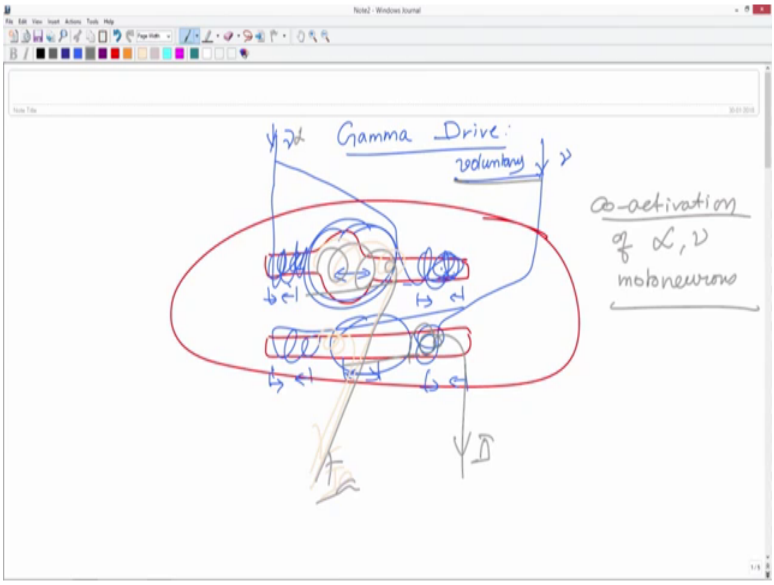

It is called the gamma drive. So, now let me again draw this, nuclear bag and nuclear chain. Let us say, this is a whole spindle, we are talking about. So, the gamma drive, it is coming to. So, the only the end of the nuclear bag and the nuclear chain or muscles, the, the center is the receptor.

So, this is a gamma drive, we are talking about, gamma is coming. Similarly, here also and, this also gamma so, what happens when you, when you stimulate the muscle? It contracts correct. So, this part of the muscle alone is going to contract. Similarly, this part of the muscle alone is going to contract. When this contracts, what happen? This center part is going to stretch, is not it. So, it going to stretch it; stretch means the receptor is increasing it is firing, because the length is increasing right.

Similarly, this also is going to contract, and this also is going to contract, and the center part alone is going to elongate. It means, it is again, it is going to increase the length. So, what happens is, the. Let me go back to the initial one. Let us take this picture. So, when there is a length change immediately, this muscle spindles are going to start firing and immediately, this is a motor, neurons are going to ask the muscle to, to relax or whatever it is.

Suppose, if you want to maintain the position, what will happen or if you want to, if there is a disturbance, this is a position of the hand. There is a disturbance of the position; some object has fallen in it. Immediately, the muscle has to act. How does, what is happened? Because the length of the muscle is changing, the spindle sensing information to the motor neuron and the motor neuron immediately asked to, you know contract then it comes back to the initial position.

This is called the stretch reflex, stretch reflex. There is automatic, it is a monosynaptic, that is a shortest, you know reaction, possible reflex is something you know that is fastest possible right.

Now, suppose, we want to voluntarily stretch your hand, what happens the muscle spindle again, is going to happen. It is going to increase, you are going to say this way, you are going to stretch it. This way you are going to stretch it. So, the muscle spindle is increasing in it is length, when it is increasing in the length again, this motor neuron is going to fire it and then it is going to ask the muscle to contract it right. So, you will never be able to stretch, if this is the case, if the stretch reflex is present all the time, if the stretch reflex is present all the time, you will never be able to voluntarily move anything ok.

So, stretch reflexe is involuntary, but whenever there is a voluntary moment necessary. So, what, the, the, the technique, the nature our, brain uses is that, it, sense the, it as the, the gamma motor neuron also to send, to send signals to the intrafusal muscles ok. So, that is where we are here.

So, now the gamma motor neurons also, gamma motor drive also is working. When it is working, what happens is, this is getting stretched and this is also getting stretched ok. So, when this is getting stretched, the center part is actually maintaining it is same length, in the voluntary conditions. So, this is only for the voluntary, voluntary conditions, whenever there is a voluntary movement. This gamma drive is working, gamma, motor neuron is sending the signals to this intrafusal muscles and, this center portion is maintaining it is length.

So, there is the, the CNS does not see any change at all, any change in the muscle length. Therefore, the motor neuron alpha motor neuron is not going to fire, that is, because these are all connected. We know, we have seen that, this are all connected to, what is it? This is 1 a may be (Refer Time: 30:50) green. It is the green. This is a 1 a and, this is, are all 2 a, we have seen it, right.

So, the center portion, it is connected. All these fibers 1 a into 2 a sorry, 2. You have seen, you have, you have to observe that, this is connected to only the center of it ok, that is a receptor, main receptor, the main receptor are, will not change in case of the voluntary movement, that is, because of the gamma drive, gamma will be proportional to how much your voluntary, you want to do it. This gamma motor neuron, which is in the spinal cord, will send signal proportional to whatever is necessary to make sure, that this receptors are not firing. So, that alpha motor neuron does not fire at all ok.

So, the concept of co activation, this is called the co activation of, co activation of alpha and gamma motor neurons together. So, only with a co activation of alpha and gamma motor neurons, you can voluntarily move otherwise, you cannot move at all. The stretch reflex will be all the time there ok, that is a concept I wanted, you take ok.

Now, let us look at this picture again, you can see that this is the gamma, can you see this ok. You can see that, this is a gamma drive coming up ok, that is to the end of the nuclear bag and nuclear chain and, this is a 1 a afferent. There is also, dorsal root ganglion, which is over here, this we have seen in the last class and then, from the brain cortex.

There is a descending motor traffic, which is coming over here, but this is the, this is the alpha motor neuron over here. This is a monosynaptic, this is a polysynaptic, this is a gamma motor neuron, this is a ventral root. There is the, there is the, dorsal root is this picture clear right? We will move on to the next one.

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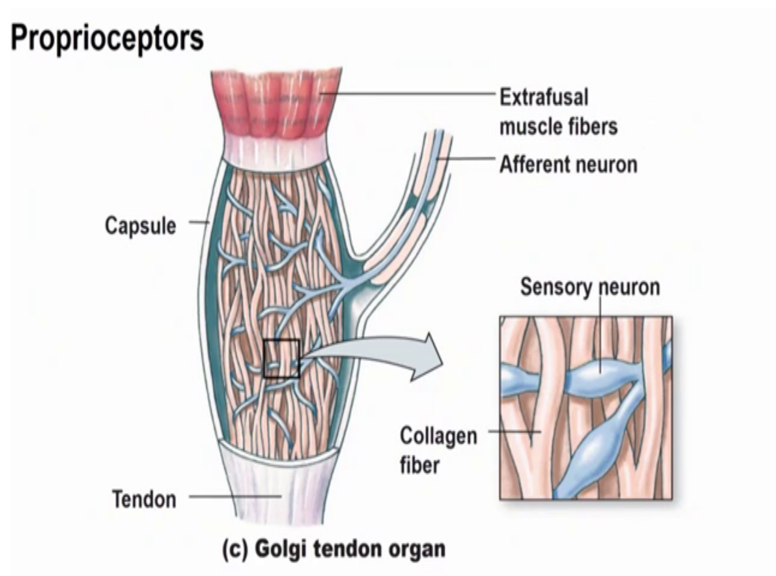

Now, Golgi tendon organs let us look at the Golgi tendon organs in little detail. So, tendons are very, tough fibers right, in the inside, the fibers ok. There are afferent neurons, which is embedded over here. So, these fibers are made up of collagen fibers, which are very-very tough over here. So, you can see that the blue color or these sensory neurons.

So, when the, the organ is getting stretched you can see that the sensory neurons are getting compressed, depending upon how much it is compressed, it will send outs, the, send out the, the firings that will be a measure of, how much force the, the muscle is actually experiencing or applying.

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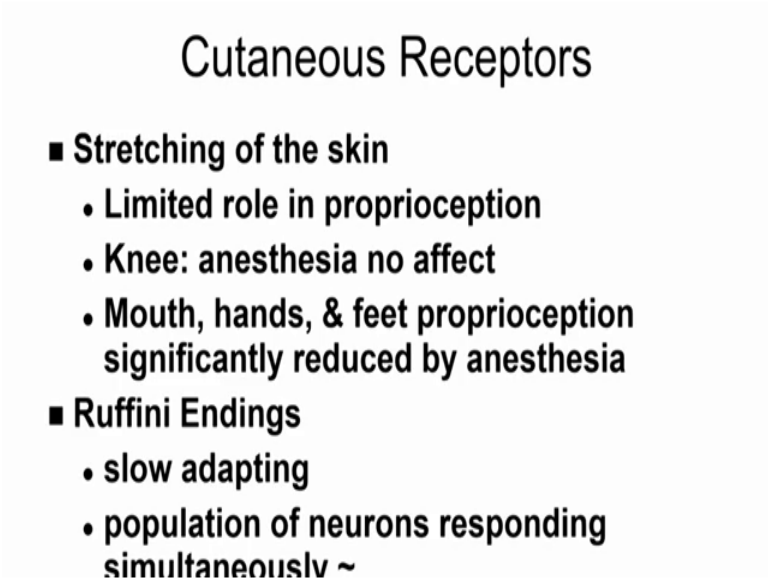

So, spindle we have seen, Golgi tendon organs we, we have seen cutaneous receptor also is going, is contributing to the, proprioception. We have seen stretching of the skin limited role in, proprioception of their main role is tactile sensation, but it has some secondary role in proprioception also, also knee kinesthesia, you know effect at all mouth, hands and feet proprioception, significantly reduced by kinesthesia.

Whereas, in the knee, kinesthesia does not have any effect at all whereas, in the mouth, hand and foot at, when, when you have kinesthesia, anesthesia, the proprioception significantly reduced. It means and there are joints and, or cutaneous receptors, which is contributing to the proprioception significantly.

Ruffini endings since, we, they are slow adaptive population of the neurons responding simultaneously, that has very significant input to the cutaneous receptors. So, let me ok.

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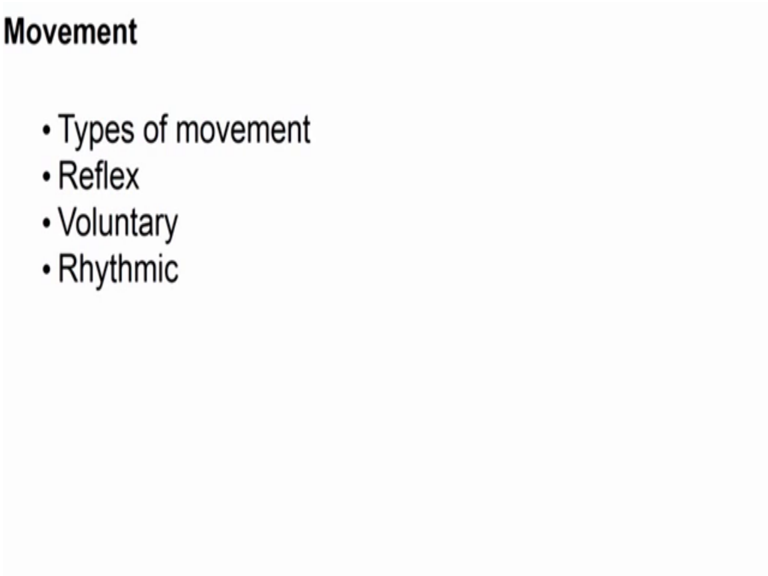

So, I will, the next class, we will, we will talk about the, what are the different type of the moments and, how kinesthesia, basically we are going to talk about the, some psychophysical measurement of kinesthesia. There are more concepts such, as the, such as the you know motor units and all the things, we will see in the next class.

Now, I will take questions from, um, today's class, if you have any questions, I will discuss ye.

Student: (Refer Time: 36:38) Golgi tendon organs measuring force. How it is measuring (Refer Time: 36:41).

How is it measuring force? So, you can see that, there are collagen fibers, basically tendon is nothing, but, fibers tough, fibers, they are fibers, are made up of the collagen fibers. So, this, sensory neurons, there are inter intervened with a fibers.

So, when there is a tension, all the fibers are compressing, this sensory neurons, so depending upon the tension, this fibers are compressing the sensory neurons ok. So, the sensory neurons fires depending upon how much the fibers are compressing it. There is a way; it is measuring the force, any other doubts.

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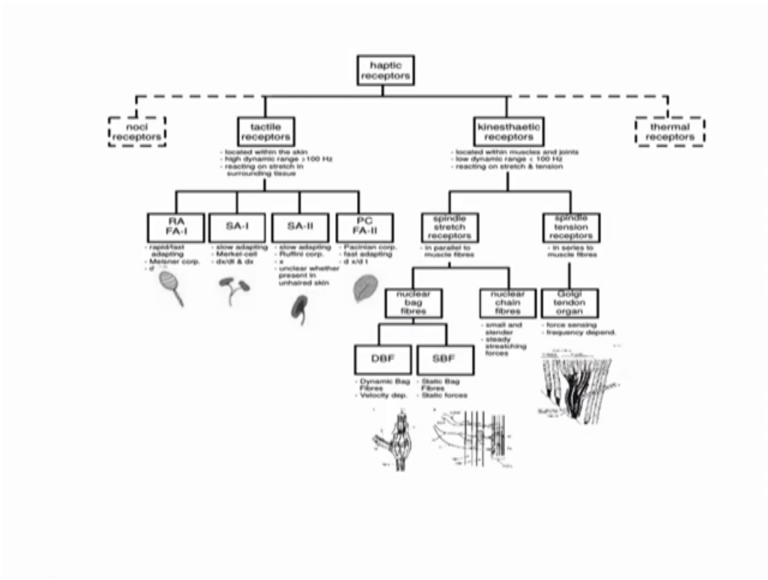

Let us go back to the first one. Now, the kinesthetic receptor, let us look at it, spindle stretch receptors, we have looked at in some details, spindle tension receptors there is nothing, but the, you know collagen tendon receptors. So, nuclear bag and nuclear chain fibers, we have seen it ok. So, dynamic bag fibers, static bag fibers that we have again seen it, bag has two components dynamic and.

Now, one of the questions, I asked, probably we can clarify it. Now, why do we need? Why do the muscles need length as well as the velocity? Ok. Can anybody you know guess, why you do? We need length as well as the velocity ok.

Student: Sometimes we need reflexes.

Sometimes, we need refluxes.

Student: To go to one portion, to another portion, we need not (Refer Time: 38:41) only and we need velocity also to go to that another portion

Yea, (Refer Time: 38:46) velocity also right so.

Student: Sir.

Yea, the, the answer is this, if you want, if you do not want to overshoot it, if you take a very, any control systems ok. I want to move from this point to this point, but I can move it without overshooting it. See, if you have only, you know length based control then what happens? It is going to slightly overshoot it and then finally, I will settle at the point, but that is not happening in their hands, when we have the velocity without overshooting, we can go there to the final point. This is called the, you know, pid controller, you have all seen it right.

Here, we are talking about a, you know proportional to the length as well as the, the derivative of the length. So, proportional plus derive, derivative is a concept, proportional to a proportional plus derivative.

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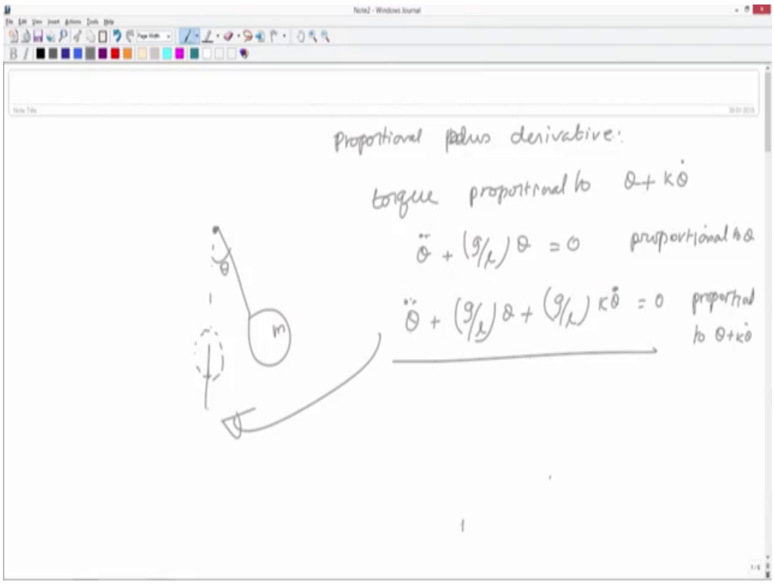

So, I can explain, this is in a, simple example, let us take, one pendulum. Let us say the pendulum has, m over here and that is at theta and it wants, it has to come to the resting position without overshooting. Suppose, if we have, a you know torque, at this point, which is proportional to the theta, then it will overshoot, if there is no damping, it will, infinitely overshoot. I mean, it will oscillate it, if there is a damping then there will be you know damped oscillation and finally, it will settle there.

But instead of, yeah torque proportional to, to know theta plus some constant times, theta dot, then we can show that this is actually settled without overshooting. You know there is, our simple, pendulum equation is theta dot, theta double dot plus g by l into theta is equal to 0 that is without the proportional whereas, here this is with, proportional to theta torque proportional restoring, torque proportional to theta alone.

So, the same equation, we can write theta dot plus g by l theta plus g by l K times theta dot. We can show that in case of the proportional to theta plus, K times theta dot. So, this equation will, will make you, make sure that it settles without overshooting and this is what our muscles are using it, for this we need the velocity also. So, theta dot is nothing, but c sorry. Here, it is only the theta dot, we need the velocity also.