

PHYSIOLOGICAL RESPONSE TO BODY EXERCISE

INTRODUCTION

Exercise represents one of the highest levels of extreme stresses to which the body can be exposed. For example, in a person who has an extremely high fever approaching the level of lethality, the body metabolism increases to approximately 100% above normal; by comparison, the metabolism of the body during a marathon race increases to 2000% above normal. 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. Chemical, mechanical and thermal stimuli affect alterations in metabolic, cardiovascular and ventilatory function in order to meet these increased demands. Compared to our resting state, exercise poses a substantial increase in demand for the body.

- At rest, our nervous system maintains a **parasympathetic tone** which affects the respiratory rate, cardiac output, and various metabolic processes.
- Exercise stimulates **the sympathetic nervous** system and will induce an integrated response from the body.
- This response works to maintain an appropriate level of homeostasis for the increased demand in physical, metabolic, respiratory, and cardiovascular efforts^[1]
- Exercise challenges many human physiological systems that need to adapt in order to maintain homeostasis, this is the inner balance of the body.
- While exercising, homeostasis is endangered by the increased amount of O₂ and nutrients demand, the need to get rid of CO₂ and metabolic waste products, rising body temperature and acid imbalance and varying hormone levels.

FUNCTIONS

Exercise has been shown to have many health benefits. Through functional exercise, we can see benefits in but not limited to:

- Cognition: Studies have shown exercising subjects to have higher concentration scores than non-exercising subjects.
- Flexibility and mobility
- Cardiovascular health
- Improved glycemic control and insulin sensitivity
- Mood elevation
- Lower risks of cancer
- Increased bone mineral density

Through a properly executed exercise program, the body adapts and becomes more efficient at performing various exercise.

These adaptations are acute and/or chronic

1. Acute Adaptations to Exercise

CARDIOVASCULAR RESPONSE

To accommodate the increased metabolic activity in skeletal muscle, the circulatory system must properly control the transport of oxygen and carbon dioxide, as well as help to buffer the pH level of active tissues.

- This is accomplished by increasing cardiac output (increased heart rate and stroke volume) and modulating microvascular circulation.
- In addition, the action of local vasomediators such as nitric oxide from endothelial cells helps to ensure adequate blood flow.

1. **Cardiac Output**

Cardiac Output (Q) -

- The amount of blood pumped by the left ventricle per minute expressed as litres/minute. $Q = (HR) \times \text{stroke volume (SV)}$.
- With a stepping working rate, the cardiac output increases in a nearly linear fashion in order to meet the increasing oxygen demand.
- Cardiac output is measured by echocardiography.

VO₂ is the consumption of oxygen and can be explained by the Fick equation.

This equation states that $VO_2 = [\text{CardiacOutput}] \times [\text{Difference in arterial and venous oxygen levels}]$.

VO₂max is a measure of aerobic exercise capacity and is defined as the highest rate of oxygen uptake an individual can maintain during intense activity.^[1]

- At rest, the value is on average about 4-5 mL/100mL of blood and
- can raise progressively during an exercise up to 16 mL/100mL of blood (4).

The 4-minute video below explains the A-VO₂ difference

Blood flow is preferentially shunted away from the gastrointestinal (GI) and renal systems and toward active muscles through the selective constriction and dilation of capillary beds with increasing physical stress,^[1]

- at maximal rates of work, 80 percent of the cardiac output goes to the activated muscles and the skin
- in rest this value is just twenty percent.

2. Blood Pressure

There is a linear increase in systolic blood pressure to peak values of 200 to 249 mmHg in normotensive individuals, and the diastolic pressure value remains near rest level.

- Hypertensive individuals reach higher systolic blood pressures at a given rate of work, and they can also reach higher diastolic values.
- The peripheral resistance of blood flow is related to vessel diameter and length and blood viscosity in the peripheral vessels.
- Under physical demands the vessels dilate, increasing their diameters.
- Hypertension patients have increased peripheral resistance compared to normal, and this is a major cause of their higher average blood pressure.

Two to three hours post-exercise blood pressure drops below pre-exercising values, this is known as "post-exercise hypotension".

3. Coronary Circulation

Coronary arteries supply the myocardium with blood and nutrients; on average one capillary supplies one myocardial fibre in the ventricular walls and papillary muscles^[3].

PULMONARY SYSTEM ADAPTATION

Pulmonary ventilation is initiated via the respiratory centre in the brainstem with parallel activation through the motor cortical drive that activates skeletal muscles and afferent Type III-IV muscle afferent fibers.

The respiratory system works in junction with the cardiovascular system. The pulmonary circuit receives almost all of the cardiac output. In response to the increased cardiac output, perfusion increases in the apex of each lung, increasing the available surface area for gas exchange (decreased alveolar dead space).

Maximum exercise training ventilation rates in normal-sized healthy people may increase by a factor of ten, compared to ventilation rates at rest

MUSCUSKELETON SYSTEM

There are 3 types of muscle fibers which have different characteristics.

Type-I fibers are known as slow-twitch fibers. These fibers have abundant mitochondria and myoglobin with great vascular supply.

- They have: Low myosin ATPase activity, High oxidative, Low glycolytic capacity
- These fibers are predominant in postural muscles as they provide low force but don't fatigue as easily as the others.

Type-IIa fibers are known as fast-twitch oxidative fibers.

- They have: High myosin ATPase activity, high oxidative, high glycolytic capacity
- Relatively resistant to fatigue
- These fibers are recruited for power activities which require sustained effort such as weight lifting for multiple repetitions.

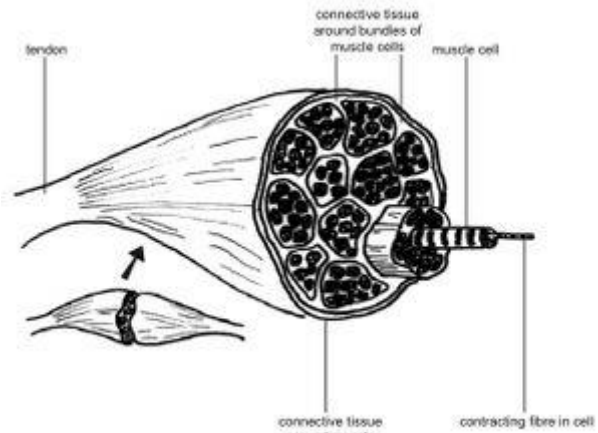
Type-IIa fibers can be considered as the middle-ground type of fiber, between the slow but fatigue-resistant type-I fibers and the fast but fatigue-prone type-IIb fibers.

Type IIb fibers are known as fast twitch glycolytic fibers.

- They have high myosin ATPase activity, low oxidative, high glycolytic activity.
- Rapidly fatigue
- These fibers are recruited for high intensity, short duration exercise such as full effort sprints.

With the introduction of progressively overloading exercise training, we can expect skeletal muscle fibers to hypertrophy meaning they increase in diameter and volume.

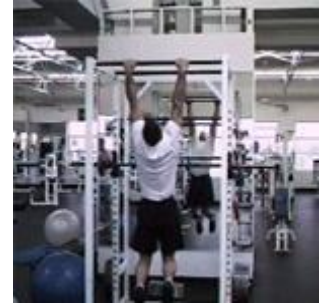
- Muscle contraction acts upon the skeleton and initiates movement. When a progressive force is applied to the muscles over time, they will adapt to the increasing load.
- Satellite cells play a role in this repair and growth process.
- The process of exercise (eg long-distance running or powerlifting) places a burden of stress on muscle fibers and bones which causes micro-tears and trauma.
- In response to this, satellite cells are activated and mobilize to regenerate damaged muscle tissue.
- This process is made possible by the donation of a daughter nuclei from the satellite cells after multiplication and fusion.
- The bones will increase their mineral density over time to manage this increasing load.^[1]



Resistance Exercise

Dynamic training and resistance training differ primarily in the fact that resistance training produces a vigorous increase in the peripheral vascular resistance.

- resistance training, high isolated forces generated in the activated musculature which compresses the small arteries and thus increases the peripheral vessel resistance^[4].



Skeletal Muscle Fibre Type

The type of physical exercise being undertaken determines the predominant muscle fibre type.

Endurance Training (regular)

- increases the number of mitochondria and the gas exchange capacity of the trained myofibrils.
- In marathon runners, slow-twitch fibres dominate the trained leg muscles (while sprinters possess predominantly fast-twitch fibres).
- has the potential to change the metabolic properties of skeletal muscles in the direction of an oxidative profile. The question as to how far muscle fibre types can be reprogrammed remains open.

HORMONAL RESPONSE TO EXERCISE

Endocrine System

Plasma levels of cortisol, epinephrine, norepinephrine, and dopamine increase with maximal exercise and return to baseline after rest.

- The increase in levels is consistent with the increase in sympathetic nervous system activation of the body.
- Growth hormone is released by the pituitary gland to enhance bone and tissue growth.
- Insulin sensitivity increases after long-term exercise.
- Testosterone levels also increase leading to enhanced growth, libido, and mood
- Catecholamines are part of cardiovascular and respiratory training adaptations and in fuel mobilisation and utilisation.

IMUNOLOGICAL ADJACEMENT

Moderate training enhances some components of the immune system and thereby reduces the susceptibility to infections. In contrast, reduced functionality of immune cells occurs after overstraining.

2. Chronic Adaptations of Exercise

SKELETON MUSCLE TO ADAPTATION

1. Endurance Training

Slow-twitch fibres: The cross-sectional area of slow-twitch (AKA red) fibres increases slightly in response to aerobic work.

Fast-twitch fibres: These fibres develop a higher oxygen capacity.

Capillary bed density: Trained muscles possess a higher density of capillaries than untrained muscle, which permits a greater blood flow with increased delivery of nutrients.



2. Resistance Training

Resistance training causes increased muscle size (hypertrophy) through an increase of myofibril size and number of fast- and slow-twitch fibres. Moreover, the recruitment pathway of muscle fibres become more effective. Resistance training thus leads to greater force development of the trained muscles.

Ligament and Tendon Adaptations

There is an increase in the cross-sectional area of ligaments and tendons in response to prolonged training, as the insertion sites between ligaments and bones and tendons and bones become stronger.

Metabolic Adaptations of Prolonged Exercise

Endurance training

- increases the size and number of mitochondria in the trained muscle
- the myoglobin content may sometimes increase, thus the oxygen storage capacity increases.
- trained muscles glycogen storage capacity increases, and the ability to use fat as an energy source.

Long Term Cardiac Adaptations

When healthy individuals participate in a long term aerobic exercise programme they undergo positive cardiac adaptations, both morphologically and physiological ie.

- Increased early diastolic filling and increased contractile strength.
- Morphological changes appear in both the left and the right ventricle.
- Cardiac adaptations lead to increased cardiac output while exercising, and a higher VO₂max after exercise^[5]
- Post-training heart rate is decreased at rest and during sub-maximal exercise.

Stroke volume increases through long term endurance training.

- Endurance training increases plasma volume, which elevates the blood volume that returns to firstly the right heart and after that to the left ventricle.
- The greater amount of blood in circulation causes an increase in the amount of blood in the left ventricle when the end-diastolic phase is reached. The end-diastolic phase is the phase in which the passive filling (diastole) of the heart finishes.
- The left ventricle is fully filled and its wall is stretched.
- The passive stored energy in the wall helps to a forceful contraction in the emptying phase (systole).
- As a result, the heart muscle is hypertrophied.
- Each heart muscle fibre increases in size. The hypertrophy refers to the ventricle and the posterior and septal walls.

High blood pressure = systolic blood pressure ≥ 140 and/or diastolic blood pressure ≥ 90 mm Hg blood pressure. The positive correlation of blood pressure and cardiovascular disease (CVD) risk starts from 115 mm Hg systolic and 75 mm Hg diastolic and doubles with every 20 mm Hg systolic and 10 mm Hg diastolic increase.

According to the American College of Sports medicine, dynamic aerobic training reduces blood pressure (BP) in individuals with hypertension.

- Hypertension is a risk factor for cardiovascular events.
- Endurance exercises lower arterial blood pressure for some hours after a bout of exercise: this phenomenon is the post-exercise hypotension.
- Post-exercise hypotension seems to be greater in people with higher pre-exercise blood pressure values.
- Blood pressure reductions occur after short bouts of exercises of 3 minutes duration and an intensity of 40% VO₂max.
- Morphological cardiac adaptations are less in people with cardiovascular disease than when compared to younger, healthy people.

Long Term Respiratory Adaptations

The blood flow in the upper regions of the lungs increases after prolonged endurance training and the respiration rate increases.

Absolute Contraindications to Exercise



Unstable Cardiovascular Disease (peripheral and central)^{[6][7]}: acute myocardial infarction or unstable angina until stable for at least 5 days, dyspnoea at rest, pericarditis, myocarditis, endocarditis, symptomatic aortic stenosis, cardiomyopathy, unstable or acute heart failure, uncontrolled tachycardia.

- Fever: should be settled to avoid a risk of developing myocarditis.
- Acute pulmonary embolism or pulmonary infarction. Excessive or unexplained breathlessness on exertion.
- Any acute severe illness
- Serious musculoskeletal injury/problem
- Severely impaired cognitive functioning

Precautions with Exercise

- Uncontrolled or poorly controlled asthma.
- COPD: Patients are required to be stable before training and oxygen saturation levels should be above 88-90%.
- Cancer or blood disorders: when treatment or disease cause leukocytes below $0.5 \times 10^9/L$, haemoglobin below 60g/L or platelets below $20 \times 10^9/L$. If a patient has a platelet count of $<20\ 000$ then only AROM and ADLs are advised due to the increased risk of bleeding, 20 000-30 000: light exercise only
- Diabetes: If blood glucose is >13 mmol or <5.5 mmol/l then it should be corrected first. Patients with severe diabetic peripheral or autonomic neuropathy or foot ulcers should be assessed before undertaking exercise. Cease exercise with diabetes with acute illness or infection.
- Hypertension: resting blood pressures of a systolic >180 or diastolic >100 or higher should receive medication before regular physical activity with particular restrictions on heavy weights strength conditioning, which can create particularly high pressures.
- Osteoporosis: avoid activities with a high risk of falling.
- Unexplained dizzy spells.

Adverse Effects

Musculoskeletal Adverse Effects

Sudden force development or repetitive movements can lead to musculoskeletal strain, tear or fracture.

Cardiovascular Events

In an epidemiological study, Prevalence of Sudden Cardiac Arrest (SCA) was studied between 2002-2013 and was compared with medical data in the USA.

- Of 1,247 cases of SCA, 63 occurred during sports activities.
- The affected persons were 51.1 ± 8.8 years old.
- The incidence is 21.7 (95% -CI 8.1-35.4) per million per year and varies based on sex for sports SCA.
- Men possess a Risk Ratio of 2.58 (95%-CI 2.12-3.13)

Another study investigated the US National Registry of Sudden Death in Athletes. They found

- A total of 2406 deaths between years 1980-2011.
- The young athletes were 19 ± 6 years old and were engaged in 29 diverse sports.
- Young men were affected 6.5 times more frequently than women.
- The most common reason was hypertrophic cardiomyopathy.