**A LITERATURE REVIEW**

**ON**

**CARDIO-RESPIRATORY RESPONSE TO EXERCISE**

**BY**

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**OCTOBER, 2019.**

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**CERTIFICATION**

This is to certify that this seminar was carried out by **OBASIGIE HARRISON** with matriculation number **BMS1502045** in partial fulfillment for the award for B.sc in department of Physiology, School of Basic Medical Sciences, College of Medical Sciences, University of Benin.

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**DEDICATION**

To God Almighty: to him be the glory, honour and power forever.

And to Irene, Nicholas, Bryson, Precious, Valentine and Marley who makes everything worthwhile.

**ACKNOWLEDGEMENT**

I would like to express my gratitude to God Almighty for giving me the strength and ability to finish this work. I wish to thank my supervisor **DR. (MRS.) M.I OMIGIE** for her exemplary guidance, monitoring and for giving me the golden opportunity to do this wonderful literature review on the topic (Cardio-respiratory response during exercise) under her supervision. Special thanks to my siblings and my lovely parents **MR. AND DR. (MRS.) E. OBASIGIE** for their spiritual, moral and financial support, without which this work would not be possible.

I also want to take this opportunity to express my profound gratitude and deep regards to my colleagues Ayo, Marley, Collins, Monica, Gift and Faith of the 400level class for their constant advice and encouragement throughout the course of this thesis.

I also wish to thank the Head of department, **PROF. F.O AGOREYO** for the fatherly role he played throughout the period of this literature that guided me to a successful finish.

**SUMMARY**

Exercise is a subcategory of physical activity that is planned, structured, and repetitive for the purpose of conditioning any part of the body (Matthews *et al.*, 2011). The cardio-respiratory system consists of the heart, blood vessels, lungs, and airways (Michelson, 2009). According to the intensities of exercise, it can be divided to three categories- light, moderate and vigorous exercise (Ross, 2007). During exercise, cardiac output, stroke volume, heart rate and systolic blood pressure, increase rapidly and reach steady state within approximately 2 min. Diastolic blood pressure remains relatively unchanged, and resistance decreases rapidly and then plateaus (Poliner, *et al.,* 2005). Exercise poses various effects on the body. They include; Increase oxygen demand/expenditure Increase heart rate, increase cardiac output, hyperventilation and so on. These added burden is usually overcome by a variety of cardio-respiratory adjustments like hyperemia, temperature regulation, sympathetic stimulation, redistribution of blood flow etc. to achieve homeostasis. The decrease in pulmonary bed resistance that accompanies exercise has two important implications. First, the decrease in resistance allows greater blood flow to the working muscles. Second, the decrease in resistance keeps blood pressure from rising excessively. The increase in cardiac output, which is a relative function of venous return, would produce a much greater rise in blood pressure if it were not for the fact that there is a simultaneous decrease in resistance (Abernethy *et al.*, 2012). The pattern of cardiovascular response is the same for both sexes. However, males have a higher cardiac output, stroke volume, and systolic blood pressure at maximal exercise. Additionally, males have a higher VO2max. Most of these differences are attributable to differences in body size and heart size between the sexes and to the greater hemoglobin concentration of males (Brooks *et al.,* 2007).

**INTRODUCTION**

Physical activity is defined as any bodily movement produced by skeletal muscles that require energy expenditure (WHO, 2016). The term “Physical activity” is not equal to “exercise”. Exercise is a subcategory of physical activity which is structured, repetitive, and purposeful (WHO, 2016). “A sound body has a sound mind” It means that if a person is weak, dull, and sick, he is not able to do his work efficiently and quickly. It is very important to have a fresh mind before any work, like office work, study or some creative work. The people who make exercise as essential part of their routine are more happy and efficient than others. Exercise does not only mean going to some club for daily activity; it only means to do some level of physical activity no matter how and where. Exercise is useful in preventing or treating coronary heart disease, osteoporosis, weakness, diabetes, obesity, and depression. Strengthening exercises provide appropriate resistance to the muscles to increase endurance and strength. Cardiac rehabilitation exercises are developed and individualized to improve the cardiovascular system for prevention and rehabilitation of cardiac disorders and diseases (Jones *et al.,* 2000). The cardiovascular system consists of the heart, blood vessels, and blood. Its primary function is to transport materials to and from all parts of the body. The heart pressurizes blood and provides the driving force for its circulation through the blood vessels (Rodrigues *et al*., 2006) Blood is propelled away from the heart in the arteries and returns to the heart via the veins. Substances transported throughout the cardiovascular system can be categorized as (1) materials entering the body from the external environment (e.g., O2 and nutrients); (2) materials moving between cells within the body (e.g., hormones and antibodies); and (3) waste products, from cells, requiring elimination (e.g., heat and CO2). The exchange of materials between blood and interstitial fluid occurs across capillaries in the microcirculation (Louis, 2011). The heart has four chambers. The two atria serve as reservoirs for blood returning to the heart. The two ventricles are pumps that propel blood through the circulation. A septum divides the heart into right and left sides. The right atrium is the reservoir serving the right ventricle, which pumps blood to the pulmonary circulation via the pulmonary artery (Madoc, 2009). Blood returns from the lungs to the left atrium via the pulmonary veins. The left ventricle propels blood, via the aorta, to all other organs in the body through the systemic circulation. Systemic and pulmonary circulations are arranged in series. Organ blood supply in the systemic circulation is arranged in parallel (Madoc, 2009) Circulation of blood is completed as the blood from the systemic circulation drains into the right atrium via the superior and inferior venae cavae. The term “right side” of the circulation refers to the pulmonary circulation, which is served by the right ventricle. The term “left side” of the circulation refers to the systemic circulation, which is served by the left ventricle. The right side of the heart propels deoxygenated blood to the lungs, and the left side of the heart propels oxygenated blood to the tissues (Voss *et al.,* 2013).

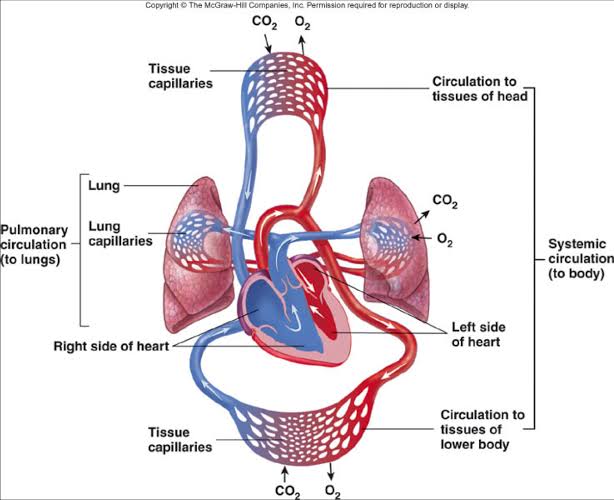
Respiration is the movement of oxygen from the outside environment to the cells within tissues, and the transport of carbon dioxide in the opposite direction (Curtis, 2008). Maleek (2013) argued that the physiological definition of respiration differs from the biochemical definition, which refers to a metabolic process by which an organism obtains energy (in the form of ATP) by oxidizing nutrients and releasing waste products. Although external respiration is necessary to sustain cellular respiration and thus life in animals, the processes are distinct: cellular respiration takes place in individual cells of the organism, while external respiration concerns the diffusion and transport of metabolites between the organism and the external environment (Iyawe, 2010) In animals with lungs, external respiration involves respiratory cycles of inhaled and exhaled breaths. Inhalation (breathing in) is usually an active process. The contraction of the diaphragm muscle causes a pressure variation, which is equal to the pressures caused by elastic, resistive and inertial components of the respiratory system. In contrast, exhalation (breathing out) is usually a passive process. Breathing in, brings air into the lungs where the process of gas exchange takes place between the air in the alveoli and the blood in the pulmonary capillaries (Voss *et al.,* 2013) The process of breathing does not fill the alveoli with atmospheric air during each inhalation (about 350 ml per breath), but the inhaled air is carefully diluted and thoroughly mixed with a large volume of gas (about 2.5 liters in adult humans) known as the functional residual capacity which remains in the lungs after each exhalation, and whose gaseous composition differs markedly from that of the ambient air. Physiological respiration involves the mechanisms that ensure that the composition of the functional residual capacity is kept constant, and equilibrates with the gases dissolved in the pulmonary capillary blood, and thus throughout the body. Thus, in precise usage, the words breathing and ventilation are hyponyms, not synonyms, of respiration; but this prescription is not consistently followed, even by most health care providers, because the term respiratory rate (RR) is a well-established term in health care, even though it would need to be consistently replaced with ventilation rate if the precise usage were to be followed (Maxwell, 2011).

**AIM**

The aim of this literature is to enumerate the effects of the Cardio-Respiratory responses to exercise.

**CARDIO-RESPIRATORY SYSTEM**

The cardiorespiratory systemconsists of the heart and blood vessels, which work with the respiratory system(the lungs and airways) (Saltin, 2008). These body systems carry Oxygen to the muscles and organsof the body, and remove waste products, including Carbon dioxide. The number of times the heart pumps, or beats, is counted in a minute. This is known as the pulse rate. (Belllo, 1999). A person’s pulse is affected by their current level of activity. If you are sleeping or do no physical activity at all, your heart is pumping at a resting heart rate (Saltin, 2008).



Pearson Review, 2005: The Cardio-Respiratory System

**FUNCTIONS OF THE CARDIORESPIRATORY SYSTEM**

* Removal of carbon dioxide and other metabolic waste.
* Delivery of oxygen and other nutrients.
* Maintenance of acid–base balance and overall body fluid balance.
* Matching metabolic demands with supply.
* Transport of respiratory gases.

**WHAT IS EXERCISE?**

Exercise is a subcategory of physical activity that is planned, structured, and repetitive for the purpose of conditioning any part of the body (Matthews *et al.*, 2011). Exercise is used to improve health, maintain fitness and is important as a means of physical rehabilitation. Also we can define exercise as any bodily movement performed in order to develop or maintain physical fitness and overall health. (Matthews *et al.*, 2011). Exercise and physical activity fall into four basic categories- endurance, strength, balance, and flexibility (Christensen, 2016). Endurance, or aerobic, activities increase the breathing and heart rate. They keep the heart, lungs, and circulatory system healthy and improve the overall fitness. Building the endurance makes it easier to carry out many everyday activities. Walking, jogging, mowing, raking, digging and Dancing are kinds of this type (Prakash, 2007). Strength exercises make the muscles stronger. Even small increases in strength can make a big difference in one’s ability. We can find this type of exercise in Lifting weights, using a resistance band with body weight (American Heart Society, 2011).Balance exercises help prevent falls, a public problem in older adults. Many lower-body strength exercises also will improve balance. This type can be noticeable in Standing on one foot, Heel-to-toe walk and Tai Chi (American Heart Society, 2011).Flexibility exercise stretches the muscles and can help the body stay limber. Being flexible gives one more freedom of movement for other exercises as well as for everyday activities. Some examples include- Shoulder and upper arm stretch, Calf stretch and Yoga (Mariam and Copeland, 2014).

According to the intensities of the exercise it can also divide to three categories- light, moderate and vigorous exercise. Heart Rate is typically used as a measure of exercise intensity (Ross, 2007). Heart rate can be an indicator of the challenge to the cardiovascular system that the exercise represents.

**LIGHT EXERCISE**: Does not induce sweating unless it is a hot, humid day. There is no obvious change in breathing patterns, sleeping, writing, desk work, typing, very slow walking, are examples for this first category (Julie, 2009).

**MODERATE EXERCISE**: It should raise heart rate, make’s one breathe faster and make one feel warm enough to start sweating after performing the activity for about 10 minutes. Breathing becomes deeper and more frequent. Bicycling, very light effort calisthenics, home exercise are examples in this category (Melvin, 2012).

**VIGOROUS EXERCISE**: will make one breathe hard, increase heart rate significantly and makes one hot enough to sweat profusely after 3-5 minutes. Breathing is deep and rapid. One can only talk in short phrases. Examples for this type include running, jogging, jogging in place, calisthenics (e.g. pushups, sit-ups, pull-ups, and jumping jacks), heavy vigorous effort, rope jumping (Brenda *et al.,* 2001).

**NEED OF EXERCISE**

Exercise means the daily practice of doing some physical work. Exercise is the key to good health and fresh mind (Musa, 2013). The daily practice of some physical work does not mean to take stress on body, but it is actually the stress relieving activity. A good health is obligatory for doing a good work. A famous quote is *“there is awesome evidence that people who lead active lifestyles are less likely to suffer from illness and more likely to live longer”.* Exercise not only makes one physically fitter but it also improves the mental health and general sense of well-being. Effective exercise can be achieved through 30-60 minutes of moderate-intensity exercise (five times a week) or 20-60 minutes of vigorous-intensity exercise (three times a week) or a combination of both types. (Stampfer, 2014).

**IMPORTANCE OF EXERCISE**

Everyone has a physical body made of muscles, blood, bones and various other living tissues. When any of these are injured or not working properly, one gets ill (Distorted Homeostasis) (Enrique, 2009). It is important the body is kept healthy and fit. Exercising the body is one way of keeping it healthy. If we do not exercise, then our muscles become weaker and we are less able to do things properly. Also the bones can become weaker and thus break easily (Enrique, 2009). Exercise is performed for various reasons, including increasing growth and development, preventing aging, strengthening muscles and the cardiovascular system. (Wilson, 2009). Frequent and regular physical exercise boosts the immune system and helps prevent "diseases of affluence" such as cardiovascular diseases, type II diabetes, and obesity (Mason and Stampfer, 2014). It may also help prevent stress and depression, increase quality of sleep and act as a non-pharmaceutical sleep aid to treat diseases such as insomnia, help promote or maintain positive self-esteem, improve mental health, maintain steady digestion and treat constipation and gas, regulate fertility health, and augment an individual's sex appeal or body image, which has been found to be linked with higher levels of self-esteem (Abubakar, 2018). Childhood obesity is a growing global concern, (Harriet, 2006) and physical exercise may help decrease some of the effects of childhood and adult obesity. Some health care providers call exercise the "miracle" or "wonder" drug—alluding to the wide variety of benefits that it can provide for many individuals (Harriet, 2006).

**BENEFITS OF EXERCISE**

Regular exercise makes the heart stronger and the lungs fitter, enabling the cardiovascular system to deliver more oxygen to the body with every heartbeat and the pulmonary system to increase the maximum amount of oxygen that the lungs can take in. Exercise lowers blood pressure, slightly decreases the levels of total and low-density lipoprotein (LDL) cholesterol (the bad cholesterol), and increases the level of high-density lipoprotein (HDL) cholesterol (the good cholesterol). These helpful effects decrease the risk of heart attack, stroke, and coronary artery disease. In addition, colon cancer and some forms of diabetes are less likely to occur in people who exercise regularly (Mustpha, 2014). Exercise makes muscles stronger, allowing people to do tasks that they otherwise might not be able to do or to do them more easily. Every physical task requires muscle strength and some degree of range of motion in joints. Regular exercise can improve both of these qualities. Exercise stretches muscles and joints, which in turn can increase flexibility and help prevent injuries. Exercise may also improve balance by increasing strength of the tissues around joints and throughout the body, thus helping to prevent falls (Mustpha, 2014). Weight-bearing exercise, such as brisk walking and weight training, strengthens bones and helps prevent osteoporosis (Mustpha, 2014). Other health benefits include the following:

**REDUCE STRESS AND ANXIETY**

Stress relief is one of the most common mental benefits of exercise. Regular Exercise can help to manage physical and mental stress. Exercise also increases concentrations of norepinephrine, a hormone that can moderate the brain’s response to stress. Being active greatly causes a reduction in tress levels (Mariam, 2015). Aerobic and anaerobic physical training are helpful for overall health. Study suggests that 30 Minutes Exercise for 5 or more days in a week, helps in lowering the desperation and mental stress (Belle, 2015).

**BOOST HAPPY CHEMICALS**

Exercise releases endorphins, which create feelings of happiness and euphoria. Studies have shown that exercise can even improve symptoms among the clinically depressed (Frederick, 2013). For this reason, doctors recommend that people suffering from depression or anxiety partake in regular physical activities. In some cases, exercise can be just as effective as antidepressant pills in treating depression. Higher energy levels resulting from exercise help a person in remaining fresh and happy. Following a suitable exercise program can add some fun and brightness to the day. Working out for just 30 minutes a few times a week can instantly boost overall mood (Julie, 2016).

**IMPROVES MUSCLES AND BONES STRENGTH**

Exercise involves a series of sustained muscle contractions, of either long or short duration, depending on the nature of the physical activity. Muscle-strengthening activities can help one increase or maintain muscle mass and strength (Richards, 2017). Strong muscles and ligaments reduce the risk of joint and lower back pain by keeping joints in proper alignment. Additionally, with exercise improvements to the circulatory and respiratory systems can facilitate better delivery of oxygen and glucose to the muscle (Curtis, 2009). Research shows that doing aerobics bone-strengthening physical activity of at least a moderately-intense level can slow the loss of bone density that comes with age, along with that hip fracture is a serious health condition that can have life-changing negative effects, especially if it is an older adult. But research shows that people who do 120 to 300 minutes of at least moderate-intensity aerobic activity each week have a lower risk of hip fracture (Jensen, 2008).

**PREVENTING OBESITY**

Obesity and overweight are associated with increased risk for hypertension, osteoarthritis, abnormal cholesterol and triglyceride levels, type II diabetes, coronary heart disease, stroke, gallbladder disease, sleep apnea, respiratory problems and some cancers (Mapother, 2012). Obesity is a significant health problem all over the world for all ages. Genetics can play a role in the possibility that a person will become obese, the condition occurs when the amount of calories consumed exceeds the amount of calories expended over a long period of time. The more you exercise, the easier it is to keep your weight under control (Jerkins, 2011). Excess calories are stored as fat in the body, and with long-term caloric excess, an individual eventually becomes obese. Exercise can help prevent excess weight gain or help maintain weight loss. When you engage in physical activity, you burn calories. The more intense the activity, the more calories you burn. Regular exercise (and proper nutrition) can help reduce body fat. Weight loss will achieve most effectively when we follow a cardiovascular exercise of moderate-intensity activity accumulated over 5-7 days per week. Eating a healthy diet are ways in which to combat obesity (West, 2007).

**REDUCE RISK OF HEART DISEASES**

The heart is a muscle and needs exercise to stay in shape. When it is exercised, the heart can pump more blood through the body and continue working at optimal efficiency with little strain (Cedric, 2008). This will likely help it to stay healthy longer. Regular exercise also helps to keep arteries and other blood vessels flexible, ensuring good blood flow-perfusion and normal blood pressure. Daily physical activity reduces one’s chances of stroke and the risk of heart disease. According to the American Heart Association (AHA), exercising 30 minutes a day, five days a week will improve your heart health and help reduce your risk of heart disease. (Henry, 2009).

**RISKS OF EXERCISE**

Too much exercise can be harmful. Without proper rest, the chance of stroke, heat stroke or other circulation problems increases, and muscle tissue may develop slowly (Gareth, 2006). Extremely intense, long-term cardiovascular exercise, as can be seen in athletes who train for multiple marathons, has been associated with scarring of the heart and heart rhythm abnormalities (Dennis, 2000). Exercise in itself causes a state of disrupted homoeostasis (Fikir, 2011). Cardiovascular changes, sympathetic stimulations, increased ventilation and many other autonomic adjustments bring about the cardio respiratory responds during exercise.

**RESPONSE TO EXERCISE**

The physiological response to exercise is dependent on the intensity, duration and frequency of the exercise as well as the environmental conditions. During physical exercise, requirements for oxygen and substrate in skeletal muscle are increased, as are the removal of metabolites and carbon dioxide (Keith *et al.,* 2009) Chemical, mechanical and thermal stimuli affect alterations in metabolic, cardiovascular and ventilator function in order to meet these increased demands (Rodgers, 1999). The response of the Cardio-respiratory system to exercise is a remarkable one. As the body’s demand for Oxygen (O2) increases, more O2 is supplied by increasing the ventilation rate: Excellent matching occurs between O2 consumption, carbon IV oxide (CO2) production, and the ventilation rate. Depending on the functional condition of the body system, as well as the environmental conditions, change in the intensity of skeletal muscle blood flow is observed even at rest (Wilmore *et al*., 2008). The effect of the recovery modalities is associated with an increase in blood volume and its distribution from less active muscles to more active muscles (Laughlin, 1999).

Some of the cardio respiratory responses to exercise include

* Cardiovascular adjustment
* Respiratory response
* Increased oxygen consumption and circulatory changes
* Temperature regulation
* Oxygen Debt
* Hyperemia

**CARDIOVASCULAR ADJUSTMENT**

At the onset of short-term, light- to moderate-intensity exercise, there is an initial increase in cardiac output (Q) to a plateau at steady state (see Figure 1.a). Cardiac output plateaus within the first 2 minutes of exercise, reflecting the fact that cardiac output is sufficient to transport the O2 needed to support the metabolic demands (ATP production) of the activity. Cardiac output increases owing to an initial increase in both stroke volume (SV) (Figure 1.b) and heart rate (HR) (Figure 1.c). Both variables level off within 2 minutes. During exercise of this intensity the cardio-respiratory system is able to meet the metabolic demands of the body; thus, the term steady state or steady rate is often used to describe this type of exercise. During steady state exercise, the exercise is performed at intensity such that energy expenditure is balanced with the energy required to perform the exercise. The Plateau evidenced by the cardiovascular variables (in Figure 13.1) indicates that a steady state has been achieved. The increase in stroke volume results from an increase in venous return, which, in turn, increases the left ventricular end–diastolic volume (LVEDV) (preload). The increased preload stretches the myocardium and causes it to contract more forcibly in accordance with the Frank-Starling law of the heart. Contractility of the myocardium is also enhanced by the sympathetic nervous system, which is activated during physical activity. Thus, an increase in the left ventricular end–diastolic volume and a decrease in the left ventricular end–systolic volume (LVESV) account for the increase in stroke volume during light to moderate dynamic exercise (Poliner, *et al.,* 2005). Heart rate increases immediately at the onset of activity as a result of parasympathetic withdrawal. As exercise continues, further increases in heart rate are due to the action of the sympathetic nervous system (Rowell, 2007). Systolic blood pressure (SBP) will rise in a pattern very similar to that of cardiac output: There is an initial increase and a plateau once steady state is achieved (Figure 1.d). The increase in systolic blood pressure is brought about by the increase in cardiac output. Systolic blood pressure would be even higher if not for the fact that resistance decreases, thereby partially offsetting the increase in cardiac output. When blood pressure (BP) is measured intra-arterially, diastolic blood pressure (DBP) does not change.

When it is measured by auscultation it either does not change or may go down slightly. Diastolic blood pressure remains relatively constant because of peripheral vasodilation, which facilitates blood flow to the working muscles. The small rise in systolic blood pressure and the lack of a significant change in diastolic blood pressure cause the mean arterial pressure (MAP) to rise only slightly, following the pattern of systolic blood pressure. Total peripheral resistance (TPR) decreases owing to vasodilation in the active muscles (Figure 1.e). The vasodilation of vessels in the active muscles is brought about primarily by the influence of local chemical factors (lactate, K+, Adenosine, and so on), which reflect increased metabolism.

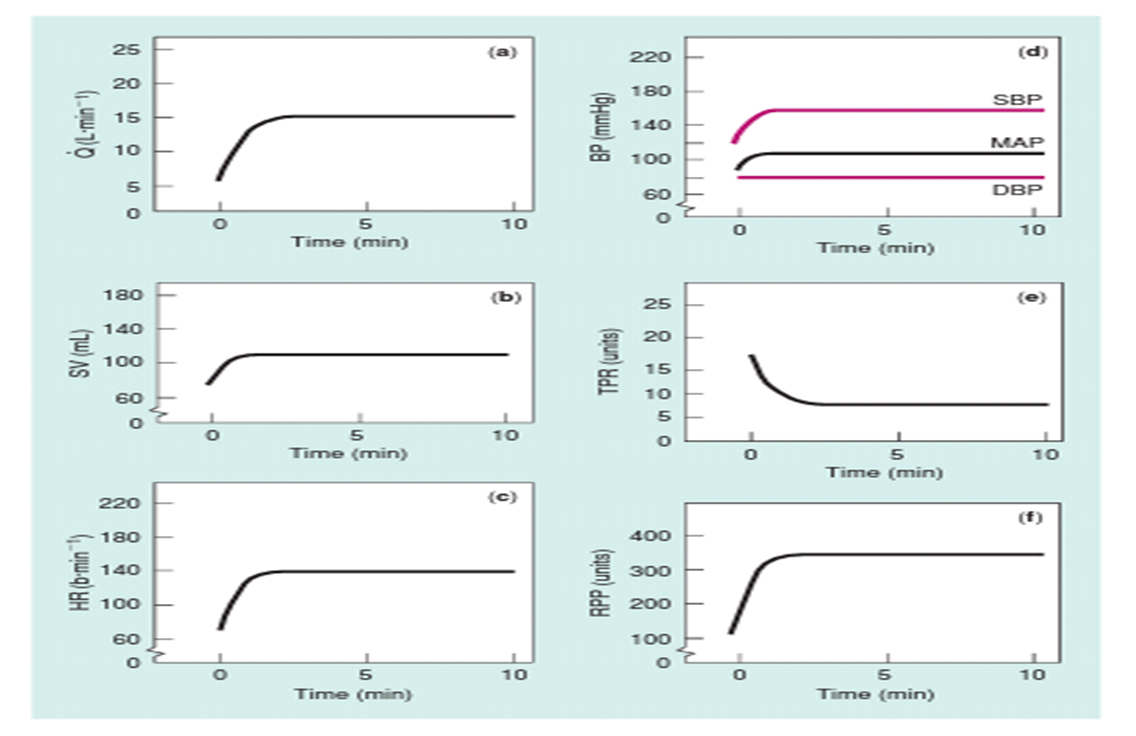


FIGURE 1 ***Source:* Data from Anderson (2004).**

**RESPIRATORY RESPONSES TO EXERCISE**

The respiratory system also responds when challenged with the stress of exercise. Pulmonary ventilation increases almost immediately, largely through stimulation of the respiratory centers in the brain stem from the motor cortex and through feedback from the proprioceptors in the muscles and joints of the active limbs. During prolonged exercise, or at higher rates of work, increases in CO2 production, hydrogen ions (H+), and body and blood temperatures stimulate further increases in pulmonary ventilation (Terjung, 2000). At low work intensities, the increase in ventilation is mostly the result of increases in tidal volume. At higher intensities, the respiratory rate also increases. In normal-sized, untrained adults, pulmonary ventilation rates can vary from about 10 liters per minute at rest to more than 100 liters per minute at maximal rates of work; in large, highly trained male athletes, pulmonary ventilation rates can reach more than 200 liters per minute at maximal rates of work (Richardson, 2016).

**OXYGEN DEBT**

Vigorous physical activity (such as exercise or hard labor) increases the body's demand for oxygen. The first-line physiologic response to this demand is an increase in heart rate, breathing rate, and depth of breathing. Oxygen consumption (VO2) during exercise is best described by the Fick Equation: VO2=Q x (a-vO2diff), which states that the amount of oxygen consumed is equal to cardiac output (Q) multiplied by the difference between arterial and venous oxygen concentrations (Grace, 2003). More simply put, oxygen consumption is dictated by the quantity of blood distributed by the heart as well as the working muscle's ability to take up the oxygen within that blood; however, this is a bit of an oversimplification. Although cardiac output is thought to be the limiting factor of this relationship in healthy individuals, it is not the only determinant of VO2 max. That is, factors such as the ability of the lung to oxygenate the blood must also be considered (Patricks, 2002). Various pathologies and anomalies cause conditions such as diffusion limitation, ventilation/perfusion mismatch, and pulmonary shunts that can limit oxygenation of the blood and therefore oxygen distribution. In addition, the oxygen carrying capacity of the blood is also an important determinant of the equation (Patricks, 2002). Oxygen carrying capacity is often the target of exercise (ergogenic aids) aids used in endurance sports to increase the volume percentage of red blood cells (hematocrit), such as through blood doping or the use of erythropoietin (EPO). Furthermore, peripheral oxygen uptake is reliant on a rerouting of blood flow from relatively inactive viscera to the working skeletal muscles, and within the skeletal muscle, capillary to muscle fiber ratio influences oxygen extraction (Demain, 2009).

**INCREASED OXYGEN CONSUMPTION AND CIRCULATORY CHANGES**

The increase in blood flow to muscles requires an increase in the cardiac output, which is in direct proportion to the increase in oxygen consumption. The cardiac output is increased by both a rise in the heart rate and the stroke volume attributable to a more complete emptying of the heart by a forcible systolic contraction. These chronotropic and inotropic effects on the heart are brought about by stimulation from the noradrenergic sympathetic nervous system (Powers *et al*., 2004). The increase in heart rate is also mediated by vagal inhibition and is sustained by autonomic sympathetic responses and carbon dioxide acting on the medulla. The efficacy of systolic contraction is particularly important in trained athletes who can achieve significant increases in cardiac output as a consequence of hypertrophy of cardiac muscle. Table 1 shows that increased maximal cardiac output in endurance trained athletes is a function of greater stroke volume rather than an increase in maximal heart rate, which is, in fact, lower in these athletes. Heart rate and stroke volume increase to about 90% of their maximum values during strenuous exercise and cardiovascular function is the limiting factor for oxygen delivery to the tissues (Brooks *et al.,* 2007). Oxygen utilization by the body can never be more than the rate at which the cardiovascular system can transport oxygen to the tissues. There is only a moderate increase in blood pressure secondary to the rise in cardiac output. This is caused by stretching of the walls of the arterioles and vasodilatation, which in combination reduce overall peripheral vascular resistance. There is a large increase in venous return as a consequence of muscular contraction, blood diversion from the viscera and vasoconstriction (Brooks *et al.,* 2007).

**Table 1: Comparison of cardiac function between athletes and non-athletes**

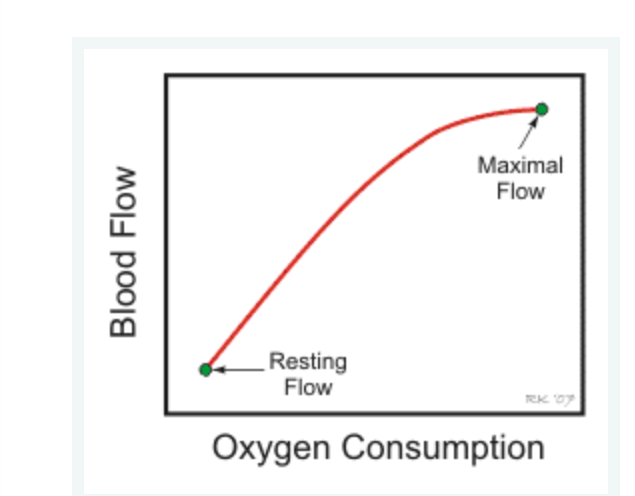
|  |  |  |
| --- | --- | --- |
|  | **Stroke volume (ml)** | **Heart rate (BPM)** |
| **At rest** |  |  |
| Non-athlete | 70 | 70 |
| Trained athlete | 100 | 50 |
| **Maximum exercise** |  |  |
| Non-athlete | 110 | 190 |
| Trained athlete | 160 | 180 |

**BODY TEMPERATURE**

The maximum efficiency for the conversion of energy nutrients into muscular work is 20–25%. The remainder is released in a non-usable form as heat energy which raises the body temperature. In order to dissipate the extra heat generated as a result of increased metabolism during exercise, blood supply to the skin must be Increased (Rodahl 2007). This is achieved with vasodilatation of cutaneous vessels by inhibition of the vasoconstrictor tone. Evaporation of sweat is also a major pathway for heat loss and further heat is lost in the expired air with ventilation. The hypothalamus is responsible for thermoregulation and it is important that this process is effective (McArdle 2017). However, during exercise in hot, humid conditions evaporative heat loss through sweating might not be able to remove sufficient heat from the body. Regulation of body temperature may fail and temperatures may be high enough to cause heat stroke. This presents with symptoms of extreme weakness, exhaustion, headache, dizziness eventually leading to collapse and unconsciousness. Physical activity has numerous beneficial physiologic effects. Most widely appreciated are its effects on the cardiovascular and musculoskeletal systems, but benefits on the functioning of metabolic, endocrine, and immune systems are also considerable (Bloomfield *et al.,* 2008).

**HYPEREMIA**

Exercise hyperemia refers to the increase in skeletal muscle blood flow that occurs during muscular activity because this increase in blood flow occurs in response to increased cell metabolism (Jeremiah, 2012). Exercise hyperemia is referred to as active or functional hyperemia, terms which also apply to the increase in flow to any organ that experiences an increase in parenchymal cell metabolism (Jeremiah, 2012). The aforementioned adjustments in the cardiovascular system are required during exercise to coordinate the delivery of oxygen and nutrients to the tissues where they are most needed—the heart, respiratory muscles, and contracting skeletal muscles (Yosr, 2011). The largest of these increases in blood flow occurs in the exercising skeletal muscles, owing to their cell metabolism. To sustain the increased metabolic demand of these tissues, increased oxygen and nutrient delivery are accomplished by increasing cardiac output, blood flow, microvascular surface area available for exchange in the active tissues, oxygen-carrying capacity of the blood, and oxygen extraction from the blood (Alvord, 2003). Blood flow increases because of the increased oxygen consumption during muscle contraction, stimulates the production of vasoactive substances that dilate the resistance vessels in the skeletal muscle (Majeed *et al.,* 2009). Other examples include the increase in gastrointestinal blood flow during digestion of food, the increase in coronary blood flow when heart rate is increased, and the increase in cerebral blood flow associated with increased neuronal activity in the brain. The figure shows that there is a resting flow associated with the basal oxygen consumption of the tissue. As the oxygen consumption increases, there is generally a near-linear increase in blood flow until the vessels begin to achieve a maximally dilated state. The magnitude of active hyperemia responses differ among organs because of the relative changes in metabolic activity from rest and their vasodilatory capacity. Active hyperemia can result in up to a 50-fold increase in muscle blood flow with maximal exercise, whereas cerebral blood flow may only increase 2-fold with increased neuronal activity (Harvey *et al.,* 2004). Active hyperemia can also be influenced by competing vasoconstrictor mechanisms, Active hyperemia may be due to a combination of tissue hypoxia and the generation of vasodilator metabolites such as potassium ion, carbon dioxide, nitric oxide, and adenosine (Dennis, 2001).



**CONCLUSION**

Exercise is any physical activity of keeping the body fit. During exercise, pulmonary ventilation must rise in proportion to the increase in metabolic rate so that arterial blood gas homeostasis is maintained. In the healthy person, multiple neural feedforward and feedback mechanisms act to increase alveolar ventilation in proportion to metabolic rate. Heart rate, cardiac output, hyperventilation and stroke volume will show marked increase at the onset of exercise.

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