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

Lecture – 21
Motor Units – PIC & EMG

Welcome to this class on Neuroscience of Human Movement course. So, this is on persistent inward currents and a EMG as part of the motor units topic. So, we have been seeing motor units, so what is a motor unit a motor unit is basically a motor neuron and all the muscle fibers associated with it and we said: the higher the input to this motor unit, the motor neuron the higher the input it receives the higher is going to be the force.

Actually it turns out that it is a linear relationship.

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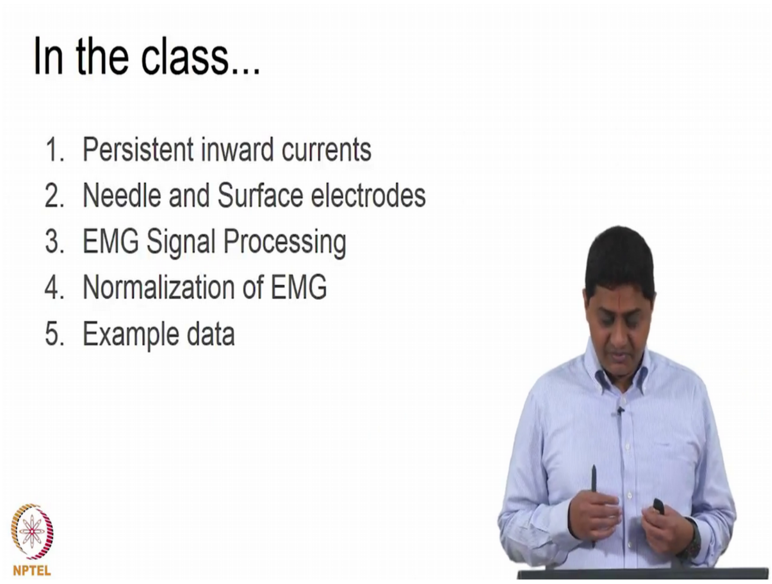

In what condition we mentioned that that there is a joker in the pack, there are other things in consider in that needs to be taken into consideration. And we said that that is a persistent inward current. So, in this class we will talk about the importance of Persistent inward currents and EMG; the difference between Needle and Surface electrodes in EMG, how to process a EMG, and how to Normalize EMG data, and some details some discussion of Example data.

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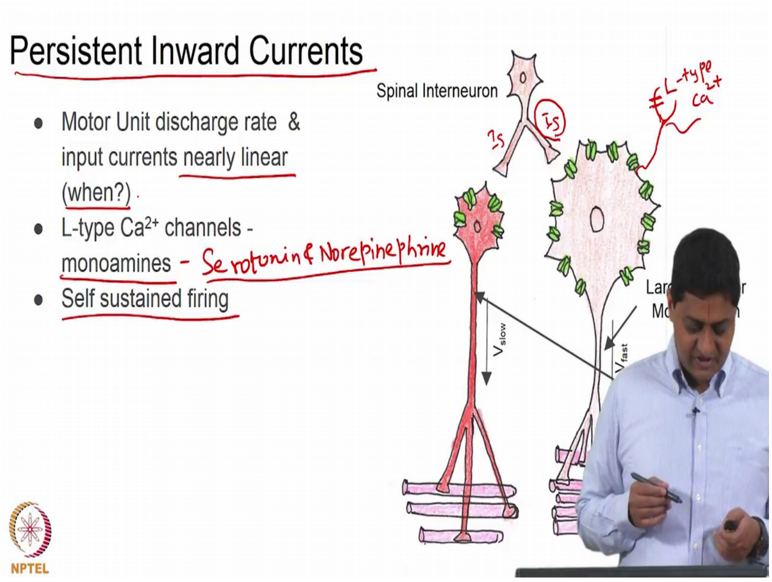

We said yesterday that motor unit discharge rate and input currents. So, we said that there is a synaptic current that is depolarizing that is attempting to depolarize the motor neurons; and we use this picture actually for size principle illustration of size principle, we will continue in the same picture does not really matter.

So, suppose the synaptic current is attempting to depolarize 2 motor neurons, it turns out that as the current increases the discharge rate of this motor neuron also increases. So, in other words; and actually that is a nearly linear relationship, as I keep increasing not only as I keep increasing the current not only does the discharge rate increase it is also a linear over a relatively wide range, so it is also approximately linear over a relatively wide range.

But when this is true? This is true in the absence of any other inputs; if the synaptic current is the only input under consideration, then this relationship is approximately a linear over a wide range. But it turns out that there are other things, suppose there is a dendrite on this motor neuron and called this dendrite and this dendrite has a special channel to call this channel as L type calcium channel. This channel is capable of firing in response to the presence of monoamines. What are these monoamines? These monoamines and the discussion are serotonin and norepinephrine epinephrine these monoamines come from the brainstem. So, these monoamines when they are present on this when they when they arrive and influence the L type calcium channel are. These calcium channels open causing a large influx of calcium causing an inward current. What we said long time ago in one of the early classes that the inward current is the influx of cations into the cell are the out flux of a anions right.

So, calcium is a cation and this inward current causes firing that is known to sustain for relatively long periods, this firing is called as self sustained firing and this inward current is called as Persistent inward current. Persistent inward current is this response of these motor neurons to the presence to the arrival to the in influence of monoamine serotonin and norepinephrine through L type calcium channels. So, this L type calcium channels allow a large influx of calcium and causing a relatively large inward current. And this inward current is large enough to let the firing continue or sustain even after an input is received even after an input is removed. So, this synaptic current alone produces some output, if monoamines are present the output due to this synaptic current is going to be greater.

So, in a way what this does what this Monoaminergic input this Monoaminergic input comes from the brain step. So, what this mono aminergic input from the brain brainstem does is to provide some sort of a tuner; so I am able to control the gain of the firing. So, this is linear over a relatively wide range when there is no Monoaminergic input, but in the presence of Monoaminergic input the response of the system are the discharge rate for a given for the same input current the response becomes non-linear. So earlier what was a simple and straightforward now has been complicated by the presence of this Monoaminergic input.

So, this what would be the purpose of such a process consider the situation when for example I am just standing, I am standing a maintaining posture for this purpose what you need is relatively sustained firing of motor neurons and the sustained contractions in the muscle for relatively long period. For example: this class may last up to 40 minutes or 50 minutes, I am going to be standing for about 40 to 50 minutes. So, that is a relatively long period in neuronal terms we are talking about you know a very long period in neuronal terms.

So, we need to keep the force sustained for a relatively long period and we said what type of motor neurons are suitable for this; what type of motor units are suitable for this the slow motor units, the small motor units are suitable to produce sustained low force levels for relatively long periods of time is it not. These are these can be activated by these monoamines and to keep the postural system produce sustained amount of force for relatively long period of time ok, so this is a one this could be one purpose of the persistent inward currents.

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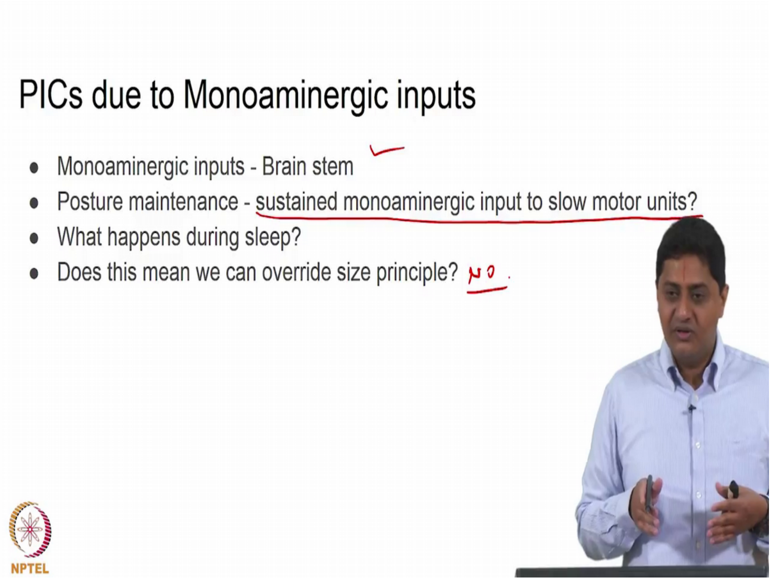

So, we said that the Monoaminergic input comes from the brain stem and posture maintenance is due to sustained Monoaminergic, this is believed again you know that is the reason. I have put a question mark here one way in which I could maintain posture is by sustaining a Monoaminergic input to slow motor units, this is believed to be the probable method mechanism by which posture is maintained and then what happens during sleep, suppose you go to sleep what you see is that you know these posture maintenance mechanisms are withdrawn.

So, this Monoaminergic input to the posture maintaining muscles is withdrawn temporarily until you wake up from sleep it is. So, during sleep there is a temporary switching off of this of this persistent inward currents or the Monoaminergic system. So, that you know the person can sleep in relaxed you know with relaxed muscles relaxed body is it not.

A question is does this mean that I can override size principle, I said that by increasing in the earlier slide I said by having the L type calcium channels and Monoaminergic input and a invert current. I could increase the force for a given synaptic current does that mean that I could override the size principle. In other words can a small motor unit produced can a larger motor unit be recruited first and the smaller motor unit recruited later is that a possibility that is the question the answer is no why not.

Because it turns out that I it turns out that even with Monoaminergic input, it is the slower motor units it is a smaller motor units that are getting recruited first and then the larger motor units and then the faster motor units. So, this means that a size principle continues to be relatively universal principle that guides this process more than the so and so that means Monoaminergic inputs are only a tuning knob where I can change the gain of the system. I can change the gain or specifically more specifically I can change the excitability of the motor neuronal pool.

So, the greater the Monoaminergic input the more is the probability that a given motor neuronal pool is going to go to depolarization or the easier it is going to be for me to take a particular neuron in that motor neuronal pool to depolarization to threshold and to action potential. Let us remember note I am talking about taking the motor units to depolarization and action threshold an action potential no at every time this motor neuron is firing the fiber does not have the choice of not firing.

Here I am talking about whether a motor neuron can fire or not, so the motor neuron has the choice or the motor neuron can produce graded potentials and action potentials. Whereas, a every time there is an action potential in the motor neuron the muscle fiber must fire we said that that relationship is obligatory. Here I am not talking about muscle fiber but rather about the motor neuron I am talking about the neuron ok. So, we cannot overwrite the size principle let us also remember that the size principle is actually a coordinative rule and not a prescribing rule I we said that earlier.

Suppose there were like 5 or 6 motor units of the same size and I need only one of them to be recruited, the system does not choose which exact point to be recruited. So, it is not a prescribing rule size principal does not choose which 1 of the 5, because all of them are equal in size right. Which 1 of the 5 do I recruit that prescription does not come from size principle, but rather a coordinative rule in comparison with the larger motor units motor units of this size are preferred at this point in time. So, it is a coordinative rule in that sense ok, this is one effect of Monoaminergic input.

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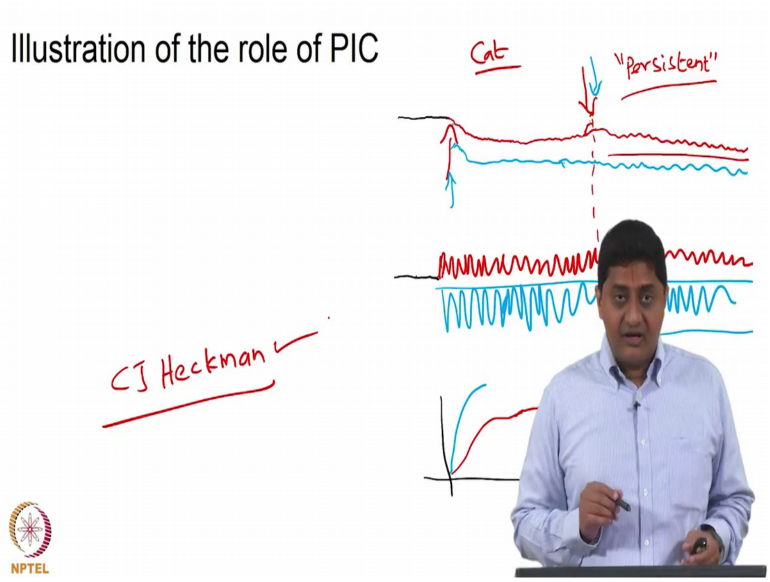

So, what would happen illustration um? Suppose let us take a few case and let us take a couple of cases when the Monoaminergic input is relatively small and the Monoaminergic input is relatively large and see what would be the difference that would be observed ok. Let us I am going to draw the slow ones the slow case first with red color ok.

So, suppose there is we will start with the normal case and there is no Monoaminergic input, there is no Monoaminergic input the response is like this is the current and then a Monoaminergic input of relatively small amplitude is present say for example ok. So, some Monoaminergic input is present something is present and it is withdrawn.

By the way how do I take the system back to the original case, inhibitory mechanisms come into the picture to take the system back to the original resting state ok. So, suppose the input is withdrawn, And what this does is that a sustained tailed current is produced for a relatively long period of time it does not go back to 0, immediately it takes a relatively long time. We said persistent inward current right this is the persistence part of the persistent inward current.

Even after removal of the Monoaminergic input the current, so here Monoaminergic input is withdrawn here it is introduced even after the Monoaminergic input is withdrawn, the current does not go back to 0, but rather sustains at a at some value right. Suppose and what happens to the firing rate what happens to the firing rate, here there was no firing I am going to draw that in black initially when there was no input there was no firing it was like this and in the presence of Monoaminergic input just after the Monoaminergic input comes that is you know sustained firing and this continues.

So, here is when here is the time when the Monoaminergic input is withdrawn, but the cell the discharge rate of the cell does not go back to 0 immediately after the input is withdrawn this continues for sometime. We said that this is you know persistent inward current this is the persistent part or we call this as a sustained firing is it not, so this is the sustenance part of the sustained firing.

Suppose I gave a greater input the current is greater or the Monoaminergic input is greater suppose it is like this, I am using a darker blue I will use a different blue ok. Suppose the input is so much I am giving at approximately the same time a different input and I am removing at approximately the same time a relatively larger input right. Then what this does also this also produces a tail current that is going to continue for a relatively long period and the response. Again I am drawing it here in the bottom below this line and the response continues or maybe with the higher frequency. And again sustains for a relatively long period, even after the removal the removal is happening at this point. But even after the removal of the Monoaminergic input the output the discharge rate continues at an elevated level.

So, once again so if you want to keep if you want to you know make the system respond to a relatively small current and keep it sustained for a relatively long period of time that is going to be possible by tuning this Monoaminergic input. If I keep the Monoaminergic input relatively high this is going to continue for a relatively long period of time and the other things.

So, suppose I was suppose we were what this means is that the force levels how would the response be for the force levels under consideration. Suppose I am doing I am using the small Monoaminergic input suppose that was the level that was there developed that was a force level that was developed. For the same conditions with the higher input the forces force develop is going to look like this, meaning that you know I am going to be able to develop a relatively large amount of force and relatively smaller period of time with the Monoaminergic input.

So, this means we could this has profound very deep influence on how force can be controlled how firing rate of motor neurons can be controlled. So, the relationships between synaptic current and discharge rate synaptic current and recruitment that we saw earlier using size principle and rate coding is taken for a task, is taken for taken to a one level one notch higher because of this influence. Because, of the influence of brain stem in controlling so the brain stem is responsible for controlling these Monoaminergic input, what are these monoamines serotonin and norepinephrine is it not.

So, with this topic is relatively broad and relatively deep there is insufficient time to discuss this. So, those who are interested can go through the work of Professor CJ Heckman of northwestern university US ok. Professor CJ Heckman there is a very nice review people where he talks about the role of persistent inward currents and a how they originate, what are the various things this could do by the way these are data, these are actually representations of a real data from cat from these are animal data real data. So, it is not you know simulations or this is actually observed experimental data from the cats leg muscle I suppose. So, those who are interested can go through the work of professor CJ ok.

So, with this we finished the topic of persistent inward current and we move on to the next topic which is Electromyography or a Electromyogram.

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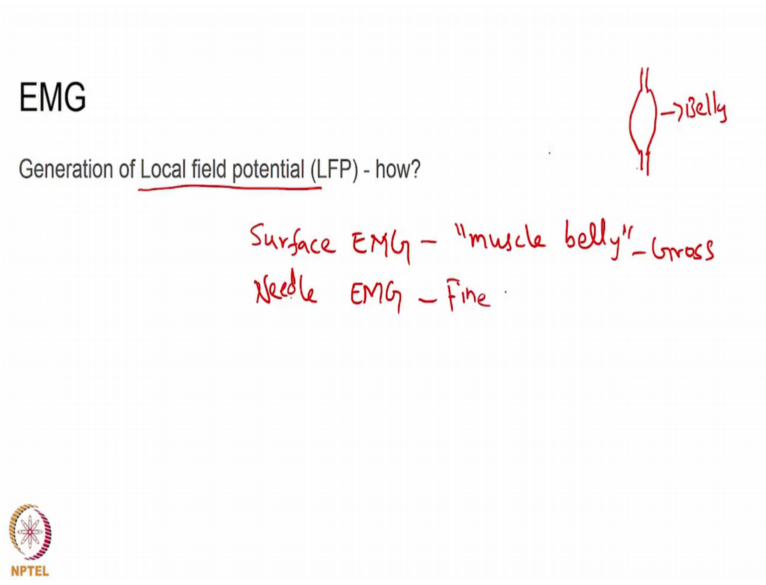

What happens when there are when a motor neuron fires when a motor neuron is activated when it produces an action potential, it causes action potential in all the muscle fibers innervated by it at approximately the same time. So, this may be about 50 or 5 or 10 or a different number of muscle fibers may be innovated by this motor neuron. So, all the fibers go to threshold at a approximately the same time causing a local field potential, this local field potential is sometimes actually in large muscles large and a superficial muscles. Superficial means those that are closer to the surface of the skin right large superficial muscles this local field potential is absorbable using a electrodes that are placed on the skin.

So, I can place electrodes on top of the skin and measure these local field potentials ok. So, when I place these electrodes on the surface of the skin we and measure the muscle activity what we are doing is a method called surface EMG also called as interferential EMG. So, this is surface EMG or another method that is used is suppose I am interested not in observing activities of multiple motor units, but rather I am interested in observing the fine activity of just a few motor units and even 1 motor unit at a time is it possible for me to do that.

Technology is available to do this so what we do is we insert a needle, so whenever we say that we insert a needle we are talking about an invasive procedure. So, we are actually taking a person or an animal and inserting something into the body is it not. So, we insert a needle into the muscle of interest and this needle contains a very fine wire that is electrically isolated from it. So, inside the needle there is a wire that is passing through and that wire is isolated electrically from it is from the needle itself and when it is placed inside at the tip of the wire the tip of the wire alone is not isolated.

So, the difference in potential between the needle and the tip of the wire is measured as a potential difference through the regular measurement techniques right and this can represent activity of a few 4 5 or sometimes as much as 10. But preferably a smaller number of a motor unit giving fine information that is not observable from surface EMG. So, this method is called as needle EMG, are also called as fine wire EMG; I am going to call this as surface EMG and needle EMG for the rest of the class needle EMG ok.

This is also called as fine wire EMG there are details that vary there are several variants that have different names and the details vary, but we will call this as surface EMG and needle EMG. A question is how do we measure surface EMG how do you know several questions arise, how do you know where to place the electrode um. The answer is you usually know what muscle is responsible for a particular you know mechanical action. So, when I am performing a particular action you already know what muscle is responsible for that you should know and you know the approximate location of this muscle on the person's body approximate location.

You can place the electrode on what is called as the muscle belly, so you want to place the electrode on the muscle belly. What do I mean by muscle belly muscle? Belly is that part of the muscle that that is laying between 2 tendons basically a muscle attaches muscle is attached between 2 bones through tendons is it not, that part of the muscle that is not a tendon that is not attached to the tendon is the belly. So, suppose I have a tendon like that and I have a muscle like that and the other tendon is here this is belly, it is not clear where the muscle belly is located for a different muscles in different people.

So, sometimes it requires some amount of a trial and error you need to keep moving the electrode while performing the same action you need to keep moving the electrode to different points in the body. Wherever you are getting the maximum amplitude of or the maximum response that is the point where you want to keep the electrode. Usually, this is one method in which this is done there are other experimental approaches that come into this picture.

So, we want to place the electrode in the muscle belly and so what is the goal the goal is to measure the ensemble activity of a whole number of motor units. So, this may be hundred motor unit this may be several tens of motor units. So, what you are measuring in some sense is a grass you know measurement. So you are you are getting a grass idea of what the muscle itself is trying to do what the not what the motor unit is trying to do you are getting an idea of.

So, this is grass or a representation of the muscle activity whereas the needle electrode again you need to place it within the muscle belly of course not on the tendon, this represents fine measurements that may be due to a few motor units ok.

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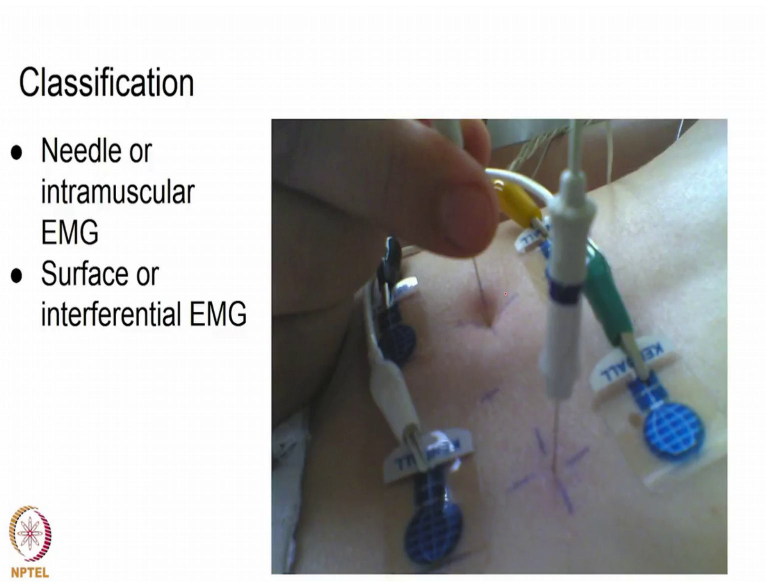

So, now what else is that so there we said that there is needle this needle EMG is also called as a Intra, Intra means within muscular. So, within the same muscle if the EMG is measured that is called intramuscular or needle EMG or surface or interferential EMG ok.

So, here there is an example of how the needles are placed let us agree that you know this is an invasive procedure, so that means there is an amount of a discomfort associated with this procedure. It is not free it is not like painless as much as the experimenters will try to tell you oh this our procedure is absolutely harmless will not you know torture you or a whatever it turns out that you know these procedures are a little oh relatively uncomfortable. Actually somewhat painful from time to time depending on the expertise of the person depending on how well who is doing the part, if the person is a novice the chances are you are going to feel a relatively large amount of pain.

So, there exists some amount of discomfort in this procedure, but why do that then there are reasons why you would want to do that that I will discuss that in the future slides. So, also that means ethical considerations come into the picture the moment you are saying you want to put something inside a person's body the ethics committee is up in arms. You want to because you see there is a local ethics committee in every institute we have a IIT madras institutional ethics committee.

So, suppose I am saying I want to measure you know needle EMG for a particular reason, immediately the ethics committee wants to know what is the big scientific achievement that you are going to make by putting people through such pain and there is some validity in that question right because, you cannot just put people through pain and get nothing out of it there must be some justification for the discomfort faced by the subjects. There must be some reasonable scientific justification for that of course and of course, you cannot keep pushing that that justification too far there must be I mean that must be really reasonable.

So, there are like 10 15 people who sit and check whether what you are doing is actually worth your way in terms of doing this. So, let us not get into that topic so there are ethical considerations when it comes to needle EMG where is this more frequently used we need to check that. So, there are these 2 differences one is surface the other is needle, what are the major differences I said that major differences is that fairly large number of group of muscle fibers not muscles fairly large group of muscle fibers ok.

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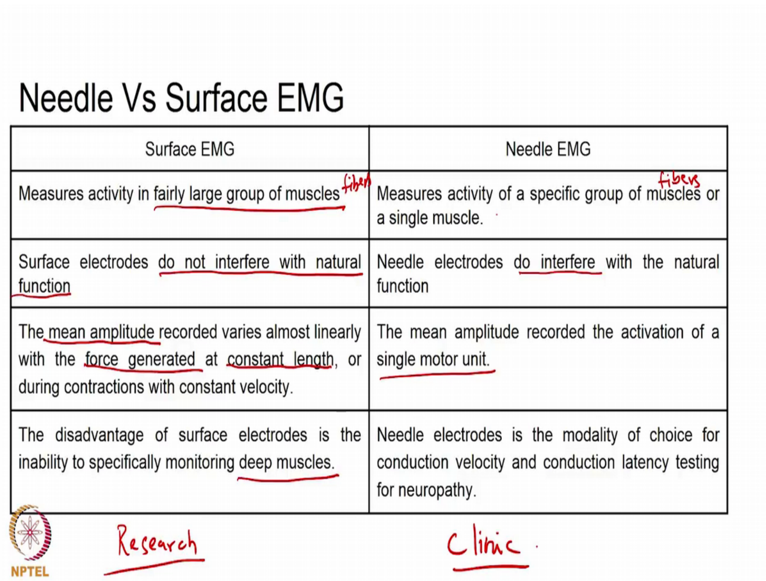

Surface EMG	Needle EMG
Measures activity in fairly large group of muscles	Measures activity of a specific group of muscles or a single muscle.
Surface electrodes do not interfere with natural function	Needle electrodes do interfere with the natural function
The mean amplitude recorded varies almost linearly with the force generated at constant length, or during contractions with constant velocity.	The mean amplitude recorded the activation of a single motor unit.
The disadvantage of surface electrodes is the inability to specifically monitoring deep muscles.	Needle electrodes is the modality of choice for conduction velocity and conduction latency testing for neuropathy.

Measures activity of a specific group of fibers or within a single muscle and in general it is believed that if you would like to measure something. You do not want to have the measuring method to interfere with the process that is being measured, is it not I am interested in understanding how movement happens I do not want to you know do something that will affect the way in which the movement itself happens.

So, in that sense surface electrodes are more suitable because they do not interfere so much or they interfere less the right we are saying this is the interfere less with the natural body movements, when compared with Needle electrodes. Needle electrodes cause sufficient pain to consider that they cause substantial interference with how you would naturally. Otherwise naturally behave, usually there is a relationship between how much activity you are measuring the mean amplitude of the EMG and what is the force that is generated by that muscle right are at constant are at either at constant length or isometric are at constant velocity.

So, the force is usually proportional to the EMG, so the greater the EMG the greater is the force that is going to be measured. Whereas, here you are talking about single or a few motor units, so this does not constitute the muscle itself and you cannot measure forces of a individual motor units you can measure forces produce by individual muscles. But not by individual motor units not in a live person, not in a live individual not in a the not in humans not so easy to do that.

The disadvantage is that what you are measuring is you cannot measure what is going on deep inside the skin. So, you are restricted to be to measuring superficial and large muscles in the case of a surface EMG. So, you cannot do deep analysis of deep muscles that is not possible because, what happens is that the muscle itself is deep above that there are other muscles above that there are above that there is a fat and above that there is a several layers of skin. Above all that you are placing the electrode above the skin you have hair and on top of that you are placing the electrode.

So, by the time the signal reaches it is sufficiently attenuated that you get no specific, you know input that concerns the that that relates the force with the actual electrical activity, what you are measuring is going to be nothing not very useful for the deep muscles. So, surface EMG has the big disadvantage and needle EMG can be used for deep you know. Since I can you know insert this deeply that is the whole purpose of having a deep the whole purpose of having needle EMG.

So, I could do that however the problem is it comes with the cost there is a there is some discomfort or pain associated with it and it turns out that the major use. Surface EMG is more frequently used in research in labs, labs like mine where we perform experiments on specific human movements. So, and it is easier to get a approval from ethics committee for surface EMG. You just have to like it is a noninvasive procedure you just have to convince the committee that it is a noninvasive procedure and you are going to ensure that the person is not going to get any form of shock.

Once they are convinced that your system is not going to shock the individual, the chances are very high that you your proposal for study research study is going to be approved by the ethics committee. Whereas, the same research if I want to perform with needle EMG chances are relatively low because, it is an invasive procedure. So, then what is the use of having this it turns out that this is more frequently used in the clinic, we are interested in studying a conduction velocities of say in health and disease.

So for example, diabetes causes you know neuropathy this causes a profound change in the connection velocity of the system, how does that affect how is that to be measured right. So, in such cases needle electrodes is the modality of choice for us, so this is more frequently used in the clinic when compared with the you know surface EMG, surface EMG is used more frequently in the lab whereas needle EMG more frequently in the clinic ok.

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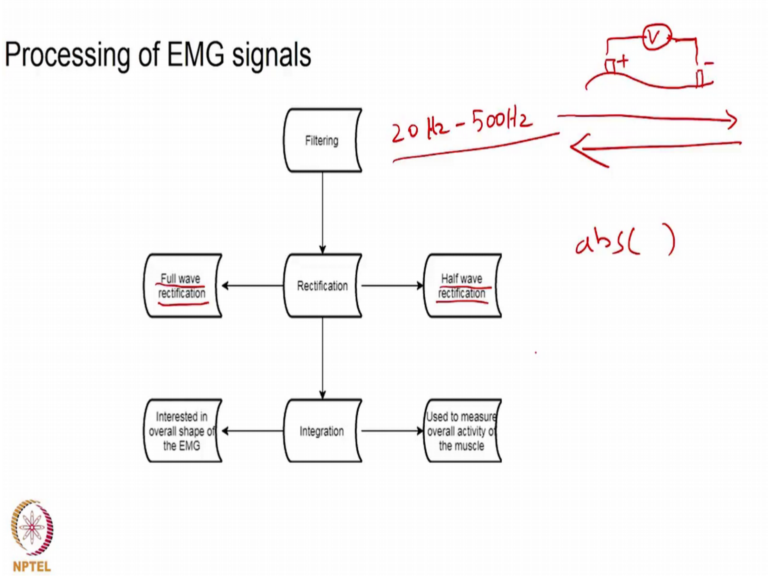

How do you process this signals first involve filtering, so it turns out that the dominant power in the EMG signals is between 20 hertz and about 500 hertz. There are some muscles it seems there are some muscles in which the dominant frequencies can be up to 1000 hertz, but usually this is between 20 hertz and 500 hertz. So, you want to filter between 20 hertz and 500 hertz and you want to rectify this it turns out that because, I am placing 2 electrodes suppose there is this suppose that is the skin surface I am placing on a electrode here and I am placing another electrode here.

The wave of depolarization is going in that direction, what you are measuring is the potential difference that is measured with some amplification right, with some amplification that is what I am measuring. You see one of them is considered plus and minus if the wave of depolarization is traveling in that direction, versus the wave of depolarization traveling in that direction the polarity of the signal is going to change. So, EMG is has components below 0, because of this reason, so it has both positive and negative components.

So, if you need to you know rectify this then that takes us to the regular electrical engineering question, whether do you want to perform full wave rectification or whether do you want to perform half wave rectification. Usually we perform full wave rectification in this case. So what that means is that all the negative components will be so it is like taking absolute of a number. So, in mat lab you would do that absolute of a number of made basically what that does all the negative numbers are made into positives, where a half wave rectification they it they make them into 0.

As the differences in terms of algorithmic approach in terms of algorithm this is how you do that and then what you do you integrate them or perform a moving average window. After that to find out how the movement itself is related right you integrate it at a integrate it. And then low pass filter rate perform an envelope detection type of analysis to find out how moment itself is related to EMG there is an example.

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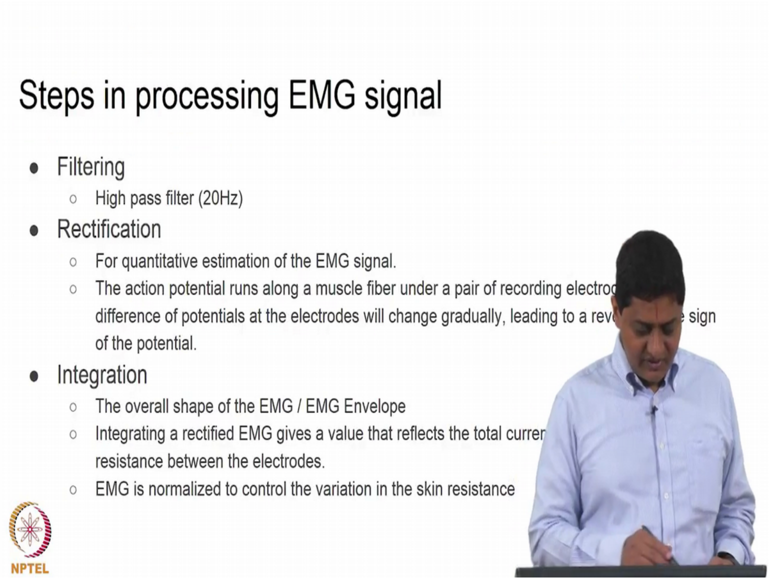

So, we have discussed these things almost all of these and as an example we will discuss in the future sets.

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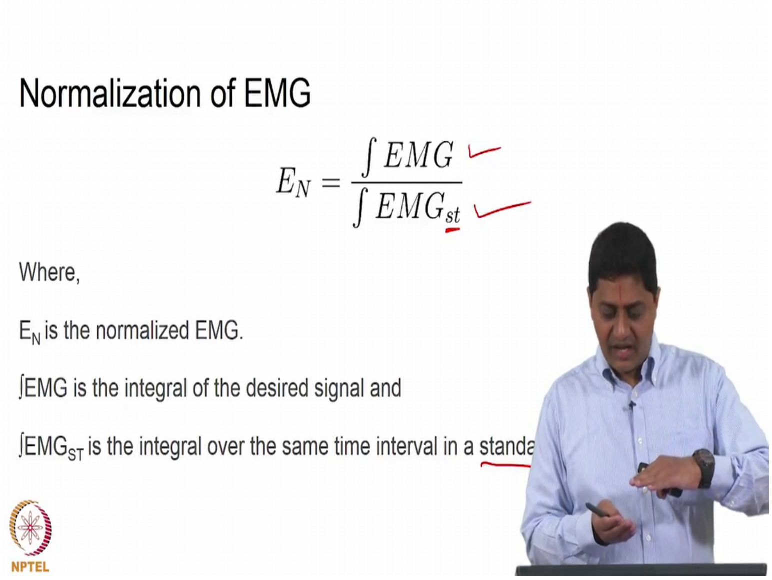

So, one particular problem is that different people produce the same force with different levels of EMG.

So, a given voltage that is not necessarily given EMG amplitude does not necessarily tell you what the force produced by that muscle is, so you cannot there is absolutely no predictability with that. So, because of that reason usually it is required for you to normalize the EMG signals in some sense. So, with so what is usually done is that you find a EMG the measured EMG and you compare it with a standard task. This is usually what is called as a maximum voluntary contraction task allowed or the maximum force that the person is trying to produce, what is the EMG at that time in comparison with that EMG what is the EMG produced during a particular task. So, this is one way in which you could standardize or normalize this. Then we will be compare very well relatively well to the force and then I can take it I can compare this across individuals, this gives me a chance to compare them across different people.

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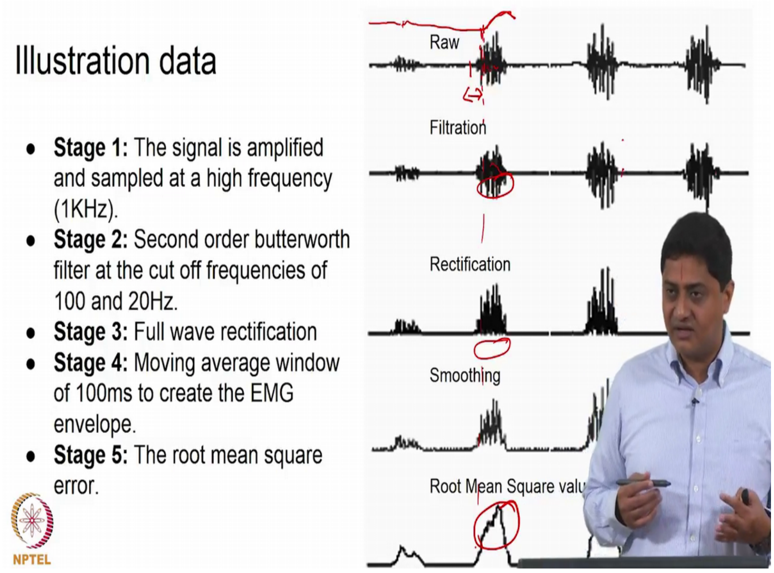

So, here is an example suppose this is a row data that is produced and after some filtration you get this and I rectify this. So, this part is now missing here and the amplitude of that is increased and then I smoothen them. So, a low pass filter it at relatively a low frequencies and then either I integrate them or I take a root mean square or I take a moving average window or a something of that sort to produce this and if I compare so importantly usually what is done is movements are also mu moments are kinematics is measured along with the EMG.

So, suppose that was the displacement some displacement is there and that displacement. So, suppose that is a displacement and there is some displacement here and then there is one more displacement there. So, what you usually compared is the timing or the onset of the displacement versus the onset of the EMG, usually there will be a some differences these differences reflected in some sense health or disease and so on and so forth.

So, usually we are interested in latencies and how the amplitude of the displacements are the forces you could either have displacements or you could measure forces. So, this could be a force curve also the amplitude of the forces how do they relate to the amplitude of the EMG itself are integrated EMG itself. And the latencies between the force change in force versus the change in the EMG. These are the things that are of interest for us.

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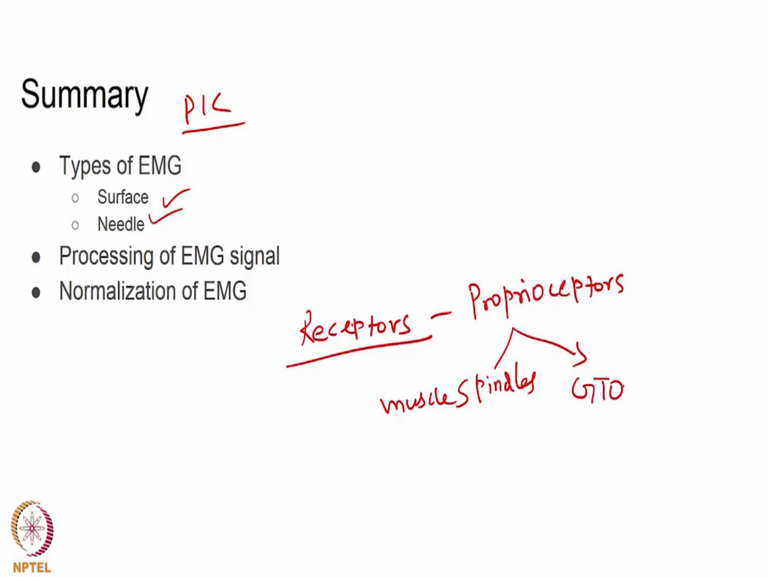

So, we have seen in summary we have seen PIC persistent inward current and Monoaminergic input in relatively great detail and we have seen surface EMG needle EMG the differences between surface EMG and needle EMG and we have seen how to process EMG signals. So, what are the steps filtering rectification and then integration by the way that order is important? You cannot for example exchange integration and a rectification, because obviously if you integrate a signal that is looking like this right you are going to get a relatively small value.

So, you cannot exchange into these 2 steps rectification and a integration always integration must follow rectification obviously and normalization of EMG how is EMG normalize compared with a standard task or a maximum voluntary contraction task.

So, with this we come to the end of this class what next what lies ahead for us. The next topics are receptors with particular with particular reference to proprioceptors and some discussion of other receptors cutaneous receptors. So, proprioceptor means muscle spindle so proprioceptors those that give you a sense of where you are right muscle spindles muscle spindles and Golgi Tendon organs ok. These will be discussed in future classes so.

Thank you very much for your attention.