Introduction to Exercise Physiology & Sports Performance
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Lecture - 09
Cardiovascular System and Exercise - Part 2

So, welcome once again to this NPTEL course on introduction to exercise physiology and performance. So we are continuing with the part 2 of cardiovascular system and exercise. I am Dr Chandrashekara Guru, Assistant Professor, Sports Medicine with the Armed Forces Medical College, giving you a brief perspective of a sports medicine physician in this topic. So, you will be learning in these lectures about the basics, the parameters, various responses of the cardiovascular system and the application in exercise training. So to revise, what we have covered in the previous part one, so we covered the basics of cardiovascular system, wherein we discussed about the components, we discussed about the function of the cardiovascular system, the structure of the heart, the location, how it is divided into various chambers, what are the different valves that are there in the chambers, how the blood flows from the right side of the heart from different parts of the body to the right side of the heart to the inferior and the superior vena cava into the right atrium, thereafter into the right ventricle followed by the movement into the pulmonary artery, into the lungs and where it is again the oxygenated blood is transported from the lungs to the pulmonary veins, and from there it is transported to the left atrium; thereafter through the mitral valve into the left ventricle where the left ventricle pumps out the blood to be supplied to different parts of the body through the aorta with the high pressure. So, we also discussed about the blood vessels where the arteries carry the oxygenated blood, which is pumped by the left ventricle into the aorta, the largest blood vessel or the artery of the body. And from which it is further branched out into arterioles into different small network of capillaries in the tissue level to promote easy exchange, and how their you know organization or the wall of the capillaries where they have single layer of cells for easy diffusion and transport of the nutrients and the gases. We saw how the blood flows across and deoxygenated, blood moves into the veins, venules, the veins and thereafter into the right side of the heart through the superior and the inferior vena cava.

We also discussed about the components of the blood; divided as the liquid component called the plasma, and the cell components called the RBCs or the red blood cells, white blood cells and the platelets. We also discussed about the importance of viscosity in the blood. So moving ahead, let us discuss certain parameters. When you speak of the cardiovascular system, you speak in certain terms of parameters to understand the effectiveness of the cardiovascular system.

So, the first thing which we saw was the conduction system, wherein you have the beating of or what you call the contraction of the heart per minute, which is an automatic activity by the specialized tissue called as the cardiac cell; and the specific point from which this automaticity or also called the impulse generation happens is called as the SA node or the sinoatrial node, and the inherent capacity of this node is to beat at around 100 beats per minute, but because of the various other external factor it gets reduced to a resting rate of 72 beats per minute. So, that leads to parameter called as heart rate; heart rate is the number of contractions that you could measure over a minute, it is beats per minute and it is generally 72 beats per minute. The next important parameter is the stroke volume; so the heart contracts, and because of the contraction, you have the left ventricle ejecting some amount of blood, right? So, with every contraction, how much blood that is coming out of the left ventricle is called as the stroke volume. And it is about 60 to 70 ml. And when you combine the stroke volume into the number of contractions that happens over one minute, that becomes your cardiac output. So, cardiac output is the product of stroke volume and heart rate, and it is depicted as ml per minute. It is very simple right, and the fourth parameter is the blood pressureI So I mentioned in the previous session that the left ventricle pumps out blood with an enormous pressure, so that pressure is exerted onto the valves of the arteries, and that is what you measure using your BP instrument or sphygmomanometer using a cuff around your left arm and that is called as your blood pressure.

Cardiac Output (CO) = Stroke Volume (SV) x Heart Rate (HR)

The blood pressure is what you measure, the pressure which is exerted across the wall of the artery is what you measure using your BP equipmen;t and as we mentioned, the heart pumps and causes a contraction you know and then it relaxes for filling up or receiving the blood from the atrium. So there are two different phases right, so because of which there is a difference in the pressure at the level of the arteries as well. So, hence you have a systolic blood pressure, that is when the pressure that is exerted because of the systolic phase or the contraction of the heart, and you have a diastolic blood pressure which is because of the relaxation of the heart. So, the pressure exerted in the blood vessels when the heart relaxes during the diastole is called as the diastolic blood pressure. So, when you take an average of this is called as the mean arterial pressure, which is given by cardiac output and the total peripheral resistance. So, obviously the pressure is determined by the cardiac output, the amount of blood that is you know ejected by the heart over a minute; and the resistance that is offered at the level of peripheral tissue that is called as the total peripheral resistance. And the final parameter is the blood distribution; because it is also important that the right amount of blood is distributed to the needy tissue, that is where the component of blood distribution comes into play.

So, we will look about each and every parameter in detail and in this particular session we will focus mainly on the heart rate: how the different you know components of heart rate based on the exercise activity, how they are measured? how the body responds to an exercise, how the heart rate is measured based on the response to the exercise, and also the application of the heart rate in the sports training together. So, we have the heart rate. We start with the resting heart rate. The resting heart rate is nothing but the heart rate that you measure when you are rested. The name simply gives you the meaning, and it normally ranges between 60 to 100 beats per minute.

Whenever the heart rate is less than 60, it is called as bradycardia. Whenever the heart rate is beyond 100 beats per minute, it is called as tachycardia. So, how do you measure this resting heart rate? So, resting heart rate is generally measured in the early morning time when you are lying flat on the bed, you open up from sleep but then you are not completely got up from the bed you just open your eyes and then measure your heart rate either using your three fingers sliding across the you know neck, and you will feel the pulsation you can measure. That is the best way of measuring your central, you know heart rate; or you can also it is called as the central pulse, because it is close to the heart rate or you can also measure using your traditional way of measuring using your wrist. So this particular heart rate has to be measured over a period of one full minute. So you count the number of times you feel the pulsation in your palpating finger for one full minute, and that is called as the resting heart rate. The normal range as I have said earlier, it is between 60 to 100 beats per minute. All this heart rate is controlled. It is important to understand because I have been saying since beginning that the SA node has an inherent activity to beat at 100 beats per minute.

But then, I now said that more than 100 would be termed as tachycardia. But then the normal range is generally between 60 to 100, how this is happening: that is because of the extrinsic control. Extrinsic control is by two different systems, one is the nervous system, mainly by the parasympathetic system. The parasympathetic system generally reduces your heart rate, it calms down the heart rate. Si, I will give an example; you detach the complete heart from the body, keep it alone, because of the feature of automaticity it can pump on its own, it can beat without any other connection with the body; so that is the special you know feature of the heart, because of the automaticity, but then that time it will be pumping at around 100 beats per minute. Then now, by virtue of being inside the body there is control, there is override of the nervous system over the inherent beating capacity. So, that results in a reduced calming effect by the parasympathetic system. And whenever there is a need, whenever there is an immediate response, you would have heard about the fight, flight and the fright response. So, whenever in these kind of situation you have additional you know release of certain hormones in the blood, so that is the second extrinsic component through the blood in terms of adrenaline and the noradrenaline and also the nervous system as a sympathetic nervous system component; so all these components result in increasing the heart rate. So the inherent capacity of the heart to beat at 100 beats per minute can be controlled to be reduced by the parasympathetic system to increase beyond if requirement is there by the sympathetic subsystem and the hormones.

That is about the resting heart rate. Moving ahead with the maximal and the submaximal heart rate. So, we learnt about the resting heart rate, which is the basal heart rate. Now, we learn about the maximum; so maximum individual can take the heart rate during an exercise on a peak exercise is called as the maximal heart rate. So, the maximal heart rate is generally given by the formula 220 minus age. say for example I am 40 years old So, my maximal heart rate would be 180, right. However, this formula has a variation between 10 to 12. So, if I actually do, by calculation, my maximal heart rate is 180. Whereas, if I perform an activity, I can go even up to 190 or 192.
Maximal Heart Rate = 220 - Age

It may happen or I may not be able to reach even 170, so there may be a variation of 10 to 12 beats on either side, both on an higher side as well as on a lower side. So, that's one of the thing that you should remember with respect to the maximal heart rate, and the other important aspect is this maximal heart rate decreases with age. You know, obviously the age increases (220 minus the age) age increases, so obviously the maximal heart rate will reduce down right. What is the submaximal? So, if you are not performing at the maximal effort, you are performing at a lower than the maximal effort, what happens is body reaches a state wherein you are able to meet the demands, so steadily you are able to meet the demand the energy system are able to meet that demand which is imposed through the activity So, because of which your heart rate and the other aspects or other parameters also becomes stabilized or steady and that particular is called as the steady state heart rate, and it is called the submaximal heart rate. So, this happens in cases of the submaximal activities. Generally maintained between 55 to 70 percent of the total effort that you could perform. So that is the submaximal heart rate. Generally these are expressed as percentage of the training activities, or the training intensity are generally expressed as percentage of the maximum heart rate. The third component or the generally commonly used parameter of heart rate is the heart rate reserve.

So, we saw the resting heart rate, we saw the maximal heart rate. So the in between heart rate values between the maximum and the resting is what you have for your exercise activity right, and that is called as heart rate reserve. That is the heart rate reserve that you have to perform an activity, that is maximum heart rate minus the resting heart rate, and it is further you know used by Karvonen, a famous scientist to give a formula to identify the training heart rate The training heart rate is given by the heart rate reserve that is MHR minus RHR into the training percentage or the intensity in terms of percent plus the resting heart rate. So, have the resting heart rate, the training heart rate is the reserve percentage of intensity. So, that is what is given by the heart rate reserve. And this particular heart rate reserve or the training heart rate is closely associated with the maximal oxygen consumption.
Heart Rate Reserve (HRR) = Maximum Heart Rate (MHR) - Resting Heart Rate (RHR)

Karvonen Formula: Training Heart Rate = HRR x %age + RHR

Moving ahead, we have the recovery heart rate. So, you have done the activity, you have come to an end. They have completed the activity. Thereafter, the heart rate which has reached the maximum has to come down to baseline, right? So that particular time duration by which the heart rate during the exercise comes down again to recovering back to the baseline level. The time taken is the recovery and the heart rate dynamics which happens during that period is the recovery heart rate.

And it has again been found to be a measure of cardiorespiratory fitness. An important aspect which you should know is that, if the reduction in the heart rate is not more than 12 beats per minute, it signifies that the individual has a mortality risk, especially in patients. That has been proven. The last parameter is the heart rate variability. It is a widely used parameter nowadays and it is nothing but the variation between every beat.

From one beat to another beat what is the variation? That becomes the heart rate variability. It is recorded generally using ECG, where you find exactly the R wave and then you can find out the difference between two different beats. So that is again considered to have a better correlation with the cardiorespiratory fitness; and more so when you take the HRV reading during sleep that gives a better state idea about the training state of the athlete or the individual. You will have to also remember that as the heart rate increases, the variation reduces, because the heart rate is frequently coming so obviously the difference is low. When the heart rate decreases, that may be because of the increased sympathetic stimulation or may be because of decreased, you know, parasympathetic input to control or can also be a sign of overtraining.

So, that is the importance of heart rate variability. So, let us see it with an application in terms of a Maximal graded test. What is the maximal graded test? When you ask an individual to do a treadmill or a field test. Field test, for example, is a beep test or a yo-yo test. So you want the individual to exert to the maximum. But, not that randomly the individual will exert a maximum, but with a prescribed protocol and graded over a period of time. So, that is called as a maximal graded test. Commonly, we do a yo-yo test in cricket or football and that is a field test. In the lab, you can use a treadmill with different protocols to reach the maximal exertion.

So, what is the heart rate response in this? This is an heart rate response of an athlete who we had measured in our institute using you know a smart watch or a heart rate monitor. So, the individual you see here before the starting of the event, the individual knows that you are going to run right. Mere thought of that itself you know releases hormones, adrenaline, because you know that in anticipation that you are going to run, so your body starts warming up and preparing yourself, so that itself releases the sympathetic hormones; namely the adrenaline and norepinephrine, and causes an anticipatory response, so your resting heart rate starts to increase. So, as and when see the the resting heart rate has started to increase around the 72, so you have a anticipatory response, minimal increase from the baseline, and then from here onwards the activity had increased over a period of 24 minutes. So you will find that heart rate gradually increased with every grade increase in the grade, it reached a level wherein further there was no rise so that particular increase had resulted in maximal heart rate. So, for this individual it was 201 beats per minute, and he reached maximal heart rate. So, that was the end of that maximal , which he could reach and thereafter the exercise was stopped.

So, the criteria to terminate a maximal graded test is when the individual has reached the volitional exertion. So, we stopped the test and he has reached maximal heart rate. So, from that time onwards the heart rate you see, has started decreasing gradually over a period of time you know. And during the activity also if you see, you see the different colors. So, this entire heart rate reserve, heart rate reserve can be divided into different zones based on different percentage of the maximal heart rate.

So that's how you have different zones, which is automatically programmed in these watches. So you will find these watches giving you all these zones, you know, when you run only. And thereafter, With the recovery, the heart rate has started reducing and it took some time. So, we have recording only till 32 minutes. Further, it would have taken some time to come down to baseline.

So, this entire process is the recovery time and the heart rate that is measured is called as recovery heart rate. So that's what about a maximal exercise and the heart rate response. We discussed something about the submaximal heart rate. So now the common lab test that is used to measure the submaximal heart rate and indirectly predict the VO2 max or the maximal oxygen uptake is called as an Astrand cycle ergometer. The picture shows this Astrand cycle ergometer in our lab.

Then the individual is asked to do the activity on an ergometer, so you can program, they are already pre-designed and programmed in the cycle. So it is a six minute test, where even an old aged individual with any limitation also can perform this activity since it is a non weight bearing activity. So, let us focus on the submaximal heart rate, in response to this submaximal exercise. So, I want you to pay attention to this graph wherein, see this is with time up to six minutes we have done the test, and then we have have you know plotted the heart rate and the revolution per minute and the pedal revolution is plotted here. So, if you see the rpm is what you see it has been kept constant at 60. See this green part, the individual was asked to maintain a 60 revolutions per minute. So, that is what the pedaling rate is, and during that time, gradually the power was increased until the period of 3 minutes. The first 3 minutes you gradually increase the power or the weight in the cycle. So, gradually the resistance was increased, and after this point say when the individual reached 900, it was not increased further. From this point onwards, if you see, the heart rate also gradually increased along with the increase in the weight, you know with the demand, the heart rate increased and when the demand was fixed constant or steady, the heart rate also started becoming steady, so that is called as a steady state heart rate. Steady state heart rate is what you get from a submaximal heart rate, and this particular heart rate at the fifth and the sixth minute is taken, last five seconds of this is taken to calculate your VO2 max, so in this individual the VO2 max was 38.37 ml/kg/minute; thus with the heart rate you can also predict the VO2 max, or the cardio respiratory. Moving ahead, I discussed about various heart rate zones, so this slide gives you an idea about the different heart rate zones based on the percentage of maximal heart rate, and how they are used in various training phases. So, you can go through the slide and you can also go through the reference books that I will be showing at the end of the talk for further in depth knowledge. So, let us focus on an exercise with whatever we have learnt till now. So, you have a 50 years old Mr. Ram who has recently joined your gym. As a fitness trainer, you want to give a scientific advice to your client.

So, he is interested in improving his cardiorespiratory fitness. Okay, so his resting heart rate is 70 beats per minute. You had, you know, kind of assessed it and then thereafter you wanted him to train in a low intensity of 40% only initially because he is just a beginner and you wanted to not, you know, first you want to condition him and thereafter, you know, prescribe him a higher intense exercise considering his age as well. So, how do you calculate what should be the training heart rate, because he says I have a smart watch so you tell me how much should be the heart rate which I have to train so how much should be the training heart rate that he needs to maintain during the treadmill walking session? Can you give that? so it is a very simple problem, see, we studied about the Karvonen formula to identify the training heart rate right. So, training heart rate is given by maximal heart rate minus the resting heart rate and it is multiplied by the percentage of intensity that you wanted the individual to perform and then to that you add the resting heart rate.

So, we know the resting heart rate that you measured was 70 beats per minute right. So, just fit in the values in the formula. So, maximal heart rate is given by 220 minus age, age here is 50 years. Then you reduce 70 which is the resting heart rate from it and then multiply it with the intensity that you want him to perform that is 40%. And then you add the resting heart rate to it which is 70. So that gives a value of 110 beats per minute.

THR = (220-50) - 70 x 0.4 + 70

100 x 0.4 + 70

= 110 bpm

So, you can tell him that Mr. Ram you can maintain your activity of walking and monitor your watch for not crossing beyond 110 beats per minute. In fact, you can also give a range between you can maintain your activity between 105 to 115 beats per minute. So, that is a range where you can arbitrarily give. So, that is what you can advise your client using this scientific methods.

Let us also consider another exercise as well.

The same individual you know, you have trained him. He got conditioned over 10 weeks of your training program. He improved and his resting heart rate when you measure now it has come to 60 beats per minute. So you see the effect of training which was initially 70 has now come down to 60 beats per minute. So this is a subsequent lecture which we will deal with later.

So this 60 beats per minute is the resting heart rate that you mentioned. You have measured then you have given, he was able to maintain a training heart rate given at 148 beats per minute during a treadmill jogging session. So you did a test wherein you say that my heart rate has reached 148, then how do you calculate what was the percentage at this at which he had done the exercise treadmill session? So again, the reverse of Karvonen formula can be used, you just feed in whatever the details that you have you have the maximum heart rate minus the resting heart rate so maximum heart rate here would be 220 minus the age, and then you reduce 60 which is what you have, and then thereafter you can also include the training heart rate that is 148, so that will give you the intensity that is 80%. So initially you started with 40% intensity now the individual could go up to 80% intensity over 10 weeks of training. That is the interpretation of this particular formula. So that is how you can objectively you know come to a conclusion how the individual is improving his fitness with your exercise prescription. Another important you know aspect that we use is the lactate threshold training zone prescription using the heart rate.

Lactate obviously I had mentioned in the previous session in bioenergetics that lactate is one of the method by which you can identify the anaerobic aerobic transition, and thereby you can prescribe them the activities or the exercise activities or the training. So, let us see a case scenario wherein this guy is a 21 years male, the boxer and we estimated his lactate threshold so that we wanted him to do it on the ground. So on the field you cannot carry a blood lactate analyzer and then you prick and then take blood and then analyze and say okay this is your lactate level, you will have to now do in that way, which is not possible. So what we do is, we do it in the lab using this thing you can also do it in the field also, so probably once in a quarter or once in a six monthly you can assess based upon your protocol and the feasibility of the resources, and that is now done and it is end of plotted on a graph. So now, if you see this graph want to pay your attention to the x axis, the x axis is marked as per the time duration in minutes the activity done, so here you have the individual reaching the maximum say at around 18 minutes okay, unlike the previous one, and we have marked the y axis with the blood lactate, the y axis is blood lactate, and the y dash is with the heart rate which is also measured when the test was performed; so when you see the lactate is given in the continuous line, and the heart rate is given in dotted line. Okay, so let's focus on the lactate line, so when initially the individual started, it was somewhere around 1.6 or so, you plotted here; as the individual did the graded maximal exercise test, after every two minutes, the individual's finger was pricked, the blood was taken and then it was measured using a blood lactate analyzer and the reading was plotted.

So this reading has been plotted after every two minutes, and then a graph has been made. So basically this was an outlier. So, we have used this and gradually there was an increase. So there was a point at which the lactate suddenly started increasing, you see that, so that is a disproportionate increase, and that is the point which you call as the lactate threshold point; and from that point what we did was, we marked the corresponding heart rate from here, so we got this point as the heart rate which was during that particular lactate threshold, and this you know you catered for the range so you calculated between 154 to 166 is the lactic threshold training that the individual has to perform. So that is how with the help of lactic threshold you can indirectly provide the input to the athlete, and the coach for them to further train the athlete in the field. That's how heart rate becomes an indirect measure to summarize. We discussed various cardiovascular parameters.

We also discussed about the various components in the heart rate that is utilized in the field of sports and exercise. We had a scenario or case scenario of the heart rate response happened in a guy who performed a maximal exercise test. Then we saw about the submaximal exercise wherein I showed a graph of an astrand cycle ergometer done on an athlete, and how the submaximal heart rate was useful in predicting the maximal oxygen output. Thereafter, we saw the different heart rate zones and two different exercises using the Karvonen formula, and also we saw the application of heart rate and the lactate threshold in exercise prescription and further assessment. So, for further in-depth knowledge you can consult or go through these standard textbooks. Thank you so much for being here.