Introduction to Exercise Physiology & Sports Performance
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Lecture - 10
Cardiovascular System and Exercise - Part 3

So, welcome back again to this NPTEL course on Introduction to Exercise Physiology and Sports Performance. So, we are dealing with the cardiovascular system and exercise, and we are into the part 3 of this session. So, I am Wing Commander Dr. Chandrashekara Guru. I am a sports physician an Assistant Professor in the field with the Armed Forces Medical Services. So to revise what we have covered till now; we saw about various cardiovascular parameters, about heart rate in detail, about the response that it gives in the maximal test and the submaximal exercises. We had gone through various heart rate zones and how you utilize them in exercise prescription to your clients using Karvonen formula.

We had two different exercises as well, and we also saw about various lactate threshold, and the relation with the heart rate and then exercise prescription. So the CVS parameters that we saw were basically heart rate in depth, we saw about heart rate in part 2; now in this part 3 session, we will cover in detail about the other CVS parameters and few applications as well. So the other parameters are: the stroke volume, cardiac output, blood pressure which is the pressure exerted across the walls of the blood vessel, and you have the blood distribution which is again how well the body is able to distribute blood to the needy organs. So that's what we are going to see about. So, moving ahead with the stroke volume and the cardiac output. I have clubbed both of these parameters because they are very much interrelated, okay, so if you remember we have discussed what do you mean by stroke volume; stroke volume is the amount of blood that is pumped out of the left ventricle after a single contraction. So it is generally about 60 to 70 ml right, so if you see, pay attention to the graphics that I have shown there, see the heart is relaxing slowly and then it is contracting at a rate. So this relaxation phase is what you called as diastole, you see it has taken some time you know longer than the systole. So the relaxation happens for about 0.5 seconds, and the contraction which happens it lasts for shorter than the diastole that is 0.3 second so collectively it forms 0.8 second. Say for example, in an individual with an average heart rate of 75 beats per minute, so that particular thing you know one diastole and one systole collectively contributes one cardiac cycle; so various mechanical events happens during the cardiac cycle, and the key thing why we should know about this particular cardiac cycle is to understand two different volumes. So if you again pay attention, as the heart is relaxing, the

valve is open, the blood vessel is filling. You know, the valve is open, the blood is coming inside and it is filling. In the right and in the left. Both the sides it happens, because of which the volume increases.

So, the point at which the maximum diastole happens, and the volume which is there during that time is the end diastolic volume. The volume of blood that is present in the ventricle at the end of a diastole is the end diastolic volume. The naming of the volume itself clearly gives you the definition. Similarly, when the heart undergoes a systole or a contraction, it pumps out certain amount of blood outside into the aorta, right. The left ventricle pumps out the blood at the end of systole into the aorta.

So, but not the complete amount of blood that is there in the left ventricle is pumped out. Some amount of blood remains within the left ventricle. So, the volume of blood that is present within the left ventricle after the pumping out of the completion of the systole is called as end systolic volume. Now, come to third concept called as ejection fraction. What is this ejection fraction? You understand the stroke volume, that is the amount of blood that is sent out.

So, the ejection fraction is the amount of blood that is pumped out, that is the stroke volume as a fraction of blood that is available in the left ventricle at the end of diastole. So, the heart had relaxed, it had some amount of blood at the end of diastole and then it has pumped. So, certain amount of blood has gone as the stroke volume. So, the stroke volume divided by the total end diastolic volume in percentage gives you the ejection fraction. We will discuss this in detail with an exercise subsequently.

So the stroke volume is given by end diastolic volume minus the end systolic volume, and it is also a factor of cardiac output. Cardiac output is given by heart rate into stroke volume. The definition of cardiac output is; the amount of blood that is pumped out over one minute. So, that is identified by stroke volume: it is the amount of blood pumped out per beat into the number of heartbeats. So, that gives you cardiac output that is amount of blood that is pumped out over 1 minute.

Stroke Volume = End Diastolic Volume - End systolic volume

Cardiac Output = Stroke Volume x Heart Rate

Ejection Fraction (%) = Stroke Volume/End Diastolic Volume x 100

Understood? Moving ahead, we will do an exercise to understand this concept. Let us spend some time. So, what is the stroke volume if 100 ml of blood is filled at the end of relaxation in the left ventricle and 40 ml of blood remaining in the left ventricle after ejection. So, what do you mean by this? It says that in diastolic volume, that is the volume at the end of relaxation, that is diastole is 100 ml. and the end systolic volume that is the amount of blood a volume of blood

that is remaining in the left ventricle post contraction or a systole is the end systolic volume that is 40 ml so what is the stroke volume then; stroke volume is given by end diastolic volume minus the end systolic volume which comes to 60 ml, so stroke volume here is 60 ml. So, what is the ejection fraction in the above example? So we discussed, ejection fraction is nothing but stroke volume divided by the end diastolic volume into 100 expressed as percentage. So, here it is 60%. And moving ahead, how do you calculate the cardiac output in this case with the resting heart rate of 72 beats per minute? As simple as that cardiac output is equal to stroke volume into heart rate. Stroke volume is 60 into heart rate. That is 72, which is given in this problem. So cardiac output in this case is 4320 ml per minute. You can also express it as 4.32 liters per minute. So that is what you have achieved from this exercise. So, I hope you have understood the concept of end diastolic volume, end systolic volume, ejection fraction and cardiac output calculation.

So, what happens to the stroke volume during exercise? As you exercise, there is stimulation of the sympathetic nervous system. So, I said there is hormonal raise, you have adrenaline and the noradrenaline, also the stimulation of the sympathetic nervous system. So, this causes increase in the vasomotor tone; thereby the diameter of the vessel constricts throughout the body, especially in the veins, which causes an increase in the venous return. Venous return is nothing but the blood that is transported by the veins into the right side of the heart, so that has increased, so you have the deoxygenated blood coming more into the right side of the heart; and because of which there is an increase in the volume. So, there is an increase in the end diastolic volume during relaxation. So, now also because of the sympathetic nervous system, sympathetic nervous system receptors are also there in the heart muscles.

So, this causes the increase in the force with which every contraction happens, the heart pumps increase because of the sympathetic drive. Also, there is something called the Frank-Starling mechanism. That is, as the heart increases in size because of the volume that is getting filled in, there is stretching of the cardiac muscle fiber. The stretching of the cardiac muscle fiber in itself because of the inherent specialized nature of the heart muscle, can contract with much higher force, so that is called as the Frank-Starling mechanism; and both of which result in better contraction. So, the blood that will be remaining after every contraction will be less; that is reduction in the end systolic volume. Both of these would result in an increase in the stroke volume, so as an end product the stroke volume which is pumped out after every contraction is going to be very high. So, as you do an exercise in a maximal graded test, for example, so till 40% to 60% the cardiac output increases because of an increase in the stroke volume also concomitantly.

But then as you progress beyond 60% of your maximal exertion, the stroke volume does not increase further. Okay. That you will have to remember. What happens to the cardiac output? Same thing happens by increasing the stroke volume. In addition, the sympathetic nervous system also overrides your parasympathetic and the SA node. By which, we have discussed in

the previous lecture where the parasympathetic system by the extrinsic control increases the heart rate as well, so that results in increased heart rate. So, increased heart rate as well as stroke volume increase. What is cardiac output? Cardiac output is the product of heart rate into stroke volume.

So here you have increased the heart rate as well as the stroke volume. So there is an increase in cardiac output as well. So the normal value of cardiac output when you are at rest is about 5 liters per minute. So what it means? It means that every minute your heart pumps out, the left ventricle pumps out 5 liters per minute. However, in an untrained individual who performs a maximal test, so in such individual, it can reach up to 20 liters per minute.

It does not mean that the blood volume increase. It is just that amount of blood that is pumped out during the activity, it increases this manifold. Further, in case of trained and elite world class athletes, it can reach up to 40 liters per minute. An interesting point which I said previously is that up to 40 to 60 percent the increase is by both heart rate and stroke volume, but then beyond 60 percent the stroke volume does not increase, so the predominant contributor for increasing cardiac output is your heart rate. Moving on to the next parameter: that is the blood pressure. So, we have defined blood pressure: blood pressure is because of the pumping of the blood from the left ventricle, and it produces a pressure on the walls of the arteries, and that is measured by a Sphygmomanometer. An example is shown in this slide, and it is called as the BP cuff, which is wrapped around the arm, and then you measure the pressure. So, as I said earlier as well, because of the cardiac cycle as the systole and the diastole, the pressure also changes during these two cycles. So, the pressure that is measured during the systole is your systolic blood pressure, and the diastole is your diastolic blood pressure.

So, normal BP will be between 120/80 millimeter of mercury (mmHg). Since mercury is used to measure that, it is mentioned as a unit of millimeter of mercury. So the blood pressure is measured using your BP cuff across the arteries right. However, there are two different values: systolic and diastolic, but then we generally also use another value called as the mean arterial pressure. Then it is not the true mean.

Generally what is true mean is, you had two values and divided by the number of values gives you the average. But in this case, here in blood pressure, it is because of the difference in the duration as well. So you have two-third of the diastolic and one-third of the systolic added together that gives you the mean arterial pressure. The mean arterial pressure at the aorta is about 100, which is the maximum during the cardiac this thing, and the minimum can go up to 0 when measured at the right atrium. So, if you see from the left side of the heart at the aorta to the right side of the heart at the level of right atrium, there is a pressure differential which happens across the body, and that is one of the reason why you have the which helps in better blood flow and transport of various substances through the blood. So that is important about the blood pressure,

that is given by delta p (Pressure). In addition to that, there are various factors which contribute to the blood pressure. It depends on the length, the longer the blood vessel, the blood pressure will be different.

Blood viscosity, we discussed it earlier as well. If the blood is thicker, then the resistance is more. So, pressure is going to be measured will be more. Required also will be more to deliver the blood.

And again, diameter. Diameter is very simple. So, if the lumen is, you know, increase in size, so obviously the pressure is going to be low, and if the lumen is going to be constricted or vasoconstriction is what the actual term is, so the vasoconstriction will cause further increase in the blood pressure. So that is the determination of blood pressure based on these factors. So what happens to the response of blood pressure with respect to exercise? When you do exercise as said earlier, you stimulate the sympathetic nervous system. So what it does? It also increases your cardiac output. And because of which there is increase in the systolic blood pressure, because more the output, more the sympathetic tone; so you have a increased systolic blood pressure; whereas at the level of the exercising muscle, you will have lot of waste products that are being released and there is increase in need for oxygen because oxygen is being utilized by the exercising body to produce energy as we have discussed this during the aerobic pathway of the bioenergetics module. So, there is an immediate requirement for oxygen. So, our oxygen is delivered just through the blood right. So, hypoxia is a chemical stimulator and also other chemical substances and the waste products also stimulate the oxygen. The nervous system because of which there is release of certain chemical mediators like nitrous oxide.

There will also be release of adenine, adenosine which is there in the skeletal muscle which is again a vasoactive substance. These chemical substances; what they do is, they dilate the blood vessel at the level of exercising muscle. So, throughout the body what you have is a sympathetic tone because of which the diameter of the blood vessel, the veins reduces so that the increase in venous return is envisaged. Then the cardiac output and the blood flow increases. The vasoactive substances in the exercising muscle causes an increase in the lumen of the arteries in these tissues, and this causes distribution of the blood from the least needed organs to the most needed organs.

So, that is that is how the response happens, and because of this there is not much of change in the diastolic blood pressure. This causes a better transport and delivery of the nutrients as well as the gaseous substances, and an important aspect that one need to pay attention here with respect to blood pressure and exercise is your valsalva maneuver. Valsalva maneuver is a very simple maneuver you can you also try, you can hold/pinch your nose and then try to blow out/exhale out as you close your mouth and the nose. So this is a maneuver which I am kind of simulating but this is generally done by the weight lifter when you are lifting heavy weight. What they do is,

you exhale against a closed nose and the mouth. So this causes an increase in the intrathoracic pressure, which further increases the blood pressure. It has been seen that in such individuals, the world class athletes who lift more weight where the systolic blood pressure can reach up to the level of 400s to 300s. So, one should be aware about such kind of change that can happen in the blood pressure because of exercise. Moving on to the last parameter, that is the blood flow distribution. So, blood flow distribution normally addressed is: predominantly about 50 percent of the cardiac output is diverted to your gastrointestinal tract mainly for the digestion and the kidney. So, together these are called as the splanchnic circulation, and you receive about 15 percent of cardiac output to the brain, and about 15 to 20 percent to your skeletal muscle across the body. Heart is about four to five percent, because it also is continuously pumping, so it requires blood and circulation is required for the coronary vessels. As well and skin is considered as the largest organ, where it is responsible for maintaining the body temperature. So, skin again uses about four to five percent of the cardiac output, and your bones receive about 3 to 5 percent. So what happens during exercise? So obviously when you exercise, your requirement in the muscle increases manifold, because of which the blood requirement is there at the exercising muscle. As I said before, the excreting muscle also releases certain chemical mediators because of which there is dilation in the blood vessels. So, that also causes more blood flow towards the skeletal muscle. So, from 15 to 20 percent at rest, it goes to about 70 to 85 percent.

So, where does this blood come from? That is mainly routed from the splanchnic circulation. So if you see the kidney and liver, stomach and the GIT, which generally was receiving 50% at rest now will receive only less than 5% of the total cardiac output; and we also saw that during exercise cardiac output increases from 5 liter per minute to about 20 liters per minute. So, if you see, most of the body's requirement or the purpose during exercise would be to cardiovascular systems, main purpose objective would be to direct all the blood flow to the exercising blood vessel. What about the heart and the brain? Heart receives the same amount because it is again going to function as the requirement is more. And brain also receives the same volume but then the percentage is reduced because it is in the closed space within the skull.

So you cannot receive beyond a certain volume of blood. So it will receive about 3 to 4 percentage of the total cardiac output. However the volume remains almost the same. And bones receive only 0.5 to 1% during exercise. So if you see, exercise causes stimulation of the sympathetic nervous system. There is increase in the venous return because of the sympathetic nervous system action of the adrenaline. It causes an increase in the stroke volume. Sympathetic nervous system increases the heart rate. So you are increasing the cardiac output as well.

The sympathetic nervous system also increases the blood pressure which we saw earlier and because of which there is increase in the blood flow. How does this selective redistribution of the blood happen to the skeletal muscle? It is because of the local release of the chemical substances, mainly because of the hypoxic stimuli as well as because of release of other chemical substances

which helps in increasing the diameter of the blood vessel. What happens when you have additional activities during exercise? So, you are exercising, your need is towards the diverting the blood flow towards the exercising muscle. For example I had taken a heavy meal, so my digestion is also happening so that is also an important function that has to be carried out; so the body has to divert the blood for the digestion function as well, right. And if, for example you are doing exercise in a hot and humid environment, you are landing there for the first time and you start running a marathon in a hot and humid environment, so you also need blood supply to the skin because skin maintains your body temperature. So there is a competition for the blood supply; so all this is done. So what is the application of it; it is as simple as that body identifies the metabolically active tissue and accordingly it redistributes as per the need. So, what is the application of this knowledge in your sports and exercise? See, how can you address it? This is addressed by keeping yourself well hydrated; so hydration will help in maintaining the blood volume when you are exercising in a hot and humid climate. Also, it will help in maintaining a body temperature during the activity. In addition instead of going immediately and running a marathon, if you had gone there, say at least a week or 10 days before, you would get used to the hot and humid climate.

So, your body gets acclimatized. This process is called heat acclimatization. So, the requirement of the blood supply to the skin would be far lesser as compared to a fresh one when you land immediately and start running. So, that is the application part of it where you have to time it according to the response that you require the most. And the other aspect which I said between the digestive system and exercising. So in case you have a heavy meal and then you start doing a workout.

So obviously there is a requirement at both ends. So you will not have the complete outcome that you expect out of a workout. So it is suggested and there are standardized protocol by which you have a pre-workout meal. So this is again part of the sports nutrition module which will be dealt by the instructors in detail. So moving on to the other practical applications, that one should you know focus with respect to the cardiovascular system, specifically the heart. So the problems that one can envisage can be divided grossly into structural problems that can happen in the structure of the heart or can be electrical.

So from the structure of the heart, if you see you, will have we saw that the heart is divided into three parts: the inner endocardium, the middle myocardium and the outer pericardium; and electrically you can have the abnormal pathways or block in the existing pathways. So in the endocardium if you see, as we had discussed earlier, there can be problems in the heart valves and they are called the valvular heart disease There may be infection or inflammation which can affect the endocardium. Common condition is infective endocarditis. Even in the myocardium also you can have infection where it is called as viral myocarditis. Can be an ischemia or an infarction. Can also be a congenital or a by birth problem of myopathy. Wherein you may have

thick myocardial wall which may obstruct the blood flow. So that is again a grave condition which can happen in certain people. So it is important to identify this even before the individual participates in the exercise or sporting event. As a normal variant, I have also mentioned about athlete's heart. Commonly it is a clinical conundrum that can happen between a myopathy and then athlete's heart. Athlete's heart is nothing but an adaptive response that has happened in the heart because of prolonged sports training to endurance or resistance activity. So this will be dealt as a separate module elsewhere. And regarding pericardium, you can have infection again, inflammation in the pericardium called as the infective pericarditis of the heart.

So that can happen. So these are the problems that one can envisage as a sports physician. I have brought out a holistic kind of list that can happen in the cardiovascular system. So it is important that you always undertake a pre-participation medical checkup before involving yourself in any kind of systematized or structured exercise, workout program or a sporting activity. So, this will preclude an individual from sustaining fatal injuries as well like sudden cardiac death, which is very kind of grave and can become very fatal.

Hence it is important to be aware about such conditions. So coming to the final part of the session, that is the factors that determine the response of the cardiovascular system to the exercise. The individual factors as I said as you grow old, as age increases, the maximum heart rate changes. So the physiological response changes, age is an important factor. The gender differences as well between male and the female because of the various factors including the hormonal and the nervous related factors. Body composition: body position also affects the cardiovascular response. The heart rate may be different when you lie down, when you sit, when you walk and when you stand.

So it is important that you assess heart rate in a one particular fixed position, and then you follow it up in the same position so that you don't have any changes because of these positions per se. That is the application of this particular factor in your day to day practice in sports. Sleep is again an important factor, because all your nervous system and most of the systems in the body, they recover during sleep. If the individual has not slept well, adequate in terms of quantity and quality, it will also kind of change the responses of the cardiovascular system.

Any illness as such also will change the heart rate. Demographic features that one needs to pay attention to are the ethnicity, anthropometric changes with respect to the body size; because body size will determine the volume as well and the cardiac output as well. The race also is one of the important factors, because of which there is change in the various cardiovascular parameters. Coming to the exercise related factors: The training status of the athlete per se, there will be a lot of difference in terms of the one who is not trained, who started training and to one who is well trained. So we saw an example earlier that after 10 weeks of a proper structured program, you found the resting heart rate has reduced from 70 to 60.

So that reduction is because of the training status. Type of sports again have different kind of response. These cardiovascular responses will be different in different types of sports. In a resistance exercise the BP will be different. In an endurance activity the BP will be different.

So that is an important aspect one has to remember. Again, if you are an athlete the responses also vary with respect to the different phases of training. So if you are in season your response will be better because you are training every day. If you are off season so obviously you are taking a low load on your physical activity, so obviously the response will be slightly different. What are the other environmental factors? Environmental factors: I had earlier discussed about the effect of temperature and humidity.

Also, there are day to day variation. So why we said that the resting heart rate should be measured early in the morning. So the heart rate if you see, in the morning it is low. As the day progresses, the heart rate increases even with the temperature. The temperature which is measured in the morning at six o'clock and at evening six pm there will be difference of one degree. So that's how there is a difference in the cardiovascular parameters over a day. So the measurement that you make to monitor your progress has to be in a fixed particular position as well as the point of time of day during which you are measuring this particular activity. The other factors are what you consume, the pre-workout meal or pre-assessment meal; if you are doing an assessment if the individual is full stomach obviously the cardiovascular responses will be different. Depending on the hydration as well as what whether he has taken alcohol the previous night or has consumed coffee or tea before the exercise training, or if the individual has taken any sports drinks; because sports drinks generally have caffeine as a content, so that may again increase the sympathetic nerve system, even smoking. So, these are the other factors that one should consider when you are using cardiovascular parameter as a training tool for your exercise prescription and sports training. So the take away from this cardiovascular system and exercise module is that Heart rate is an important tool which can be easily accessed using your wearable technology by which you can access, you can prescribe and you can follow up the individual over a period of time; and it can give you very beneficial, important inputs, objective inputs apart from the response that the individual per se can give you. So sports is a very important aspect and also about blood flow distribution.

So you know this effect of different activities. So accordingly that will also vary your direction of that distribution of the blood flow to the needy organ. So accordingly, you can plan your activities and avoid such activities during exercise workouts. The other important aspect is about the blood pressure which I said, blood pressure and specific maneuvers can also increase them especially in resistance training that needs to be given some attention. So with the various aspects that can happen in the heart and the blood vessels and the blood, it is very very important that an individual should undergo a pre-participation screening by a qualified physician so that

you get to know if you are having any issues with respect to this cardiovascular system.

So that if you do not have an effective cardiovascular system, obviously you will not be able to reach a level of good sports performance. That is why, the knowledge and the screening of these factors are very essential. And last but not least, when you are exercising in hot and humid weather conditions, it is always important that in order to have a better performance, you hydrate yourself and have adequate heat acclimatization, so that your cardiovascular system can function efficiently during the event per se. So most of my lectures have been covered from standard textbooks. For additional requirements and in depth knowledge, you can consider these standard exercise physiology and sports textbooks which are shown here. Thank you so much. Thank you for participating in the course.