Introduction to Exercise Physiology & Sports Performance

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Directorate of Medical Services

Lecture - 23

Adaptations to aerobic and anaerobic training - Part 1

A gym trainer comes to you and asks, my client is a long-distance runner. When I assess his endurance, he is far better than any other clients who train for better body shape. So, he has this doubt, what would the reason for these changes that have happened in him and how are these two category of training different? And he also has a doubt, can I include weight training to my client who is an endurance long-distance runner? So, if you are looking for answers for these questions, then you are here with me today in the NPTEL conducted course on introduction to exercise physiology and sports performance, to this module on adaptations to aerobic and anaerobic training. So, I am Wing Commander Chandrasekara Guru. I am a sports medicine specialist with the armed forces medical services, and I shall be covering this module under three parts.

So, let's get into the core of it. So, you will be learning in this module about aerobic versus anaerobic capacity. What are the training adaptations that happens due to aerobic training and anaerobic training? And what are the factors that influence these training adaptations and various use-case scenarios which are useful for exercise professionals as well as for sports scientists? So, what do you mean by exercise training? Exercise training, broadly, we can classify as aerobic training and anaerobic training. Under aerobic training, you mainly, you know, aim at increasing the cardiorespiratory function, increasing the blood flow to the exercising muscle, and also addressing the oxidative energy system to produce ATP.

Whereas in the anaerobic training, your focus is mainly on, kind of increasing the neuromuscular function, and your focus is mainly to trigger the anaerobic pathway of energy system to produce ATP for the relevant exercise activity. So, with repeated bouts of exercise which are planned and systematic and performed over a period of time, you kind of induce the adaptations to this exercise training. And these cause physiological adaptations which are very specific and what we have discussed earlier in another module that is on exercise training principles. So, the adaptations in the physiological stimulus happens in the body is in response to specific exercise stimulus. By means of this, you're trying to increase the exercise capacity and the sports performance.

So now this becomes more sports-specific or what is the goal that you wanted to give to your client. So, if you're giving an aerobic training to your client to increase the performance, it will be more of an endurance performance. The sports would be majorly covering the endurance

sports, namely long-distance running or can be swimming, can be hiking or trekking, which is going to have prolonged duration. Whereas an anaerobic training would be given to sports which are specific, which triggers the anaerobic pathway and they are very shorter in duration and predominantly these sports are more towards the muscular strength and performance. So that's the difference between your aerobic training and anaerobic training.

Moving ahead, are both required? That's the question. That's a very important question. An exercise professional would ask you, a gym-going enthusiast will ask you. So, exercise training principle guide what kind of adaptations that you require and what kind of performance that is required. So, this predominantly revolves around the principle of specificity. So, we had gone in detail about the principles of various basic principles of exercise training in the previous module. For those of you who are new, you may refer to that particular module to have in-depth knowledge about different training principles. One among the principles, basic principles of exercise training is the principle of specificity, wherein it is the adaptation which happens are specific to the demands that you provide. So, accordingly, you will stimulate a different type of energy pathways, thereby you produce a specific adaptation in the body. So, the anaerobic sports will have repeated bursts of activity and they are of short duration in nature. So, because of which you will trigger predominantly the anaerobic pathway or anaerobic energy system, which again we have covered in the bioenergetics module. For those of you who are new, you can refer to that particular module for in-depth knowledge. Shortly, the bioenergetics or ATP, which is the energy currency to provide you the energy for the exercise is derived from ATP, which is available in short or low quantity. Subsequently, it is refilled or replenished by your phosphocreatine pathway, thereafter by your anaerobic glycolytic pathway, then the oxidative mechanism using the carbohydrate and the fat as source. So, in anaerobic sports, it is predominantly short-duration activities. So, you will require the triggering of energy pathway in terms of ATP and phosphocreatine as well as the anaerobic glycolytic pathway. So, in order to have, so one thing which I mentioned here is repeated bursts. Say for example, you take an example of boxing. Boxing will have a bout varying between two to three minutes, but then it happens in three different sets. So, you will have three different bouts. So in between boats, you will have a very short gap. So, you will have to be the boxer has to have that energy to perform that activity with full efficiency, which is again short duration, but then repeatedly. So, the quality depends on how well the individual is trained to trigger this pathway. The aerobic sports generally, you know, is long duration, which we discussed earlier. So long duration predominant energy source is your aerobic energy source that is your oxidative metabolic pathways derived from your Krebs cycle and the electron transport chain. So, however, in these types, these athletes also, towards the end, they would also require a faster pace to complete the race. So there, the demand placed is very high, high-intense activity. So, you also require immediate energy release. So, you also require the anaerobic pathway. So, though we differentiate, saying that aerobic and anaerobic, both this group of people or athletes would require, you know, activation or adaptations in both the system.

So, it is important to remember that both would be required, our which predominates depends on the type of sports. So, it is sport-specific, there is something, a principle or a concept called as concurrent training, wherein you have both types of training happening in the same athlete that is found to improve the performance, what will be the type of sports, but then if you want to have a predominant type of training that needs to be adapted in the body, for example, a wrestler. So, as we discussed, you have three different wrestling bouts, the bout lasts for about two to three minutes. So, your requirement is more towards the anaerobic pathway, but then because of different or multiple bouts, which are happening and you want each bout to have the highest quality or maximum performance. So, the replenishment of ATP is also required, which again can happen from the oxidative. So, a wrestler probably, for better performance, predominant energy source will be the anaerobic source, but then in order to have maximal or better performance, you also need to train the aerobic pathway as well. So, in this case, a concurrent training will involve predominant training methods towards focus towards your anaerobic pathway. However, we also include the aerobic pathway along with the training protocol. So, that involves including inclusion of both your aerobic as well as anaerobic training methods in a particular, you know, session is called as the concurrent training method.

Let's go with a case scenario. Ramesh is a wrestler, wrestling requests maximal strength, which we know as per the sport-specific, he needs to defend and resist the muscular strength of the opponent. So, his training program also includes some amount of slow running activities. Do you think the sport-specific adaptation that is maximal muscle strength will be affected if he performs running? So, we said that the principle of specificity is there. However, we are now saying that a wrestler who has to have maximal strength should also have some amount of aerobic activities or aerobic training included in this program. So, the question here is, will the adaptations that are, you know, acquired because of this aerobic or anaerobic training, will they get kind of damper or reduced because of the inclusion of a running program? So, it's a very reasonable question. So, let's discuss this muscle strength require anaerobic pathway, right? And it is of high intensity and short duration. But the competition involves multiple bouts, which as I mentioned before, the replacement of ATP happens through the aerobic pathway. And he has to be ready and fit to participate in the multiple bouts during the day as well. So, it's not necessary that only during the three different bouts of that particular match, he has to be prepared, he has to be prepared for the subsequent matches as well, which can be scheduled in the same day. So that requires aerobic muscle endurance as well. So, inclusion of short running activities, not much of predominant in nature can replenish this ATP which is exhausted because of the bouts. So, the training program must focus on the principle of specificity predominantly or work can also include some aerobic activities in terms of recreational activities or in terms of very short duration or small sessions during the entire microcycle.

So, with this kind of basic knowledge, let's see what is adaptations that happen to exercise training. So, because of exercise training, we'll have training adaptations, which can happen in various physiological systems, it can happen in cardiovascular system, respiratory system, nervous system, muscular adaptations, which also happens in the bone and the connective tissue, the skeletal framework, and there are various endocrine-related systems. So, over the

past few modules, we have covered the cardiovascular, respiratory system, neurophysiology, muscles musculoskeletal physiology, as well as its relation with respect to the exercise and the responses. So, I would at this point in time, I would urge all of you to have a look or go through these modules to better understand this adaptations that happens due to aerobic and anaerobic training.

So, let's focus on adaptations that happen in aerobic training. So, predominantly aerobic training, as I said in the first slide, it is more towards to increase the cardiorespiratory fitness and also to increase the blood flow and to trigger the aerobic pathway, right. So accordingly, the adaptations predominantly happens in cardiorespiratory system, neural adaptations do happen, but then more predominantly, the respiratory system, the lungs, the heart and the exercising muscle, these three are important for your oxygen delivery. And obviously, the metabolism is important. So where the energy system is triggered, so metabolic adaptation is also an important, plays an important role in aerobic training adaptations. There are also other adaptations which happens in bone, and the connective tissue, which are the basic framework of the skeletal muscles as well as your endocrine adaptations.

So, let's focus on them one by one. So, the cardiovascular adaptations that you would generally have in because of the aerobic training are with respect to the heart size, with respect to the stroke volume, which you must be aware about stroke volume, which is the amount of blood that is pumped every after every beat with every beat of heart, the amount of blood that is pumped from the left ventricular stroke volume, and that is calculated for one minute. So that gives you a volume of blood that is pumped per minute. Then you have the heart rate, which is again the number of beats per minute, cardiac output is the product of heart rate and stroke volume, and changes that happens in the distribution of the blood as well as the blood flow.

So how do you evaluate a cardiorespiratory endurance or the aerobic capacity? So, this is again a special specific kind of topic. How do you assess various adaptations that happens in your athletes? So that's again a separate module in itself. But in order to understand, we need to know that how do you assess this endurance capacity. So, the maximal endurance capacity is one way of assessing the changes that happens in the cardiorespiratory system, objective way of measuring this aerobic capacity, when you get a numerical value, the it is nothing but the highest rate of oxygen that is consumed during a maximal activity. So, when you know, kind of ask your athlete to perform a maximal activity until exhaustion and the oxygen that is consumed during this entire process is the maximal oxygen that is consumed as the VO_2 max. And with aerobic training, you can assess VO_2 max and see how effective your training program is and how the VO_2 max has varied over a period of time. So, this improves with the aerobic adaptations.

In addition to this, there are various other things which we will not go in this and it is beyond the purview of this particular module. So those of you who are interested in knowing what are the other methods by which you can assess your endurance training, we are referred to that particular module, which is covered by Colonel Anup Krishnan.

So, let's focus on the fixed equation. So, we have discussed during our lecture on cardiovascular system and exercise, the maximal oxygen consumption is determined by two factors. One is the cardiac output, the other one is the arterial and the venous oxygen difference, how much of oxygen that is present in the artery and the vein. So that difference with the product of the cardiac output gives you the maximal oxygen consumption. And we also know that cardiac output is a product of stroke volume and heart rate.

VO_2 max= CO × ((A - V)O_2)

Where,

CO is Cardiac Output,

(A - V)O_2 is the difference in oxygen content between arterial and venous blood.

And, CO is calculated as the product of stroke volume (SV) and heart rate (HR):

CO = SV × HR

Therefore, combining these formulas, we get:

VO_2 max= (SV×HR) × ((A - V) O_2)

VO_2 max= (Stroke Volume × Heart Rate) × (Arteriovenous Oxygen Difference)

So, when we further see the maximal oxygen consumption, there is nothing but the maximal stroke volume, the adaptations which happens in terms of maximal stroke volume, maximal heart rate, as well as to have the maximal arteriovenous oxygen difference. So, all these three when they reach the maximum, you have a maximal oxygen consumption, it's as simple as that.

So, in order to achieve this, you have various adaptations that happens. So, it happens in the heart size, heart size increases. So, because of this, because of the demand, exercise demand, there is excessive working of the heart to pump more blood. So, that causes an increase in the muscle of the heart, the cardiac musculature increases, there is thickness of the left ventricle predominantly increase, because left ventricle is the one which is which pumps the blood into the aorta, right. So, the next thing is you also have increase in the volume as you get trained with aerobic form of methods. So, this also increases the volume of the left ventricle. So, left ventricle volume also increases, left ventricle thickness also increases. And this particular adaptation which happens in the athlete's heart is termed as the athlete's heart. So, the athlete's heart is a condition which is a normal variant in case of trained individuals, wherein you have increase in the thickness of the heart. Whereas in a sedentary individual, if there is these changes are detected in ECG, they are pathological or abnormal, whereas in a trained athlete, these changes are considered to be beneficial to increase the cardiac output. So, they are normal

in these kind of people. And these adaptations which happens are again specific to training. So, we discussed about principle of specificity. So, the adaptations that happens, which increases the thickness or which increases the volume is very specific to the training. So, with endurance training, there is predominantly increase in the volume. So, you will have more of a changes with respect to the increase in the volume of the left ventricle. But there also will be increase in the muscle mass as well. But then it is not so predominantly reflected as compared to the volume in case of endurance training. Whereas it is the other way around in case of what you call as anaerobic training. Anaerobic training has predominant increased thickness of the muscle mass because of the increased peripheral resistance that is there in the peripheries. So, because of which the thickness is more as compared to the volume. So that is the difference in the adaptation that happens in the cardiovascular system with respect to aerobic training and anaerobic training. So, these training adaptations are not permanent. So, with detraining, that what do you mean by detraining? The individual is not exposed to regular repeated bouts of training. So, exercise training is all about repeated programmed exercise training, right? So that is absent. So, if that is not there, then these adaptations slowly come back to normal, which was before the exercise state. So, these are reversible. So, that is an important thing that one needs to know.

Let's focus on stroke volume and heart rate. So, at rest and the submaximal rate of exercise, there is increase in the stroke volume predominantly because of the increase in the heart size. So, when the size is more, obviously the volume that is being pumped will increase. So, the heart volume is more because of which your end diastolic volume is also increased. So, we know that diastole is the phase when the heart relaxes and the blood gets filled up, right? So, if your volume is more, so obviously the filling of blood is more. So, end diastolic volume is more. So, if the end diastolic volume is more, then the heart pumps, so it can pump more blood out into the, so possible because of increase in the volume of the heart or increase in the size of the heart, which results in increasing the end diastolic volume. Moreover, what happens is because of this already increased stroke volume, so we know that cardiac output is maintained throughout the rest as well as the submaximal exercise. So, this particular, because the stroke volume has increased, so there is not much of a need for the heart to pump faster. So, the rate decreases. So, because of the increase in the adaptations that happens in the heart size, the heart rate as such decrease. So, you will find that as the individual gets trained in aerobic methods, over a period of time, the heart rate will gradually decrease. So that is an important thing that one needs to know. So that is an indirect measure by which you can say that you can assess and monitor that whether your training methods are having some adaptations or not. So, increase in muscle mass also increases the, the force by which the muscle can pump, the heart can pump. So that again increases your ejection systolic volume. So, that also increases your stroke volume. So, because of which as we discussed, the resting heart rate is lower. So, with every week of training, the studies have shown that at least one beat of the heart rate reduces by one beat. So, you can have a, one of the easiest measure to, you know, monitor is monitor the resting heart rate. We have discussed in the cardiovascular system and the exercise the method to, you know, measure the resting heart rate. So, I would urge you to refer to that particular module to have an idea of, how you measure your resting heart rate. So, the elite endurance athletes, however, have a certain kind of normal variation because of these

adaptations wherein their heart rate goes even below the normal range. So, we know that normal ranges 60 to 100 beats per minute, right? So, this heart rate, resting heart rate range falls even lower, as lower as in world-class athletes, it is found as lower as 40 even 30, between 30 and 40 beats per minute as well. So that's the kind of, you know, increase in the size which is compensated for the requirement for the heart to beat faster. So, these are the changes that happens in the heart. One more important aspect is we, we also learnt in the previous module that heart rate recovery is again an important measure for cardiac respiratory fitness, right? So, this is also a key adaptation because of this key adaptation, the individual post exercise is able to bring back the heart rate from a, you know, high or maximum level of heart rate to a base level of heart rate. So, that the rate at which the, heart rate recurs back to the resting state is also pretty fast. So, this again is an important, you know, measure, that indirect measure by which a coach or a trainer can assess whether your training which you are giving to the athlete is properly being, you know, adapted, the training is giving you the proper result or not. So that's how significant lowering of heart rate to standard submaximal work rate is a hallmark of endurance training. So, this is a key point from this slide. So, this is most commonly used sub-maximal test to assess, you know, the aerobic endurance is the Astrand-Rhyming six-minute cycle ergometer test, nothing but a cycle test, wherein you ask the individual to perform an activity over six minutes at fixed rate. So, with fixed demand, you measure the, how the heart rate varies and that is indirectly extrapolated to the oxygen consumption based on the, in which adaptation that has happened in the heart by which you can assess the VO_2 max of the individual, not doing a maximal test, you are doing a sub-maximal test, but then you are indirectly estimating the maximal oxygen consumption. So, this again dealt in detail by Dr. Anup in this module on assessing exercise testing.

So, let's discuss a case. So, Sneha started training one year before, her resting heart rate was 80 beats per minute. With endurance training over a period of one year, she found that her average one week resting heart rate has dropped down to 54 beats per minute. A doctor during a pre-participation medical found features suggestive of left ventricular, you know, enlargement in the ECG. And she was worried about the ECG because I've suddenly found some new changes and what will be the advice to Sneha with respect to the training as a clinician, what you would have given. So, we have discussed about the changes that could happen in the heart. So, because of the changes that happen in the heart or the athlete's heart, you have certain changes in the ECG as well. So, in endurance trained people, more than 50 weeks, here is the one week, one year is the length of training, duration of training that the individual has undergone. In such case of individuals who have prolonged consistent training, the adaptations happens and that's called as athlete's heart, right. So, you have a lower resting heart rate. So here it is about 54 beats per minute, called as sinus bradycardia. And you have the enlarged left ventricle. Here the endurance training, so you have more of a volume, increase in the volume, so you have more of an enlargement. You also have some amount of left ventricular hypertrophy. So, these are normal changes in an endurance trained athlete. However, this needs to be differentiated from a disease. So, it is important, that's why it is important that an athlete before starting any kind of training has to undergo a pre-participation procedure. So, you get to know, even before starting the training, whether these changes are there or not. If they are there, then this probably is because of a disease. That needs to be

evaluated. Whereas with training history, if you have something and still you want to rule out whether it's because of this thing or not, so then what are the concerns in case of these findings, you also correlate whether this individual has some symptoms or not. During training, any particular kind of cardiovascular symptoms in terms of chest pain or easy fatigue ability or increased sweating, so these are certain symptoms. There is more of breathlessness, exertional dyspnea, what we call. If these are there, then that means it's more of a pathological reason. And the other important aspect is these easy changes can revert if there is a phase of detraining. So, we discussed when you are not given that stimulus, you will end up in having kind of losing those adaptations that has happened because of aerobic training, right? So, these things will wean off. So, you will not find these changes when there is a period of abstinence from training. So, by this you can, you know, find out whether this is a pathological condition or a normal adaptation to the aerobic training that's being given.

Let's move on to the next important parameter that is cardiac output. The main aim of aerobic training is to increase the blood flow, right, when it's the cardiac output to the exercising muscle. So cardiac output is the product of heart rate and stroke volume. So here we know that stroke volume increase and heart rate decrease because of aerobic adaptation. However, the cardiac output is maintained during rest and submaximal activity. But then because of endurance training, you also have increase in the difference in the artery venous oxygen carrying difference. So that also helps in better oxygen extraction from the blood that is being supplied. This increase in cardiac output is the reason for increase in the VO_2 max as well. So, we come back to the Fick's equation. VO_2 is equal to cardiac output into A minus V of the oxygen difference, right?

$VO_2 = \text{Cardiac Output} \times (A - V)\ O_2$

Where:

VO_2 represents maximal oxygen uptake,

Cardiac Output is the volume of blood pumped by the heart per minute,

$(A - V)\ O_2$ is the difference in oxygen content between arterial and venous blood.

So, you have better oxygen extraction, you have better cardiac output, so you will have a increase in the VO_2 max. So cardiac output adaptations indirectly is the reason for the increase in the VO_2 max in improvement because of the aerobic training. So, in untrained individuals, this can go up to 14 to 20 litre per minute. Whereas in case of individuals who are trained with aerobic training, it increases up to 25 to 30 litres. In case of world level endurance athletes, the cases which documented that the cardiac output increases up to 40 litres per minute. So that's the kind of increase in the cardiac output, which helps in increasing the VO_2 max, which again helps in performing better as an endurance activity. So that's the sports performance improves because of increasing the cardiac output with training. So, the predominant factor that causes an increase in cardiac output is because of the stroke volume. So, stroke volume is the one which is responsible for increasing the cardiac output. Why stroke volume increase? That's

because of increase in the heart size and increase also in the amount of blood that is in the circulation. So, the most significant change of all this cardiac output or the cardiovascular adaptations happens between 6 to 12 months of endurance training. So, when you give aerobic methods of training, you will find these kind of changes which increases the cardiac output and thereafter increasing the aerobic performance or VO_2 max happens between 6 to 12 months of endurance training. So that should be the kind of systematic programmed training that to be given over a period of time. What about blood flow? With increasing demand, you need more blood to be there in the exercising muscle, right? So, this is increased by increasing the capillarization. Capillaries increases in number and also it improves the additional capillaries to each other. So, one, you have new capillaries coming in. Two, you also recruit the existing capillaries to supply more blood. And the body also tries to effectively redistribute the blood flow. So, we studied in cardiovascular system and exercise module that depending on the need, the body diverts the blood. So, you have exercising muscle, the blood from this splatting circulation that is from your intra-abdominal organs, the blood flow is redistributed towards your exercising muscle. So that is done more effectively with kind of adaptation that happens. We also have increase in the total blood volume. So, these are the reason by which you have increase in the blood flow. So, the ratio between the capillary to the muscle fiber, so it's the number of blood capillaries that supply the muscle fiber generally is between 1.1 in untrained which increases up to 1.6 when you, you know, have the individual trained in aerobic methods. The blood volume also increases because of the hormonal changes which happens wherein increase in the aldosterone as well as your anti-diuretic hormone. So, they retain the increases the reabsorption of sodium and water. So, because of this the blood volume increases. Also, with aerobic method of training, you also have stimulation of an hormone called as erythropoietin. So, this again increases the RBC volume. So, the RBC we all have studied in that cardiovascular and exercise module that RBC is important because RBC has hemoglobin. Hemoglobin is the main carrier of or transporter of oxygen from your, in the blood. So, the oxygen which is carried in the blood is by the hemoglobin. So, if you have more RBC, you have more hemoglobin, so better oxygen carrying capacity. So, that's again there which increases the blood flow. With respect to the blood pressure also the changes happen wherein you have increase in the systolic blood pressure. So, with more pressure the blood pumps against the heart rate. So that increases the systolic blood pressure. However, with aerobic training, we've seen that diastolic pressure, that is the pressure which is measured when the heart is filling during diastole, that is relatively unchanged. It remains unchanged. In fact, sometimes it's seen in certain studies that it slightly decreases as well. So that is the change that happens in aerobic training. Whereas in, if you see in anaerobic training, you will have both systolic blood pressure as well as diastolic pressure increasing. This is the change that happens between the aerobic training and anaerobic training with respect to blood pressure.

So, moving ahead, having covered all the cardiovascular adaptations, let's move on to the other important aspect of aerobic training which targets your lungs on both sides. That's your respiratory adaptation that happens. So, the respiratory adaptations can be broadly covered under two things. One is ventilation. Ventilation is your, how your breathing frequency happens and the gas reaches the alveoli. And the other one is your diffusion. After reaching the alveoli, how the gas diffuses into the blood so that the oxygen is transported to the blood. So,

these are the two ways by which you can understand the adaptation that's happened in the body because of the aerobic methods, training methods. So, in ventilation, if you see, because of the aerobic methods, you will have increase in the breathing frequency. And because of which there is increase in the tidal volume. Tidal volume increases, which again causes an increase in the ventilation during the maximum exercise as well. And if you see a diffusion, diffusion, you will have increase in the blood flow because opening up of more, you know, diffusion respiratory alveoli system the at the level of respiratory alveoli, you'll have more capillaries opening up, which causes increase in the diffusion with gaseous exchange between the, from the lungs into the body. Moreover, you will also find that the apical zones, the topmost zones of the lungs, generally are not involved in untrained people to a lesser extent in terms of gaseous exchange. So now these also get opened up because of the increased demand. So, you will have the gaseous exchange happening at the apical regions as well. And that causes and in addition to that you have increased ventilation. So, this causes an increase in the pulmonary gas exchange. So that's how you will have more of a better diffusion capacity in the lungs. So, because of these, there is improvement in the oxygen transferred to the blood from when it is transferred to the blood because of the cardiovascular adaptation, it is carried to the exercising muscle to deliver the oxygen. However, if you see when you consider the VO_2 max as a whole in the aerobic performance, generally pulmonary adaptation does not limit the respiratory system, does not limit the, you know, aerobic performance at all. Generally, it is the cardiovascular system that is important in kind of limiting the aerobic capacity. This is mainly because in by nature, the lungs already, the respiratory system already have a good amount of buffering capacity to improve the kind of ventilation as well as diffusion as per the requirement. So, because of which the cardiovascular system becomes the more limiting factor in terms of aerobic capacity.

To summarize in this module, so we have studied about exercise training types, the aerobic and the anaerobic and what are the main, you know, focus of this training aspect. We also have seen that the adaptation that happens in the physiological system of the body are based on the system base. So predominantly in aerobic you have the cardiovascular respiratory and the muscular changes that happens in addition to the endocrine connective tissue as well as in your metabolic adaptations. The cardiovascular adaptation is predominantly largely is because of the increase in the heart size, increase in the kind of systolic pressure that is created because of the muscle mass as well as increase in the volume that both resulting in increase in the stroke volume and which is a reason also for reduction in the heart rate as well. And the because of the changes in the stroke volume and the heart rate, you have increase in the cardiac output. The cardiac maximum cardiac output is the main reason why you have increase in the maximal oxygen consumption in the body. Further, we also saw about the respiratory system, the changes which happens in terms of the ventilation and the diffusion and we also see saw that the respiratory system is not a limiting factor in terms of aerobic capacity or aerobic performance.

So, for those of you who are further interested in studying in depth, I would recommend these standard textbooks on excessive physiology. They are very good source for you to have in-depth knowledge.

Thank you so much.