Introduction to Exercise Physiology & Sports Performance
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Lecture - 14
Neurophysiology and Exercise - Part 1

I do a lot of weight training, my muscles are tight, however I do cool down, but only for 2 to 3 minutes after an hour of workout. In such individuals what will you advice regarding cool down? What should be the ideal time one has to do the static stretches after a workout or particular muscle group? What is the neurophysiology and the science behind it? If you are the practitioner who is looking for answers to these questions, you are at the right place. Welcome to the NPTEL course on Introduction to Exercise Physiology and Sports Performance, and this module on Neurophysiology and Exercise. I am Wing Commander Chandrasekara Guru, Sports Medicine Physician with the Armed Forces Medical Services, and I shall be covering this module in two parts. In this module we will learn about the organization of the nervous system, the basic functions of the nervous system, what controls the human movement and various connections between the neuro and muscular system during the exercise, and various applications of these concepts and knowledge into a day to day practice in sports and exercise.

So the nervous system is the brain and the spine, the spine includes the spinal cord which is the extension of the brain. The nervous system is a system of communication to interact with the external environment, not only that, it also integrates various internal responses of various organs and the organ system of the body. So thus, you can rightly compare your nervous system to a personal computer. So, if you see a computer has an input unit, a central processing unit and an output unit. So similarly, our nervous system is also organized in such a way. The communication system of the human body is your nervous system, and it has multiple organs which are wired and they are interconnected and integrated through this nervous system. The final effector output is generally a voluntary output or an automatic involuntary output. These systems are so multiple that the integration process and the various aspects that happen are complicated but then still they are very closely integrated. That is the beauty of this nervous system.

So, to further expand it on, the sensory signals are basically you sense various sensations through your receptors. It may be touch, it may be vision, it may be hearing, it may be the smell, it may be the taste, it may be the balance, vibration, the position and various other receptors which are located in various internal organs. These all are the initial sensory receptors, and these sensations either internal or may be external, they are the sensory input and these sensory inputs are taken and relayed to the processing unit that is the nervous system through a system of afferent nerves. So, the nerves transmit this input to the central processing unit. The central

processing unit is your nervous system which comprises of the various components namely brain and spinal cord being the main, and from there a decision is taken and response is immediately initiated; and this response again passed through the system of nerves called as the efferent nerves. Efferent nerves convey this motor response and then affect that response. It may be voluntary or automatic or in other words involuntary.

So, what is the organization of the nervous system? Let us see how the nervous system is broadly divided. So for the ease of understanding, the nervous system is broadly divided into the central nervous system and peripheral nervous system. The central nervous system is the main part of the central processing unit. It contains the brain, the spinal cord and the various control centers in the brain and spinal cord. Subsequently, you have the peripheral nervous system. The peripheral nervous system is further divided based on the output you have the involuntary and voluntary. So you have the autonomic nervous system which performs the involuntary functions of the body. Further, the autonomic function nervous system is divided into sympathetic nervous system and parasympathetic nervous system; and these two are generally antagonistic in most of the tissues.

The other voluntary aspect is called the somatic nervous system which is your voluntary motor nerves. So this is the overall organization of the nervous system. Let us focus on the main central nervous system of the brain. So the brain is divided into various regions and correspondingly these regions undertake or register the sensory inputs and functions accordingly; and then give the respective motor output based on the specific function of this particular area of the brain. So, it is important to understand the regions in the brain and specific function that they undertake for you to understand the neurophysiology and its relevance with exercise.

So let us focus on the brain region. So it is a cut section of the brain model. So, you will have the brain which you see from outside this big cauliflower kind of shaped thing which is with lot of involutions that is called as your cerebrum, the outer part of it is called as the cerebral hemisphere. So you have two cerebral hemispheres, right and the left and they are interconnected in the middle that is called your diencephalon. So, the outer aspect of the cerebral hemisphere is called the encephalon, and that the connected part is called as the diencephalon.

And, from there when you go downwards you have the midbrain which acts as a kind of connector between the forebrain and the hindbrain or the brain which is behind the midbrain. So subsequently the midbrain is followed by pons, the cerebellum, the medulla oblongata which all these three are collectively called as the hindbrain and thereafter it continues as spinal cord in the spine, the spine canal of the spine. So, the functions which these respective regions do are;in the forebrain you have the cerebral hemisphere right. The cerebral hemisphere takes care of sensation, perception, it functions also about the thoughts that you have that is called as the cognition, learning and memory aspect of whatever you learn, the skills which you learn and

memorize the function is carried out by the cerebral hemisphere. Then for any task you plan and then programming of the responses happen and various iteration of the task happens these are all done at the level of cerebral hemisphere.

The next is your diencephalon where it is this portion is very critical because it connects both the hemisphere and then the down below. So, it acts as a relay center which relays information from periphery to the cerebral hemisphere, and incorporates the response from the cerebral hemisphere downwards to the effector organs. So and most importantly it also controls and hosts various autonomic centers and the endocrine functions. Next comes the collective area called as the brain stem which includes the midbrain, pons and medulla and this midbrain is important because it has the control of sleep and wakefulness. The rhythm at which your biological clock is set is controlled by the brain stem.

The cardiovascular and the respiratory center which we discussed previously in the cardiovascular module and respiratory system module are centrally controlled at this level. The brain stem controls the autonomic functions of the cardiovascular system and the respiratory system. In addition, it also controls and regulates the locomotion as well as the visceral body functions. It is very important to remember this aspect. Then you have another additional convoluted structure behind the posterior aspect of the brain, that is called the cerebellum.

So, the cerebellum is responsible for maintaining the posture and movement of your body; and further the brain continues as the spinal cord. The spinal cord is nothing but it relays the information from periphery to brain and brain to the periphery. So, it is important in relaying the information. So, having known about the various regions and the functions broadly of the brain it is important also to understand what is human movement. Our main focus in this module will be to understand the neurophysiology of movement and how it is important in exercise and sports and day to day practice.

So, I will not be covering in depth it is in fact beyond the scope of this particular module. So, we will limit ourselves to motor physiology, the neurophysiology and its importance with respect to exercise aspect of it. So, I have tried to simplify the concept in a very basic way for you to understand and comprehend in a better way. So, the human movement is nothing but displacement of body part either to a new position either as a part or as a whole. So, that is called movement. The study of the initiation, execution and further control of this movement by the body at the background of maintaining a particular posture is called as motor physiology.

And the movement per say happens because of the contraction and relaxation of the muscles. So, if you have this is an elbow joint and the reduction in the joint is brought out by the agonist and it is supported by the action of the antagonist. So, the agonist is the group of muscles which causes the action, the antagonist is the muscle which antagonizes the action and supports the

movement of the agonist. So, contraction of the agonist causes the movement with such a simultaneous relaxation of the antagonist. So, that is important to understand.

So, broadly if you classify the movements, movements can be classified as automatic movements and volitional movements. So, let us see what automatic movement is. Automatic movements are like a reflex. They are generally stereotyped, very simple. Here, speed of movement is more important than the accuracy.

What do you mean by speed versus accuracy? Speed is as the fastest period of time you perform an activity irrespective of how you are doing. But, accuracy is how you are doing so that you want to exactly investigate the thought or predetermined function or the activity. So, that would denote accuracy. So, in automatic movement, it is more than accuracy. They are reflexive in nature and they are very stereotyped.

So, generally it is the same response which you have. They are not complicated and most mostly they are not modifiable. And that is the key aspect of automatic movements. And they are specifically stimulated on specific sensory signals whereas, volitional movements, they are slightly complicated. They can be modified. Since there is an additional thought of voluntary or the effect of the central nervous system, or the thought process has come in this type of movements, you have some delay. So, there is a transitional delay. So, long latency will be there. And because of that iteration of the movement, the movement will be more coordinated and can be more accurate as compared to an automatic movement. So, here more of accuracy is important than compared to the speed.

And, since the central nervous system is involved where your cerebral hemisphere is involved in such movements, so you have the incorporation of emotion, attention, and motivation. So, psychological aspect also plays a role in such voluntary movements. So, thus voluntary movements become more complex. So, what is the mechanism? If you see the mechanism, it is a very simple flowchart which I am showing you wherein it is a schematic view of it. When any sensory input stimulates the afferent neuron, it goes to the spinal cord, it traverses the spinal cord to the brainstem.

And it reaches the brainstem. From brainstem, it gets related to the cerebral hemisphere from where it reaches the motor cortex. The motor cortex is the region which analyze all these inputs and then gives a signal to the affected organ to perform. So, that signal is from the motor cortex, again travells back the brainstem downwards to the spinal cord and thereafter to the effector organ to do that particular output. So, that is the normal pathway by which a sensory signal traverses and then finally, a motor output is performed. So, based on the complexity and the volitional nature of that, various segments are triggered.

So, not necessarily all the types of activity should go to the central nervous system and then come back. It can happen at various levels as well. It depends on the complexity of the task as well as the volitional nature of the task. So, every movement which the individual performs, the affected organ performs has to be, feedback system has to be there so that is incorporated into your learning and memory pathway as well. So, the feedback for the control of movement is important.

So, let us take an example. What do you do when a hot tea spills on you accidentally? Immediately it spills on you, what do you do immediately? Immediately what you do is through a local feedback. So, that is a reflex feedback where you immediately withdraw from the hot liquid and try to wipe off the liquid from your hand. So, that is a stimulation of the local feedback system. Here, you are looking at a system where you are looking for speed more than the accuracy. So, the faster you remove your hand from the hot liquid, it is better.

The sensation of the pain decreases. So, you wanted to do it as fast as possible. The speed is more important than accuracy. It is not that how you would remove slowly or what position you will remove. So, that thought process is not there when a hot tea spills over it. So, you immediately remove it. So, that way speed is more important in such local feedback loops. And these are more of automatic movements and reflexively it is done. So, this happens more at the level of spinal cord itself. So, that is how it cuts down on the relay time, thereby the speed of the movement increases and you immediately withdraw yourself from the painful stimuli or an unwanted stimuli. So, motor output would be very gross, it may not be very fine and it is very reflexive generally.

What about feedback which is involved if you want to type a reply message in your smartphone. So, you have a smartphone, everyone has a smartphone. So, you got some message in your WhatsApp and you wanted to reply. So, what is the type of feedback that is involved here? You have to type using your thumb, so that is the motor response. But then you are also incorporating the message that you have seen.

So, your vision is also incorporated and you think over it, thought process is involved, cognition is involved and based on your input and decision is made and motor output is done. So, here it is a central feedback where the central nervous system is involved, it is voluntary motor response. So, it is up to you whether you want to send or not send or you have time to think over it. So, it is a voluntary motor response and here more of accuracy is important than speed. So, the latency is also more and the motor output can be modified.

So, it is up to you how you want to do that particular activity. Now, this involves relaying of the information from spinal cord to brainstem to motor cortex. So, all the three are involved. So,

hence the complexity increases, the time taken to process and then get back to the motor necessary effector organ is also increased. So, that is about the central feedback.

Now, what type of feedback is stimulated if you want to hit a nail using a hammer on the wall? So, this is more of a special sensory feedback. Here, a peculiar type of feedback here, this is where you use your central as well as your visual input as well as your proprioception. So, you will have to position yourself in such a way that you correctly hit the head of the nail, otherwise you may injure your fingers. So, all the three are kind of special senses are also integrated in this particular motor response here.

Accuracy is far more important than the speed. So, you take some time and analysis and then you proceed with the motor output. So, integration of various inputs from different areas of the brain are required to perform this particular task. And here the complexity though I say complexity of the task is more, since the learning and memory is also integrated with the central nervous system, the more and more number of times you perform the task, it gets simplified. So, over a period of time, you learn to perform that task with the same material speed in the sense the speed will improve. So, that is how you can say how you learn initially driving then gradually with more and more practice you tend to own up the skill of driving, and then later on you do not even focus on changing the gear or when to press the pedal or accelerator or the gear.

So, these things come automatically as and when you learn. So, thus learning and memory also aids in better task execution. So, that is an incorporation of the central nervous system into your motor task learning. So, what are the components of this entire system that happens? So, the afferent neurons carry the sensory impulse to the spinal cord from the spinal cord, it goes to the brainstem, the brainstem also sends some signals to the cerebellum to know sensation about the posture and movement and it further transmits to the thalamus which is the relay center. From the cerebellum also provides input to the brainstem as well as to the thalamus to incorporate the response on the posture and movement from the thalamus further it enters into the sensory area that is the cerebral hemisphere cortex; and the part is also reflected back to basal ganglia where again posture and movement are again taken into consideration, and feedback is given to thalamus.

So, based on all these inputs, input is given to the motor area, the motor area then relays this particular information to the brainstem or it can also relate directly to the spinal cord and execute this motor activity. So, these pathways which go from sensory afferent neurons, spinal cord, brainstem, thalamus to sensory area are called the ascending pathways and the motor response which comes from the motor area either directly to brainstem or directly to spinal cord. So, these are the descending pathways and are also called as the descending tracts, and at the spinal cord level these informations are relayed and from that point it is carried by a set of specifically identified neuron called as the motor neuron which supplies a group of muscle fibers and to

perform that particular task of that particular activity. So, the fundamental component if you say in the entire motor system is the muscle and the motor neuron. So, a particular muscle which is supplied by a respective motor neuron forms the fundamental component of the motor system and rest of the components are all involved in the transmission of these impulses.

And this is basically required. The fundamental component in the motor neuron and muscle are responsible to maintain the muscle tone to generate force during any movement. So, that is why a lesion of the motor neuron can cause reduction in the tone, which we will see subsequently. So, we have different circuits based on the type of relay that happens here. So, at the initial level you have the afferent neuron going to the spinal cord thereafter and from the spinal cord with the local feedback it can provide motor response, which we discussed as a reflex motor response or an automatic activity. So, this happens because of the sensory signal influencing the motor neurons that innervate the same muscle.

So, from the same muscle, the sensory signal goes in the motor neuron there and then it immediately causes a motor response of the same muscle which got stimulated. So, that is a rapid reflexive movement at the spinal level itself. And the motor neurons again can be divided into upper motor neuron and lower motor neuron based on the origin of the cell body. Say the upper motor neuron corresponds to those motor neurons which originate from the higher centers like the cortex, the brain stem and then they terminate on the spinal cord motor neuron. So, these are long, these are called the upper motor neurons.

So, they originate from the central nervous system and the higher centers and terminate at the level of the spinal cord. What are the lower motor neurons? Lower motor neurons are motor neurons which carry the motor impulses originate from the spinal cord or any of the cranial nerves which are located in the brain centers, and then that particular motor neuron is called as the lower motor neuron. So, lesions can happen at either the upper motor neuron or lower motor neuron. So, the presentation accordingly varies. That would be beyond the purview of this particular module and those who are interested can further refer to the references which I would mention towards the end of the lecture.

So, let us focus on motor neurons, especially the lower motor neurons. Here we are mainly focusing on the spinal segment. So, the lower motor neuron has two types of motor neurons. One is the alpha motor neuron and the gamma motor neuron. The alpha motor neuron is one which comes as the final common motor pathway both from the central nervous feedback or the local feedback and it controls the skeletal muscle.

So, it supplies the extrafusal fibers of the specific muscle the motor neuron supplies. So, the two types of muscle fibers, extrafusal and intrafusal in the skeletal muscles. So, I think this would be covered in detail in skeletal muscle physiology and its relation with exercise as a separate

module. So, for those of you as a primary description, the extrafusal fibers is the one which generates the force and does the motor activity.

The intrafusal fibers mainly act as a kind of sensory response. So, the alpha motor neuron is the one which innervates the extrafusal fibers and each alpha motor neuron supplies generally 10 to 1000 muscle fibers. So, it is one motor neuron originating from the spinal cord which supplies multiple muscle fibers belonging to the same muscle group. So, thereby it can have one electric impulse which gets transmitted; it can be converted into a mechanical contraction of those relevant muscles. Gamma motor neuron is the one which innervate the other muscle fiber that is the intrafusal muscle fiber, mainly the muscle spindle to which modulates the length of the muscle fiber. So, this gamma motor neuron does not carry any kind of sensory inputs.

It is mainly influenced by the descending pathways which comes down based on which the action happens. Having seen about the spinal circuit, let us see about the supraspinal circuits. The supraspinal circuits involve the first level at the level of brainstem and the connection with the cerebellum for posture and movement. So, the brain stem controlled centers have the descending pathways coming from the higher centers and they control the postural movement. The inputs on the cerebellum are mainly in terms of the posture and movement, to regulate them. It also controls all the aspects of movement starting from initiation, planning, programming, smoothing of that coordination and termination of the movement.

So, all aspects of the movement has some contribution from the cerebellum with respect to the posture as well as the movement. So, the inputs from the cerebellum are given to the brain stem as well as also to the thalamus. The thalamus is the relay center which relays the information from brainstem to the cortex. So, it is important that cerebellum also provides the input to the thalamus and from there it further proceeds towards the sensory area. So, what thalamus does is it is a sensory relay station to the cortex, it receives also from basal ganglia as well as from the cerebellum and it is an important area which kind of coordinates sensory as well as the motor.

The next part of the forebrain circuit is the basal ganglia. So, basal ganglia is a subcortical structure which is again responsible for posture and movement. So, the disease of the basal ganglia is commonly implicated in Parkinson's disease, which affects the posture and movement. So, at the level of cortex, you have the direct control of the spinal cord through the descending pathways as mentioned here, as well as it controls via the brain stem. So, there are two different pathways which can control the motor as well as it also takes feedback from this system immediately. So, thus there is correction of movement as well with the incorporation of such multiple descending pathways to different centers; thus aiding in sensory motor coordination.

So, to summarize in this part one of this neurophysiology and exercise, we discussed about the various organization of the nervous system into central and peripheral and further how they were classified for ease of understanding, various regions of the brain and their function, how they control the movement and what are the types of movement and the mechanism there on, what is the type of feedback loops that we have in the control of movement, mainly the local feedback as well as the central feedback and in complex movements like special sensory feedback as well. So, we also saw about various components starting from the motor neuron, the spinal cord level at the supraspinal level and at the forebrain level as well. So, the motor circuits at the higher centers mainly are to incorporate various impulses or inputs from various centers and integrate them; and to perform the complex activity with ease and also incorporate the aspect of learning and memory into the movement action. So, those of you who are interested in in-depth learning, I would direct you to go through this following textbooks for further understanding. Thank you.