Introduction to Exercise Physiology & Sports Performance

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Lecture - 24

Adaptations to aerobic and anaerobic training - Part 2

Welcome back to this NPTEL course on introduction to exercise physiology and sports performance- Part 2 of this module on adaptations to aerobic and anaerobic training. With you, I am Wing Commander Dr. Chandrasekara Guru. I am a sports medicine specialist in armed forces medical services.

So, in this module we will be learning about the aerobic and anaerobic capacity, what are the adaptations that happen with respect to aerobic and anaerobic training methods, what are the factors that influence this adaptation, and various use case scenarios. So, we are in the process of understanding various adaptations that happen because of aerobic training.

So, to revise briefly we discussed about exercise training types aerobic and anaerobic. We saw various systems get, you know, undergo adaptations because of this training methods. We saw in detail about the cardiovascular adaptations in terms of increase in the heart size, increase in the stroke volume, decrease in the heart rate, cardiac output, blood flow, and the blood pressure response to these adaptations. We also saw the adaptations that happen in the respiratory system and how it is not a limiting factor in aerobic capacity.

Having covered till now about various adaptations, so let's now focus on the remaining adaptations that happen because of aerobic training. So, what are the muscular adaptations that happen which because aerobic capacity of the muscle increases with training. So that happens because of changes in the muscle fiber type, changes in the mitochondrial function within the muscle as well as the changes that happen in the oxidative enzymes. We saw that aerobic training targets the aerobic pathway of the bioenergetics, right. So, these are the changes that happen in the muscle because of the aerobic capacity improves. So, with respect to the muscle fiber type, you have more of you know increase in the oxidative muscle fiber type. So, we would have dealt in detail about the skeletal muscle physiology and the types of muscle fibers in skeletal muscle module. And you have seen that type 1 and type 2 are two broad categories of muscle fibers. Type 1 is more of oxidative type of muscle fibers and type 2 is more of the glycolytic type of and their fast response. So, if you have an activity which is which requires fast response, anaerobic pathway, and

immediately you will have to get recruited then type 2 muscle fibers get recruited. If the activity is involving a long duration oxidative type of energy system, then your type 1 group of muscle fibers get recruited, right. So, the change that happens because of training method is that you will have increase in the type 1 muscles that gets recruited during the physical activity. So, the transition or the recruitment of that type of muscle fiber is from type 1 followed by the type 2a and type 2x. These are two different sub transition type that is available in type 2 which is found in various studies that the within the type 2 only you have the certain composition based on the training methods. So, the distribution of type 1 and type 2 is predetermined genetically that's what studies have shown. And within type 2 you have certain muscle fibers that undergo transition that they can be more towards anaerobic or more towards aerobic depending on the type of training that you impart. So, this transition from type 2x which is more of a glycolytic group of muscle fibers to type 2a which is more of an oxidative group. So that transition happens because of the aerobic training and the type 1 fiber size also increases not only there is transition within the type 2 level and increase in the recruitment of type 1 you also have there's a hypertrophy of the type 1 group of muscle fibers. It increases up to 25 percent because of the aerobic training. And within the type muscle fiber itself you have increase in the myoglobin content and the capillary supply which again aids in better oxygen applied to the muscle fiber. What happens in the mitochondria? So, there is increase in the number as well as the size. So, both this increase in the number of mitochondria that is available in the muscle and because of which you will have better mitochondrial turnover. So mitochondrial turnover is also high. So, mitochondria functions at its best when the quality is good so that the younger mitochondria have better capacity and they can perform better. So, the older mitochondria which are aged also get kind of regenerated or they are kind of the turnover what you call the with the with the composition of the newer and the older is balanced and it's better in fact because of aerobic training. What happens with the oxidative enzymes? In the oxidative enzymes you will have increase in the mitochondrial oxidative enzymes. So thereby you have a better energy uh you know generation. ATP generation is better because of the electron transport chain.

So, we have seen in bioinformatics that the electron transport chain happens within the mitochondria. It is in the gap between the inner and the outer layers of the mitochondria, right? So, the enzymes that promote are involved in the oxidative metabolism or the electron transfer chain, that is enhanced. So, because of which you'll have more energy production. Also, the source of energy also changes, predominantly from fat during the submaximal stage of the endurance activity. So, that also involved a lot of increase in the enzyme activity of the fat oxidation enzymes. So, that again causes increasing in the utilization of fat as an energy source. So, when fat is being utilized as energy source, you have sparing the glycogen which is there in the muscle. So, this glycogen can spare because of which they can be later utilized when in need to give immediate source of ATPs, right? So, we know glycogen can undergo either an anaerobic glycolic pathway or an aerobic

glycolytic pathway depending on the demand. When the demand is very high, you need immediate energy requirement and then your glycogen which is stored in the muscle can enter into an anaerobic pathway, right? So, that can happen only if you have glycogen. So, if the energy source is more from the fat so you are keeping the glycogen, you know, intact. So, because of which what happens is this glycogen is available at a later stage of the race in competitive athletes to give generate energy. So, that's the glycogen sparing effect of the utilization of fat. That is possible because of the changes that happen in the oxidative enzyme because of the aerobic training.

So, let's see a case scenario. Rakhi, she is an endurance athlete. She used to perform at a pace of say six minutes every kilometer. So, she covers each kilometer at six minutes pace earlier but with six months of training, what she has found that she could improve it to four minutes per four minutes per kilometer. So, now when she was earlier covering each kilometer at six minutes now she is able to do it at four minutes. So, that means she has improved her efficiency and the aerobic capacity, right, during the last three kilometers of a half marathon. Well then, the question here is what is the reason for the improvement in the race pace towards the end. So, with six months of endurance training adaptations has happened in the cardiovascular system which you saw in the previous part wherein there is increase in the VO_2 max. So, oxygen consumption, the individual can have is improved to a great extent and also there is changes that has happened in the muscle. Muscular adaptation has happened wherein you have increase in the oxidative capacity in the muscle fiber because of which fat is predominantly utilized and there's a glycogen sparing effort and this glycogen is now available for use during the last few kilometers when the pace has to increase to reach to the final end point, right? So, that particular thing has helped the individual to increase the pace towards the last three kilometers. Further because of the muscular adaptations that has resulted in increasing the capillaries to fiber ratio so that has caused a better oxygen supply to the exercising muscle and better oxygen diffusion. So, and it is also seen that the lactate clearance is also better in these individuals because of aerobic training. So, the lactate threshold at which there is a steep increase in the accumulation of lactate is prolonged so that gets also shifted towards the right. So, that particular thing also helps in better performance towards the end.

So, having seen about lactate threshold let's move on to the adaptation that has happened in the metabolic pathway. So, because of the aerobic training we'll have certain metabolic adaptations that happens and they are broadly in aerobic capacity can be discussed under three metabolic adaptations in the assessment. So, that is the lactate threshold, the other one is the respiratory exchange ratio and the third one is the maximum oxygen consumption. So, maximum oxygen consumption we have been discussing since beginning let's focus on lactate threshold. So, lactate threshold we had discussed in the you know module on cardiovascular system and exercise. So, lactate threshold increases towards the right. So, just to recapitulate so when you, you know, ask an individual to perform a

maximal exercise and plot the lactate blood lactate every two to three minutes while doing the activity in a graph. So, along the x-axis you will have the duration of or the intensity of the exercise and along the y-axis is your the level of the blood lactate. So, when you plot it the blood lactate gradually increases with the increase in the grade of the exercise right. So, at a certain point you will find that there is a disproportionate increase in the rise certain steep rise in the accumulation of lactate within the uh body so in the blood. So, because of which that is the point when there is disproportionate increase in the lactate. So, what normally happens when lactate is there in the blood, the lactate is shuttled to the other muscle fiber or to the heart and it get utilized. Whereas now while lactate is formed now while lactate is formed because of the anaerobic pathway the glycogen is broken down enters the anaerobic pathway finally it leads into formation of lactate to give you ATP, right. So, ATP is utilized for the activity and the lactate is kind of used for as an energy source in the some other muscle fiber or at the heart. However, when the production is so high, the clearance is not able to match it because of which there is an increase in the disproportionate increase in the blood lactate, right? So, when we are able to shift this point to a right, that means, with the next grade of exercise, you are shifting it, you, you will find that the individual is not getting fatigued or not getting exhausted because of this particular point of lactate threshold. So, the lactate threshold is getting from the point at which the individual will start getting fatigued is prolonged. So that is the shifting of lactate threshold towards the right. So that is again an important assessment method by which you can understand whether your aerobic method is functioning or getting the proper response in the individual or not, okay? So, what is respiratory exchange ratio? Respiratory exchange ratio is nothing but the ratio between the carbon dioxide that is produced by the body and released outside to the oxygen that is consumed. So, it's the ratio between carbon dioxide that is measured at the level of your at the level of your nose and the mouth using a mask when you are testing for a cardiopulmonary excess testing and that measures the carbon dioxide that is coming out and the oxygen that is being consumed. So, the ratio that gives you the respiratory exchange ratio. So, this is an indirect measure of what has happened at the level of cellular level. So, generally, that gives you the rough indication of what is the predominant fuel that is being used. So, not going in too much detail, if the ratio is low, you can know that it is because of more utilization of fat. So, when fat is utilized as a predominant energy source, the ratio is less than one. When the ratio is more than 1.1 or so, you mean you can indirectly understand that predominantly it is the glycogen or the carbohydrate that is being used as the source. So here, when your respiratory exchange ratio is lower, that means that fat is being used. What we discussed earlier, so because of the changes that have happened, the muscle, the oxidative capacity to use fat has improved, right? So, because of which you will have more predominant use of fat. So, when you use RER as a method, you will find that with training gradually the RER which used would have been one can gradually come down up to 0.9 or 0.8 as well during a submaximal exercise activity. However, in the same individual with increase in the pace, the individual

will end up in using more of glycogen. So obviously, the RER will increase towards the end. So that's how you interpret RER. And VO_2 max we have discussed a lot, uh, it increases with endurance training. 15 to 20 percent increase is there which is generally seen over six months of training. So, an individual who has not been exposed to any sport starts an aerobic method of training. Six months you will find some increase of about 15 to 20 percent. So, this peaks at about six to 12 months of training. However, with age, uh, at a certain after a certain point of training, the amount of VO_2 max that individual has reached gets static. Doesn't improve much. However, the assessment can be done based on the lactic threshold method to see whether how much is the improvement in the aerobic training that has happened.

So, let's also cover about the endocrine and the neural adaptation that happens because of the uh endurance training. Because of endurance training we have increased in the hormonal levels as well as the receptors. So, both the hormones and the receptors uh increase because of the training. And you have increased this particular kind of increased level can be enhanced by high intensity training as compared to a high volume training. So, with high intensity training, we'll have better hormonal adaptations. What are the neural adaptations that happen? Initially, during the initial phase of training, it is predominantly the neural adaptation that happens which which gradually improves. And this particular neural adaptation contributes to the efficiency of the movement. Say in a runner, the neural adaptation helps in better running style and by which the economy improves. So, with the limited kind of movement, you are saving more energy so by which your economy improves and the oxygen consumption also is accordingly modified. So, that's how neural adaptation helps in improving the aerobic performance.

What about body composition? In in case of body composition you will have reduction in the fat percent. One is because of increase in the fat utilization as a source and generally it's because of the increased volume of training. So, in aerobic training if the volume is predominantly concentrated then you will have more of a catabolic state wherein the catabolic hormones are released and that also can increase in the mobilization of the fat. So, a certain amount of period or the duration is a critical factor if you want to use to mobilize the fat as a fuel. So, Generally, the intensity is moderate, so 55 to 70 percentage of your VO_2 max is the intensity. The volume is generally beyond 40 minutes, so that is when you will have predominant use of fat. With the training, this kind of the duration and the thing that is required to activate the mobilized fat also changes. When you consider the fat free mass, that is the lean body mass, there's not much of a change that happens with respect to the lean body mass because of aerobic training. As the fat percentage decreases, you will also find the body weight, uh, dipping down.

Training parameters, in terms of exercise parameters, in terms of the frequency, or intensity type and the timing of the activity. So, the two important factors in aerobic adaptation, uh, to take place are that volume and intensity. So, with respect to intensity,

when you have the parameter which determines a better aerobic power is because of variation in the intensity. When you increase the intensity, short duration vigorous intensity sessions in your program, you will have better improvement in terms of the VO_2 max, and also the short duration training should include kind of more of high intensity sprints with reduced rest, and that is also found to increase the VO_2 max. So, if you are a trainer, in addition to giving high volume training during the micro cycle, certain sessions which have short duration high intensity activity with less amount of rest interval between also should be incorporated so that your VO_2 max can have better improvement. With respect to the volume, as we discussed, long duration definitely increases, but then the mod intensity should be moderate. So, if you are going for a prolonged duration, then the intensity should be, uh, less. If you have high intensity, then the volume should be low, which we discussed in our exercise training principles. Generally, it is advised by WHO that 150 minutes of moderate intensity per week will help you to maintain the general cardiorespiratory fitness.

So again, coming back to the question, what limits the capacity and performance of aerobic methods? So, there are two different theories that, uh, you know have been hypothesized for this particular reason. What is the thing that limits the aerobic capacity? So, one is the Utilizations theory. The utilization theory is that, uh, because of inadequate mitochondrial enzymes, the oxygen, the muscle is not able to extract the oxygen that is required for the particular physical activity or the aerobic activity, and that is the reason that limits the aerobic capacity of that individual because oxygen is not available. Whereas the other theory is that the cardiovascular limitation wherein the muscle is able to extract, however, the cardiovascular system is not able to provide the oxygen or deliver the oxygen to the muscle. So, this is the other theory. However, uh, now with a lot of, uh, evidence emerging, most of the studies are, you know pointing towards the cardiovascular limitation theory. Wherein it is the, uh, uh, it is the, uh, inability or the, uh, inability or inadequate supply of the cardiovascular system to deliver oxygen to the excess muscle. So, that could be a reason why that limits the aerobic capacity in an individual.

So, let's focus on certain factors that determine the aerobic adaptations. The first one is the heredity or genetics. So, we discussed about this in our previous module as well, is the nature versus the nurture theory, right. So, most of the times it is all predetermined genetically. So, in these individuals, the upper limit is already predetermined. So, you will not go beyond that upper limit over the scope of reaching that upper limit. So, that's how training method helps you to reach that upper limit right. So, this particular influence is about 25 to 50 percent in terms of, uh, the aerobic capacity. And what about the, uh, variations with respect to male and female or with respect to the age. With age, the aerobic capacity drops because of the aging factor wherein there is an increase in the fat and decrease in the muscle mass. So, we know that muscle is the one which is responsible to consume oxygen, right. So, when the muscle mass reduces, obviously you will have a decrease in the VO_2 max. So that's the reason with age the VO_2 max decreases. When you

see between men and women, so the men have obviously have better VO_2 max that's because of their physiological composition. Again, there's more fat in women because of the gender-related, you know requirements and lower muscle mass. So that has again is a reason for more kind of better VO_2 max in males and a relatively lesser VO_2 max in females.

The other factors are the individual variation. So, you within a group of people you will have a lot of individual variations with the concept of low responders and high responders. So, even studies done conducted in twins, it is seen that there are variations between the twins as well. So that's because of the individual variations that is there within the individual. So as a trainer or as a sports scientist or as an exercise professional it is important to note that though we have a generic program generally it is important to identify the low responder group and the high responder group and tweak the training program. So that accordingly you will have the better outcome. The other important factor that can influence is your altitude. Why altitude? Because as the altitude increases the ambient oxygen pressure partial pressure decreases. So that again has various physiological changes happening. So, this is again covered in exercise in altitude module by Colonel Anup and we have we know that the hemoglobin level increases the ventilatory and the diffusion capacity in the lungs also increases because of the altitude and it also causes a buffering better buffering capacity by maintaining the acid base balance and increases the capillary session. So, this is also utilized in terms of training the athletes. So, certain you will find world-class athletes training at you know regions that are at higher altitude so that these changes can be you know stimulated in the body and because of which the performance when they come back to the plane or at the lower altitude is better because of the adaptations that has happened in the cardiovascular system. So, that's an important point that we need to remember about altitude.

The other important factor is doping as well. So, the other artificial way of improving oxygen delivery is by a method called blood doping. It is a banned method by the World Anti-Doping Agency wherein artificially you increase the RBC level in the blood by infusing your own blood cells or artificial blood cells or using any other artificial means to increase the blood cells by using erythropoietin. These are banned ways by which aerobic adaptations, which happen because of training, can improve. So that's why they are banned.

So, let's discuss a case. Lallan is a novice boxer. Okay, so he started training two years ago, 12 weeks, and his coach found him to get fatigued sooner than his counterparts. What do you think, as a coach, he has to work to prevent his fatigue ability because he's getting fatigued faster than the other people and what is the effect of fatigue on performance? What's your take? Boxing, even though it is more of a sport that requires muscle endurance, cardiorespiratory fitness is key. Why? Because you have multiple bouts and multiple matches within a day. So, there you need faster repetition and you want to perform better in each bout. So cardiorespiratory fitness is a key motor quality that needs to be developed

in a boxer. So, in this case, Lallan must have undergone some pre-participation medical, and he is so if the pre-participation medical was normal and then he has started training. So over 12 weeks training, if he is getting fatigued, then probably because of not much of adaptations that are happening in the aerobic capacity, the cardiorespiratory fitness. So, in such cases, you will have minor fatigue that can creep in which can result in decreasing the performance. It can also increase the reaction time as well as the movement times. So boxing, being a very important key sport with respect to your footwork, the reaction time and the movement, and as well as the kind of the time speed at which you are able to give a punch. So, these all are also affected if your cardiorespiratory fitness is poor because everything requires blood to be supplied where oxygen is taken and that needs to replenish the immediate stores right. So, that decreases your performance as such also your agility and neuromuscular coordination also dips. Moreover, since the blood supply to the brain also may be compromised so you will have a decrease in the alertness as well as the concentration. So, overall, there is a dip in the performance if your cardiorespiratory fitness is poor. So, hence, cardiorespiratory fitness is an essential component in the case of non-endurance sports performance as well.

This is another case where Ruby is a long-distance runner she has been training since last three years, okay, and a coach found her getting fatigued sooner than a previous training session. So, in this case, the same fatigue is there but then she's been trained since the last three years. So recently this lady she's not able to kind of she's getting fatigued faster. A coach finds that a performance has also dropped so there is also performance drop because of the early fatigue and what would be the reason for fatigue ability. So, these are two different cases of fatigue where one it was not of a predominant endurance sports but then where because of probably because of poor cardiorespiratory reserve the individual was getting fatigue. Now here this is a case of a long-distance runner who is already being trained in last almost three years. So obviously the cardiorespiratory fitness is better but off late the individual started developing fatigue and also a performance has dropped that's what the coach has found during assessment. So, what would be the reason? So, here this is an endurance activity and last three years the individual has been and fatigue is present. The performance also has shown a dip. So, the reasons probably would be because of overtraining syndrome. So, when we consider the adaptations we should also consider the concept of overtraining syndrome. Why? Because when training is not properly systematized, and you know, given the demand to the body, the adaptations may not happen the way you want. So, when, in such cases, there may be um, you know, the individual may go into a state called as overtraining syndrome. Wherein, even though their demands are given well, the response are not as expected to the demands. So that means the body is not responding properly, you know. So that is called as overtraining syndrome, and the other reasons could be lack of adequate nutrition. Nutrition may not be good enough, the individual is probably taking low in calorie as per the demand of the training program. So that would be a reason, or probably the individual is not sleeping properly, some other

health-related issue, or the mental-related issue could be there. So, the individual may also be, which is commonly seen in endurance athletes, because of the relative energy deficient syndrome. So, this can happen, which also can simulate an overtraining syndrome. So, it's important to screen for these important syndromes, as a coach or an exercise professional that you will have to understand. And the most common reason would be also maybe anemia. So, anemia is what? Anemia is a condition, medical condition, wherein the uh, the hemoglobin levels are lower, and we know that hemoglobin is important for your oxygen delivery or any aerobic activity, right? So, when hemoglobin is low, then obviously, uh, performance also will be affected, and also you will have to refer to a physician to check for other clinical condition to examine the reason why the individual has easy fatigue ability.

So, in the same case, uh, coach finds a performance drip, how would you proceed further? So, we discussed about the reason probably so if you ask me then I would say suggest that to the coach do a seven days average heart rate that will give you an idea because heart rate is one of the way by which you know that the individual is getting properly adapted or not right. So that's one thing assess the sleep quality you have to rule out at your end whether the individual is sleeping properly or not. So, you can ask the individual to monitor the sleep uh the time at which the individual goes to bed and how long the individual takes time to fall asleep after laying on the bed and when the individual gets up the next day morning how is the quality of sleep or how the individual feels after getting up waking up from the bed or you also ask should ask the individual to monitor how many times the individual had a break in the sleep probably because of going to washroom or some other reason. So those things have to be monitored and kept for at least one to two weeks so that gives you a pretty good idea about the nature of the sleep if sleep is disturbed or not. Then you also need to know what's the diet composition of the individual so you already have framed a training program ask the individual to monitor uh note down or record the activity as well as the record the diet that the individual is taking over seven days so that gives an idea how much is the intake and the output. Also screen for relative energy deficiency syndrome more common in female because of the menstrual as well as the other related issues as well so the the common triad initially earlier it was termed as female athlete triad, now it's been recent evidences have shown that the condition is also common or seen in males as well so it is not only related to female it is also seen in male it's probably because of the energy deficiency that happens in the body because of higher training output whereas the intake is slightly reduced so that gives rise to various uh problems in terms of the bone as well as in terms of the menstrual issues. The energy intake has to be addressed you'll have to also speak with the athlete to know about any menstrual issues that is having that is present in the the female also the output input output calculation as per the energy that is being consumed that needs to be taken care and also check for the other musculoskeletal symptoms to screen for the this particular thing so even after screening you find nothing abnormal then I would suggest consult a physician or a healthcare professional of the

particular team if you are a sports if you are into proper sports setup assessment for anemia is important assessment of for other vitamins and micronutrients common is vitamin B12 vitamin D these are just generally when they are low in the recommended daily range then they also affect the performance moreover in case of elite level athletes when the the training program is very exhaustive the there may be relative a deficiency that can happen in the micronutrients and vitamins as well so that needs to be assessed first in order to replenish properly and the third one is in case of these individuals who would get continuously trained because the monotony and the um the goal setting and other aspect as well you will have psychological issues as well so mental health also needs to be uh assessed is a mandatory thing that needs to be assessed. In addition it's a cardiovascular and the respiratory system which are mainly responsible for your aerobic capacity so these system also have to be screened for for any kind of pathological changes that is hampering the uh improvement in the particular athlete.

So, to summarize uh we have seen about the aerobic adaptations of the adaptations in the body to aerobic training so in this particular part we covered the muscular adaptation that happens in the mitochondria the fiber type and the oxidative enzymes uh what are the different metabolic adaptations and how we can assess them the neuroendocrine adaptations as well how the change in body composition happens because of the aerobic training and how the parameters of exercise prescription has to be tweaked in order to have better aerobic performance we also saw about various factors that influence the aerobic adaptations and we discussed certain case scenarios about the reasons for fatigue ability with glycogen sparing and how we go about in a case which is predominantly endurance with fatigue ability and or a case with non-endurance sports with fatigue ability

So, if you want to have further in-depth knowledge about this uh topic I would suggest you to towards this particular standard textbooks of exercise physiology and sports performance

Thank you