Introduction to Exercise Physiology & Sports Performance
Wg Cdr (Dr.) Chandrasekara Guru
Directorate of Medical Services

Lecture - 13
Respiratory System and Exercise - Part 3

Welcome back to this NPTEL course on Understanding Exercise Physiology and Sports Performance. This module of Respiratory System and Exercise. I am Wing Commander Chandrasekara Guru. I am a sports medicine physician from the armed forces medical services. So in this module we are learning about the anatomy of the respiratory system, breathing mechanism, various lung volumes and pulmonary ventilation and gaseous exchange process module.

We will be looking into the responses to exercises and applications. To revise what we have learnt in the previous session, we saw about different types of lung volumes, the importance and the application in disease as well as in as a diagnostic tool, as well as in the exercise training, various factors that affects the airway resistance, the process of pulmonary ventilation, sub division into minute ventilation and the difference between them, the basics of gaseous exchange and the control of breathing. To proceed further, let us see a maximal graded test. So, as we have discussed earlier in the cardiovascular responses to exercise, the maximal graded test is a test where an individual is asked to perform in a graded manner to the maximal exertion, and let us see how the ventilation or the respiratory system will respond in terms of ventilation to such a graded test.

So this is a test that was carried out in our lab, wherein the ventilation is marked against the duration of the activity. So, the individual ran on a treadmill; at every 2 to 3 minutes, we also did a lactate estimation as well. In this graph, we are discussing only the ventilation with respect to the activity. So, the exercise is marked at around 4-5 minutes here in this chart, you see. So before the onset of exercise also, you can see that there is some amount of minimal increase in the ventilation that you could see as form of some worms kind of thing on the marked in red, which is above slightly above the baseline.

So this is slightly above the normal tidal volume, and that is what you called as anticipatory response. So as and when the exercise starts, the increase in ventilation happens by both rate as well as by the depth, and thereafter it reaches a zone where the demand of the exercise is not met by the aerobic pathway or the rate is slower. So because of which you end up in the anaerobic pathway to generate the ATP that is required. This we have discussed in our module on bioenergetics earlier. So, this particular point is called as the aerobic to anaerobic transition point, and from which you see that there is a drastic improvement in the ventilation.

There is a gross improvement in the ventilation and it reaches a point of maximum where the individual reaches full complete exertion, and thereafter the individual voluntarily decides to stop the exercise. So, from that point onwards the recovery aspect starts. So, let us see these various phases in detail. So, the initial one is the anticipatory response wherein you have a pre-exercise anticipation. So, because of which it stimulates the cerebral cortex and voluntarily you are ready for exercise and that is by the central regulation or the nervous control by the brain.

Thereafter immediately within 20 seconds of this control or the initiation of the cerebral cortex to start the increase in the ventilatory process, you will have rapid increase in the minute ventilation by increase in the rate and depth of the respiration. So, that is the phase one. Subsequently, with the increase in the demand, the demand is met by increasing the depth predominantly that is by increasing the alveolar ventilation, and to an extent by increasing the rate. So this particular phase is called as the steady state exercise where the demand for the oxygen is met and the carbon dioxide is cleared effectively. So, we have also studied about the steady state exercise during our discussion in cardiovascular response to exercise.

So, this regulation of breathing during this phase is integrated by all three domains that is your neural control as well as the partial pressure of oxygen, carbon dioxide and the H plus ions which are byproducts of this activity and also by the feedback which you the body derives from the exercising muscles, the mechanoreceptors in the lungs as well as in the thoracic wall. Further, as you increase the intensity of the exercise, it ends up in phase three wherein the fine tuning of the carbon dioxide and the H plus ion constantly happens. So, because of the increase in the intensity and the aerobic transition that happens, the demand is met by the energy production through the anaerobic pathway. So, we have seen in the energy bioenergetics module wherein the energy produced through the anaerobic pathway ends up in the end product that is the lactate. So there is an increase in the accumulation of lactate and lactate ends up increasing the acidic environment which can cause fatigue.

So, this needs to be immediately buffered. So the lactate is buffered using the sodium bicarbonate in the blood; and it results in formation of sodium, lactate, and increases in the partial pressure of the carbon dioxide. So, this carbon dioxide is a potent you know we have earlier studied or learnt that increase in the carbon dioxide is a potent stimulator of the central chemical receptors. So, this causes a further increase in the ventilation which causes further increase predominantly by the increase in the rate. So, if you see further in this graph there is a disproportionate increase in the ventilation rate as compared to the demand as you compare it with the previous phase.

So, this particular point from which there is a sudden disproportionate increase in the ventilation is termed as the ventilatory threshold. This ventilatory threshold has been studied by various sports scientists and it is equated with the lactate threshold. So, we studied about the lactate threshold in our previous module on cardiovascular responses to exercise wherein lactate threshold identification can be used as an important you know parameter for prescription of exercise training to prescribe you know range in a range of heart rate where the individual can train to improve the performance right. But then to identify the lactate threshold you will have to do a lactate estimation test wherein you will have to during a maximal graded test you will have to prick the individual at every 2 or 3 minutes during the complete completion of the activity. So, that is an invasive process whereas this particular ventilatory threshold which is through wearing a mask and then identifying it based on a metabolic gas analyzer you can identify this ventilatory threshold.

So, this is a non-invasive method and can be used to identify this lactate threshold point. Based on which you can use it to prescribe training in these individual during the aerobic to anaerobic zone, and you can also use this as a you know important parameter in terms of team selection, also to monitor the training that you are giving to your client. So, that is it is an important non-invasive method to prescribe training. Subsequently you know the exercise gets completed, the ventilation drops sharply during the recovery phase. So the exercise stops and an abrupt drop in the ventilation is seen and that is again controlled by the neural mechanism, as well as the peripheral mechanism wherein the stimulus to the ventilation is withdrawn.

So, this happens in two different process one phase is the fast recovery phase where you can see in the graph there is a sharp decrease in the ventilation assets and thereafter the phase of slow recovery starts wherein it continues. Here, the graph is shown only till 28 minutes if the individual has to be monitor for prolonged period of time this would have increased slowly until it reached a baseline. So that becomes the slow recovery phase. So, we know how the ventilation response to the demand in case of a maximal exercise. So having known that let us understand what is the relation between lung volumes and exercise.

We have earlier discussed that the static lung volume is mainly genetically determined, and it depends on the size of the thoracic cage. So it is in turn determined by the age, the type of gender you are, the body size per se and the height of the individual. So, these all contribute to increase in the static volume or decrease in the static volume. So, thus there is no relevance with respect to the exercise training in terms of static volume. However, in terms of dynamic lung volumes you will have exercise training of the respiratory muscle increasing the dynamic lung volume.

So it is seen that it increases the maximum breathing capacity, and also you can use these lung volumes to diagnose exercise induced bronchoconstriction or bronchial asthma. This is again an

important application. What about pulmonary ventilation? So, we saw that there is increase in both tidal volume that is depth as well as the rate of ventilation. So, in endurance athletes this can go even up to 160 liters per minute. In certain football players, where it is predominantly you see football matches last for 90 minutes and a more predominant aerobic capacity where the need is also high.

So, it is found that the pulmonary ventilation can reach up to the level of 200 liters per minute in these individuals. In case of lower intensity exercise, the predominant increase in ventilation is achieved by increasing the tidal volume or the depth of respiration. Whereas, in high intensity exercise especially post the aerobic anaerobic transition zone, there is an increase in the production of carbon dioxide thereby increasing in the rate of the respiration. So, predominantly it is going to be more of an increase in the rate towards the terminal part of the high intensity exercise. So, breathing exercises which teaches the individual to kind of increase the depth as well as to increase the rate are found to increase the alveolar ventilation.

So, this is an important take away message wherein breathing exercises also should be incorporated as part of the training program especially in such individuals who have long duration training or long duration sports participation. So increasing in rate per se is called as hyperventilation, which further causes an increase in the carbon dioxide wash out. So, when you breathe faster, so more of carbon dioxide which is there in the blood is removed away from the blood and sent off. So this may in turn cause compensation by decreasing the H plus ions and causing a metabolic alkalosis. The pH of the blood increases rapidly, so that has various deleterious effects on the body as well as the performance of the individual.

So, increasing the pulmonary blood flow further also can decrease the transit flow of the blood. So it is a simple mathematics, so when you increase the amount of blood through a particular pipe, you will find that the molecules will move faster the transit time is going to be you know, reduced. So that is seen like from 0.8 seconds can be reduced as low as 0.2 seconds. So, that is the time that is available for gaseous exchange as well but still it is seen that there is effective exchange of oxygen molecules during even this decreased gross and decrease in the transit time during such activities and that happens because of the affinity of the oxygen to the hemoglobin molecule, and thus that is important you know oxygen buffer that is there in our which is naturally built in our pulmonary circulation and the ventilation process. So, as a response what happens is with respect to the respiratory system to the exercise what it carries on the performance per se. So, with the respiratory muscles it is seen that it contributes about 10% of the maximal oxygen consumption and the muscles are generally fatigue resistant over a period of time they become more resistant to fatigue. At mean sea level where there is not much of you know influence of the atmospheric pressure on to the pressure gradient it is generally seen that with a normal airway resistance and gas exchange, these are not limiting factors the pulmonary system does not become a major limiting factor in performance. However, the pulmonary

system can become an important limiting factor in conditions where the atmospheric pressure decreases, say as you travel you know higher in altitude for example you travel to high altitude place like Leh or Ladakh, where the atmospheric pressure is as such reduced.

So because of which there is influence on the pressure gradient and the cascade which we have discussed earlier. So, this can have a limiting factor on the performance or the exercise that you do at high altitude. What about the role of the airway resistance? So if you consider the factor of airway resistance so if you have a deceased lung especially with the parenchyma or with the bronchial airway so that may cause obstruction or restriction and this may affect the airway resistance, and that can again compromise or become a limiting factor in terms of exercise performance. And the third factor which we discussed was the blood flow. So, I am not covering blood flow since it is more cardiovascular. I am not covering this in the respiratory response as a limitation in performance.

So, let us discuss a case to understand to apply these principles that we have studied in the previous sessions on respiratory system and exercise. So let us come back to the same question which we started with. So this guy came to me saying that I stay in Delhi and I go for a long run outside in the morning hours, and I generally face breathing issues when I go for a run outside during colder weather, and he asked me whether he can wear a face mask when he goes for a run considering the pollution that is there in Delhi. So, with the knowledge that we have occurred in the previous discussions let us discuss this particular case. So, here you know that the individual is performing an outdoor activity so he is exposed outside and he goes for long run so it is an endurance based activity. Delhi again you know the location is known for high pollution levels especially during winter period so he says that he goes for run during cold times you know cold weather where he gets more of breathing issues.

So, let us break them into smaller parts. So, long runs what happens with respect to the respiratory response: you have an increase in the minute ventilation by increasing both depth as well as the respiratory rate. So there is also in addition to the inspired air, inspired air is taken more in amount, the volume increases the minute ventilation increases, the maximum breathing capacity increases in exercise. These all causes also along with the air you also have intake of pollen and the dust and the pollution particles which are available in the atmospheric air. So this is again taken inside by you when you inhale.

So, now during cold weather these particles again can be an important factor. We had earlier seen that these particles the dust, the pollens, the allergens, the foreign particles can stimulate and have an effect on the bronchial tone and the airway; so they can increase the resistance to the air flow. So that is number one which we have interpreted from this particular thing. Second thing is, long run so it is going to be over a prolonged period of time. So, during this activity

continuously you are increasing the ventilation so you have consistent exposure to these particles, that is an important aspect.

The third aspect is the cold. Cold independently is a factor which can stimulate your bronchial tone and cause bronchoconstriction, so that is what we have seen earlier. So long run outside in addition with cold in this individual says that has caused breathing issues during exercise. So, this means that it could have been an exercise induced bronchoconstriction or the individual would be having bronchial asthma because from whatever we have in this case we do not know whether individual was already an asthmatic, and then when he goes for long runs outside in Delhi during cold weather he develops or not however it might be bronchial asthma or he may be having a seasonal weather change because of the allergens or type of particles that are present during certain season or during an increase in the pollution level could have caused such breathing issue during cold weather. So, these are the possibilities that I could derive with this initial analysis. Proceeding further what would be the risk factors which are there from the available history.

So, it is seen that intrinsic risk factors here are genetic factors; individual who is already prone for pollen grains and allergens, can be a reason. Then you have the environmental factors you know environmental generally contribute in such individuals are found to be cold weather per say during the winter months and the incidence is seen more in winter sports the individual who participate in winter sports because of the cold weather per say. So, whenever the air is dry and humid that is the time also where you have because of the reduced amount of water vapor in the high humid air so the cilia epithelium is also finding it difficult to you know push the pollen or the pollutant outside. So, there comes the response of the cilia and the respiratory tree in terms of clearing the allergen; and the other important aspect is your irritants which are there. So in this case it is a runner so maybe any kind of irritant that is there in the air that could be a reason. In certain sports like swimming, the swimming pool has a compound called as you know amino compound generally used for cleaning the water. So this used as disinfectant so this again can trigger such responses in the respiratory system.

One also has to remember about the different pollen grains which are more familiar during certain type of season, say during January you will have you know the cultivation process going on where you will have more of pollen grains coming up in these agriculture regions and you also have various air pollution pollutants like sulfur dioxide and the particulate matters, which may increase in certain time of the year. The other factor is the type of sports that the individual takes part so that depends on the duration and long duration which I said and duration the prolonged exposure to that allergen and also on the training. So, certainly they say training is a factor because in with training you also get sensitize to that and become more of a desensitization happens and it is only a partial factor. So, there are classification of the sports that could lead to various you know respiratory issues during exercise. So the reference I have

quoted here. I have divided the sports into three different risk category sports like low risk sports, medium risk sports and high risk sports.

Low risk sports are sports wherein the duration is only 5 to 8 minutes. Why the duration 5 to 8 minutes, because generally in cases of exercise induced bronchoconstriction; the bronchoconstriction happens because of the exercise itself and in order for this to happen the individual should have performed at least 5 to 8 minutes of exercise which is of high intensity so that that could have triggered the bronchoconstriction per se by releasing certain chemical factors. So, that is low in certain sports because the activity or the sports duration per se is less than 5 to 8 minutes. So, the chances of existing bronchoconstriction is lower. So that is low risk sports like say jumps or throws or even sprints which are like 100 meters 200 meters, which gets completed in less than a minute.

So these are low risk sports. Medium risk sports are certain sports like soccer and rugby where you have certain amount of change in the intensity and you can have scope for you know change in the exposure level as well. High risk sports are sports where there is continuous cyclical movement, and the duration is prolonged. This is more in terms of outdoor sports like cycling, more in terms of running, swimming or long distance swimming. You also can have in winter sports like skiing or cross country skiing. These are the sports where you can generally face such kind of respiratory based issues.

So moving ahead with the particular case; further we need to evaluate to identify what the exact problem would have been. So we thought that it could be exercise induced bronchoconstriction or maybe a bronchial asthma or maybe allergic bronchitis. So a pulmonary function test would be required. So we studied the lung volumes; static and the dynamic lung volumes right. So the lung dynamic lung volumes are you know documented or recorded using spirometry or pulmonary function test.

So that will give us an idea what is the condition of the dynamic lung volume of this individual and will give us main parameter that we would use is FEV1/FVC ratio, that will help us to classify this individual as whether he has a normal value or obstructive disease or a restrictive disease. So subsequently if you feel that the individual has an exercise induced bronchoconstriction, then you would further proceed with a bronchodilator challenge. So, this is basically to rule out bronchial asthma wherein you give a bronchodilator and then again repeat the test. If there is an improvement of more than 10% in FEV1 then you would label the individual as bronchial asthma and then you treat the individual for bronchial asthma. Now, if that does not happen, it may be because of exercise induced bronchoconstriction.

So further you will have to go one more step to diagnose it using a bronchial challenge test. This is a specific type of test which is beyond the scope of this particular topic. I am just

mentioning it for you to understand that this is what the general protocol when as a sports medicine physician we follow while evaluating a case of respiratory system in an exercising individual. So you have to diagnose this excess induced bronchoconstriction and based on the FEV1 fall which happens during the test you diagnose the individual as exercise induced bronchoconstriction.

So, for evaluation you need to know this basic idea. Subsequently the individual also asks whether I could wear a mask or not. So wearing a mask what happens, definitely will be a layer in between your nose and the atmosphere pressure, so that is going to cause additional increase in the air flow resistance. So, both the inspiration as well as the expression will become an active process with the contribution of the respiratory muscles. There may be an increase in the chances of the fatiguability of the expiratory muscles because of the additional you know resistance that is offered by the mask that is being worn. So, the airway flow resistance has increased and there may also be some amount of air that is being trapped between the layer between the mask and the immediate nose and the mouth.

So when you inhale it may be inhaling the exhaled part of the exhaled air as well. So the composition of the oxygen carbon dioxide in your repeatedly inhaled also may change. So, moreover you are also using something which is external which we are not used to, and it also depends on the thickness and the filtering capacity of the mask that you use. So, that can also increase the rate the perceived exertion the individual would feel when the individual is exercising and also may increase the discomfort while doing the activity. So depending on the type of mask this can vary and then generally we have cloth mask, surgical mask, we have N95 mask.

There are also certain respirators where you have a valve there is only the valve will allow only unidirectional flow. So where you have filtering of the hair which passes through the valve from the outside. So it cuts off the pollutants and then you wear it and there is no resistance offered while you exhale it out. So such kind of mask are also there. So, depending on the type of mask that you are using the resistance will vary accordingly the discomfort and the effect on the performance.

There are various studies post COVID have been done, because during COVID there have been increased incidence of you know usage of masks just to prevent the you know spread of this virus, and various studies level 1 studies have been done by researchers across the globe, and they found that the performance level more or less does not vary much in terms of using a cloth mask. However, the performance may vary in terms of the perceived exertion and the discomfort that is felt by the person who is doing the exercise. As the thickness of the mask increases, the performance also drops down. This is one of the aspects that you need to be aware of so that accordingly you can give you know suggestions or recommendations to your clientele. So in

this case if you ask me as a sports physician what I shall recommend so I would need further detailed history.

So, with this kind of information I will not be able to completely give a good recommendation. It is important that you need to get more information which are relevant to the respiratory system. We will have to evaluate the individual I would have evaluated for the bronchial asthma as a baseline condition; thereafter go ahead to diagnose the excess induced bronchial constriction. I would have started treatment so that the symptoms would have got resolved if they were positive; and then with respect to the use of mask I would have advised to use a pollution mask with a valve wherein the resistance is minimal and the individual exercise intensity has to be guided. So, the customized grading of intensity is important as the individual gets comfortable and convenient using the mask. The individual can go ahead with continuously using it with increased intensity of exercise.

So the individual's perception, the exertion as well as the comfort level are all important when you use an additional layer in your breathing respiratory system. So, I would also recommend the individual to undergo certain breathing exercises to improve the respiratory muscle training. So that would also further help in addressing the problems the individual is facing. And most importantly the individual should always if the individual was diagnosed with bronchial asthma or exercise induced bronchospasm; I would advise the individual to carry in the emergency medicine also when the individual goes for a run, so that immediate emergency requirement if arises can be addressed by the individual on the spot itself. And more importantly, an individual should carry a small card with all these details so that it is useful for the bystanders or anyone who encounters sudden collapse by this individual while performing.

So these are the basic things that I would recommend in this particular case. So, the main takeaway from this module of respiratory system and exercise are that the healthy respiratory system does not actually have any kind of limitation with respect to the exercise. The respiratory muscle training definitely improves the dynamic lung volume, which also helps in improving the performance level as well, especially in long duration activities. And with exercise intensity there is increase in the tidal volume initially during steady state and gradually in the increase in the rate disproportionate to the demand during the non steady state or during the anaerobic phase of the long duration activity. Further ventilatory threshold at this point can be used as an important non-invasive parameter to prescribe exercise training in such individuals to improve their performance.

And the diseases of the lungs and diseases of the airway can have a major impact or limiting factor in the performance of these individuals during their activity. So hence, screening is again important pre-participation screening for any kind of respiratory disease as an individual, as a trainer will help you understand what is the basic underlying problem before even starting the

exercise training program. So for those of you who would like to further read in depth can refer to this following standard text books for further details. Thank you so much.