Introduction to Exercise Physiology & Sports Performance
Wg Cdr (Dr.) Chandrasekara Guru
Directorate of Medical Services

Lecture - 15
Neurophysiology and Exercise - Part 2

Welcome back to this NPTEL course on introduction to exercise physiology and sports performance and this part 2 of this module of neurophysiology and exercise. I am Dr. Chandrasekara Guru. I am a Sports Medicine Physician with the Armed Forces Medical Services. We are going to learn about organization and basic functions of the nervous system, human movement control, and its connection to exercise and various application aspects in sports and exercise. Let us revise what we have covered in the part 1 of this neurophysiology and exercise.

We discussed the organization of the nervous system into the brain areas, and various functions, the autonomic nervous system and the peripheral nervous system, the neural control of movement, basically the type of movement, automatic and voluntary; as well as the mechanism by which the movement happens. The neural control of movement, feedback loops, including the local feedback loop, central feedback loop and specialized sensory feedback loop, with an example we discussed. We also dwelled upon the components of the impulse transmission, starting from the sensory afferent nerves, to the spinal cord, to the brain stem inputs to the cerebellum, and to the thalamus thereafter to the motor cortex and again back descending via the descending tracts to the brainstem and the spinal cord affecting a motor response. We also studied the motor circuits, the brainstem and cerebellum, the sensory and motor integration as well as the feedback control of all this system.

Having learned about the basics of neurophysiology, let us discuss in depth about the various aspects of neurophysiology related to the exercise per se, and its application in this section of this module. So, we saw that the lower motor neuron is the neuron which starts from the spinal cord and then it affects the motor response. So, it is further divided as alpha motor neuron and gamma motor neuron. The alpha motor neuron supplies or innervates the extrafusal fibers causing the force production and actual movement, whereas the gamma motor neuron supplies the muscle spindle, and acts as a sensory response which modulate the length of the muscle fiber. So, with this background, let us discuss what is a motor unit.

Motor unit is the functional unit of movement. The various components of motor unit are the: motor neuron, the alpha motor neuron including the dendrites, the cell body, the axon including the, you know, Nodes of Ranvier through which the transmission happens across the axon,

ending into the axon terminals and then into the motor end plate with the neuromuscular junction onto the skeletal muscle fibers or the extrafusal fibers. So action potential, that is the electrical impulse which is generated in the alpha motor neuron, and all the muscle fibers which are innervated by the motor neuron gets stimulated. So, the motor units are divided into three types based on the physiological properties and their size. So, they are divided as fast-fatigable, fast-fatigue resistance and slow.

So, this is a comparison of various physiological properties between the three types of motor units. I would recommend that you go through it, you know, in detail and slowly so that this has various good practical takeaways. So let me just explain this table in brief. Say let us take this fast-fatigable. The fast-fatigable motor neurons, motor units are basically supplied by the large motor neurons. The size of the motor neurons are large. So, as the size of the nerve fiber is more, the transmission is going to be fast. So, the contraction speed and the force production is also high. And since the size is large, it also supplies the type 2 type of skeletal muscle fibers namely the fast glycolytic. So activation of this large motor neurons or the motor units results in explosive powerful activity using the anaerobic pathway, and hence they have low fatigue resistance. So they get fatigued faster because of the type of activity they perform. Whereas let us focus on the slow type of motor units. These are generally small. So, the transmission speed is slower; and have a high resistance to fatigue. So that is the reason they are involved in long duration endurance activities and they use predominantly the oxidative metabolism, or the slow oxidative muscle fibers are innervated by the slow motor units.

So, that is how the application of these size and physiological properties in the training of these particular type of muscle fibers for the relevant activities. We will see it in detail here. One of the important characteristics of the motor units and its importance that you need to understand is the neuronal facilitation or CNS excitation. The electrical activity which happens travels as action potential. So, it needs to cross a particular threshold for the action potential to be transmitted.

However, there is a concept of submission of this sub threshold action potential, which happens either because of the total amount or because of lowering of the threshold to a lower level so that the neuron can fire for a specific period of time or temporal. So it is called as either spatial summation or temporal summation happens in the motor units, which can result in facilitation or implementation of a motor movement. In addition, the motor neuron also supplies multiple muscle fibers of the same muscle. So, collective effort of a single electrical impulse can get converted into a collective mechanical movement, thereby can yield a maximum effort. So, when this particular type of facilitation is also overridden by the central nervous system excitation, say with a psychological positive effort, you also end up people doing not only maximum effort, even world record level effort.

So, neuronal facilitation is the reason for people being able to perform better and better with every increase in world events. So, what is the takeaway from this particular neurophysiological concept? If you train the neural pathway for better collective activation of the muscle, you will have better output. So when you, you know, teach someone to perform an exercise, it is always important to perform the exercise in the correct form, rather than lifting more weight at the initial stages. So in the initial stages, you are training the neural system so that the right kind of firing of the electrical activity or firing of the neurons can take place, which ends up in a collective mechanical effort. So, neural training comes prior to the actual muscle loading.

So, it is important to understand that in the initial days when you are training someone, it is important to focus on the form rather than the amount of weight the individual can lift. So, that is important takeaway point from this slide.
What are the other concepts with respect to motor unit and their relevance in exercise? So we have seen that stimulation of a motor unit results in a coordinated response. So, there are three important physiological principles, which are responsible for a coordinated response.

Number one is all are non-phenomenal. So, when a motor unit is triggered or stimulated, it results in collective activation of the entire muscle fibers which is supplied by that which causes a movement. So either it is all or it is none. So that is an important principle. Then the second principle is the gradation of force. So the force or the number of motor units that are recruited depends on the task which is on demand.

Say, for holding a knife and cutting the skin with precision by a plastic surgeon would require specific type of motor units and number of motor units to be activated. And, this kind of improves or gets simplified with practice. The complex task gets simplified with practice. Say another example of it, when you consider an example of throwing a javelin where it involves multiple firing of multiple muscle groups, it requires a coordinated force production to have a better distance covered by the javelin at the end of the throw. So, that is again a type of gradation of force that is required.

So, where more force is required, you need more number of motor units to be activated to perform the coordinated task. The third important principle is size principle. The motor task determines the size of the motor unit that is recruited. So, we have seen that motor units are of different size. Accordingly, they have different type of energy system and the type of muscle fibers which they recruit or innervate.

So, for activities which are light to moderate in nature, they recruit smaller motor units because with that itself, the endurance kind of activities are performed. So, with smaller motor units, only motor neurons only, these activity can be performed. And those activities which are prolonged in nature or a long duration, they obviously need high fatigue resistant, you know, motor units.

So these smaller motor units are recruited. Whereas if you have a motor activity which requires explosive movement or immediate maximum output is required, so in such kind of intense activity, you will have large sized motor units being recruited, so that complex or maximum output motor unit output can be given by these fast, fatigable or fast oxidative glycolytic muscles.

So, that is the application of the size aspect of this in your training, exercise training. So another important aspect to consider with respect to neurophysiology and exercise is the understanding of the concept of fatigue and the importance of the central nervous system in contributing to fatigue. So let us see, we know that consciously, the individual decides to do a motor activity and exercise for example, running, and then a CNS motor output is delivered to the motor neuron. The motor neuron relays the signal to the muscle fibers through the neuromuscular junction and from which it reaches the T tubule, from where the calcium release is seen and along with the availability of ATP, a muscle contraction happens to do that desired action. So, the entire process of electrical and mechanical transmission can be divided into central and peripheral.

Till the level of neuromuscular junction in the muscle fibers, the higher pathway is called as the central fatigue. The reasons for that constitutes central fatigue, and beyond the muscle fibers and down below would be the reasons for peripheral fatigue. For example, say for example, a tired individual with lack of sleep will have a poor motivation to kind of do an activity. So that itself is one of the factors. Second, if you consider peripheral factors, say, ATP is not available, say the adequate fuel is not there, the individual was in a fasted state that is not, he has depleted all the glycogen. So that is a state of depletion. So that itself is a, would be a reason for peripheral fatigue.

So this fatigue can be divided as central fatigue and peripheral fatigue. Having known the difference between central and peripheral fatigue, how it relates to neurophysiology and the importance in exercise training. So, with central fatigue, you understand that there is decreased CNS motor output, because of which there is decreased motor neuron stimulation, which again decreases the muscle stimulation, which causes decreased force production.

So the concept of central governor theory is important to understand this. Central governor theory states that the central nervous system is the central governor, it governs the force production of the muscles to prevent any unsafe level. So that it may not cause damage to the exercising or acting muscles. So, there is already a preset level or regulation by the CNS so that the unsafe level is not met. So, based on that it limits the exercise to a certain point when you will reach a level of exhaustion.

So automatically the central governor reduces the motor output and slows down the motor recruitment causing fatigue. So, this is a protective response which the central governor theory states. However, thus the involvement of the central nervous system in such decision making is very crucial to prevent the unsafe level of activity and further damage. However, Central governor theory also states that the involvement of a psychological motivation or verbal encouragement or playing music for example, or just shouting using certain keywords can also motivate the person to perform better, even though the person is in an exhausted state. Thus, central governor theory says that it is decided centrally by the central nervous system whether to limit your exercise or to proceed further even if you have reached an exhausted state. So, it depends on the level of training and the kind of inputs that the central nervous system provides to the motor system. So, that is an importance of central governor theory and its relation with fatigue.

Another important concept with respect to neurophysiology and exercise is neurophysiology of stretching. To understand this, we need to understand the basic reflex of the neuromuscular system. So one of the basic spinal reflexes is called the stretch reflex. It happens at the spinal level. So we discussed previously that it is a local feedback wherein the gross motor activity happens where speed is more important than accuracy at the level of spinal segment. So, there are two types of sensory receptors in the muscle. One is called as the muscle spindle, the other one is called as the Golgi tendon organ. So what is a muscle spindle? The muscle spindle as we discussed earlier, it forms part of the intrafusal muscle fiber. The intrafusal muscle fiber contains the muscle spindle arranged in close contact with the extrafusal muscle fiber.

And, they do not have the contractile portion of that. So, they do not contribute in actual force production. They act more like a sensor of change in the length of the muscle fiber. So, when the extrafusal muscle fiber increases in length, along with it the muscle spindle also increases. Because of the increase, it activates the gamma motor neuron. The muscle spindles are invaded by the gamma motor neuron. So, the gamma motor neuron also triggers the activation of the alpha motor neuron, which is correspondingly related in the spinal cord. So that immediately causes an immediate contraction. So this is a protective response, wherein, the muscle spindle activation causes an excitatory signal which in turn stimulates the alpha motor neuron to cause contraction and decrease the length of the muscle. So, protectively it decreases the length of the muscle, when it is stretched to beyond a certain extent. So thus it is called as the stretch reflex.

So in exercise training as well, when the alpha motor neuron and the gamma motor neuron are trained in such a way, they can also cause something called as alpha gamma coactivation which can result in better force production. So this can be utilized to increase the force production by the activation of the alpha motor neuron by means of stretching. So, this particular idea is used in various plyometric types of exercises.

What about the Golgi tendon organ? So Golgi tendon organ is another type of sensory receptor which is present in the extrafusal muscle fiber towards the end where it joins the bone, at the level of tendon. So this basically senses the tension developed in the extrafusal muscle fiber. So the muscle spindle senses the change in the size or the length, and the Golgi tendon organ senses the change in the tension or the pressure that is being developed within the extrafusal muscle fiber during the course of force production. So, it is again of protective response wherein when the tension increases to a certain level, it gets activated and it increases the inhibitory response to alpha motor neurons. So, because of which the alpha motor neuron gets inhibited. So, let us see how it functions in the next slide. See, these particular principles are incorporated in the stretching principle.

This is the neural mechanism. So if we understand this neural mechanism, we can address to the questions that I had put across when we started this particular module. What happens during stretching? So what happens is when the GTO gets sensed because of an increase in tension, it increases the inhibitory signal. So thereby it inhibits the alpha motor neuron. So the alpha motor neuron causes contraction. So, what happens when it gets inhibited, it will in turn causes relaxation.

So this particular thing is called the inverse of the stretch reflex. It is an inverse stretch reflex. And this principle is used for static stretching, wherein you kind of increase the tension in the agonistic muscle to an extent that it causes reactive relaxation because of the inverse stretch reflex. So, for this particular stretch reflex to happen, it is again a spinal reflex, but it takes at least 20 to 30 seconds for completion of this particular reflex to happen. So it is important to understand that, if you are advising static stretching as part of your cool down, then it is important that you at least ask the individual to hold for 20 to 30 seconds so that the relaxation of the agonistic muscle will happen after completion of this inverse stretch reflex. Hence it is very important. And for those of you who are further interested in stretching, this concept of micro stretching is coming up, where at a suboptimal level you stretch the agonist for prolonged duration of time even up to 60 seconds to more than 90 seconds. So that causes a predominant relaxation of the muscles.

Another important concept or application of neurophysiology in exercise is understanding the concept of exercise associated muscle cramps. So, I am sure that most of us would have experienced cramps after an activity or during an activity. And, these cramps are nothing but episodic and rather it is a painful spasmodic involuntary contraction of the skeletal muscle.

So, because of the painful condition, you are not able to further continue with the activity and then it causes a spasmodic contraction of the muscle. So, commonly this type of situation happens in endurance sports, especially running, when it is also associated with other environmental factors like hot and humid weather, or you are in a dehydrated state. So

accordingly, there are various theories which are put across to substantiate the reason for cramps in such sports. So various theories were: electrolyte imbalance, some few of the researchers mentioned that because of the electrolyte imbalance which happens during the process of prolonged endurance activity, cramps occur. Subsequently, a few of them said that might be because of the dehydration which has happened in the individual, and dehydration as kind of resulted in cramps.

Few of them came up with the environmental based theory, wherein hot and humid weather has posed some reason for occurrence of cramps. However, the most scientifically proven and accepted is the latest altered neuromuscular theory. According to this theory, what happens is because of the fatigue, there is alteration in the neuromuscular transmission. So, the control which is done by the neuromuscular electric and mechanical movement is altered, because of which there is excessive excitation and reduced inhibition. And, this results in increased involuntary contraction, thereby resulting in cramp.

So, the bottom line here is there is more of excitation and less of inhibition. So, what should be the treatment? If you want to apply the concept of neurophysiology, what we have learned during the last few slides, you have to immediately stop the activity. So further excitation will be stopped. Second thing is, you will have to introduce passive stretching. We saw that stretching passively to the limit where the individual does not feel the pain causes an increase in the tension, stimulating the Golgi Tendon organ causing inverse stretch stiffness leading to relaxation of the muscle. So, that is how passive stretch can be an important remedy in case of exercise associated muscle cramps.

Another kind of important concept which is coming up in a big way in terms of injury prevention as well as rehabilitation is the role of proprioceptors in exercise and sports. The proprioceptors are specialized sensory receptors which are located within the joints, muscles and the tendons. And their main function is to sense the position, the kinesthetic aspect of it, the pressure and tension and the muscle dynamics and relay them to the central nervous system. So they appreciate the position of the body, the balance, the stability, the complex movement coordination, these are all conveyed based on the proprioception, the proprioceptors which are present in the active muscles of the body.

So after an injury, it is seen that the neuromuscular control decreases. This is mainly because of the derangement that happens to the proprioceptors as well. So, the takeaway point is; when you introduce specific balance exercises in a graded fashion after an injury based on the different phases of rehabilitation, so you will be able to regain this neuromuscular control. And, the similar exercises are also introduced as a warm up protocol before doing the activity in order to activate these proprioceptors to have better performance as well. Certain activities like mini trampoline jumps, balance boards, stability ball drills, they all have been incorporated as

proprioceptive training methods to prevent injury as well as in the rehabilitation of these injuries.

It will not be complete if I do not cover the important aspect of concussion in sports when I cover this module of neurophysiology and exercise. So, even though it is more of a traumatic event, it is important that concussion has a major fatal outcome if it is not properly recognized. So what is concussion? Sports related concussion is a traumatic brain event which happens in a sports related activity, either by a direct blow to the head, neck or body or maybe by an impulsive force which would have transmitted to the brain. So this, what happens is this particular injury initiates a cascade of neurotransmitter and metabolic events, which results in possible axonal injury or maybe blood flow change or maybe because of inflammation affecting the brain. So this leads to a cluster of symptoms, which may not even be seen or viewed in the standard structural neuroimaging studies.

So, you may have a normal neuroimaging study of the brain post injury, but still the brain is involved. So these are very, the lower most spectrum of traumatic brain injury, but then if left unattended can lead to a fatal event as well. So, it is important that we recognize that it is a sports related concussion, try to reduce them by following certain rule based regulations in the sports preventive equipment to avoid or reduce the incidence of concussion. Remove the individual immediately from the scene of play. If required refer to the specialist, reevaluate again if you are in doubt, adequate rest is important and rehabilitate the individual as per standard protocols.

Then thereafter once you are satisfied that the individual is safe to continue play, then make him return to play. So the entire concept of sports related concussion has been refined over a period of time, and quite recently last year the IOC's medical commission had come up with the sixth consensus statement on concussion in sports. It is a very good document freely available in the British Journal of Sports Medicine published in 2022. It is freely available for anyone to access and I would recommend that should at least go through the ready and easy screening tool that you have just been validated and introduced in this consensus statement. So to summarize, we discussed about the motor neuron unit and what is a motor unit, what is a motor neuron, what are the different type of innovation that they do and we also discussed about the concepts, physiological concepts and their implication in exercise namely the facilitation as well as the size principle and all are none-principal or variation principle.

We discussed about the fatigue, central and peripheral and how central fatigue of the nervous system contributes to the development of fatigue as well as to the performance even when you are in an exhausted state. Employing the central governor theory and the important concept of neurophysiology of stretching and what is the mechanism and what should be the duration for a stretching to be done properly to reach that kind of relaxation after stretching that you need to

advise to your client. We also discussed about the exercise associated muscle cramps, the various theories and the most accepted altered neuromuscular theory, and how you know employing the concept of neurophysiology you can kind of treat exercise associated muscle cramps. We also discussed the proprioceptors and the role the proprioceptors and the kinesthetic have in the kinesthetic and proprioception training to prevent injuries as well as in terms of injury rehabilitation to prevent recurrence. And we also discussed in brief about probably an introduction on concussion in sports, the importance of you know recognizing it and you know following certain steps to avoid a fatality due to concussion in sports and also the latest consensus statement that is available free for use. So the take away from this module of neurophysiology and exercise is that there is definitive contribution of neural control of movement and it is important to first activate the neural component before activating the muscular component.

And we discussed about various concepts that can be utilized in exercise training including the size principle, the recruitment, the stretch reflex, inverse stretch reflex, the proprioception training. We discussed about the stretch mechanism and its practical application as a cool down strategy. We also discussed about the role of central fatigue and the performance level which can thereafter vary based on the central component on the motor activity. And finally, we discussed about the importance of neurophysiological concepts in injury prevention and rehabilitation so that you have even optimized the sports performance in a better way preventing the injury. So for those of you who are interested in in-depth reading, I would suggest the following standard textbooks in exercise physiology.

Also I would recommend you to go through the IOC's consensus statement which is the latest sixth consensus statement for concussion in sports and definitely go through the screening tool for concussion assessment in field. Thank you.