How Exercise Works

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Introduction to How Exercise Works

When you exercise or compete in sports, you notice several things about your body. You breathe heavier and faster, your heart beats faster, your muscles hurt and you sweat. These are all normal responses to exercise whether you work out regularly or only once in a while or whether you are a "weekend warrior" or a trained athlete. When you watch world-class athletes compete, you see the same responses, only magnified.

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- How Muscles Work
- Why is 90 minutes of exercise per week ideal?
- DiscoveryHealth.com: Exercise as an Aphrodisiac

The body has an incredibly complex set of processes to meet the demands of working muscles. Every system in the body is involved. In this article, we will look at how your body responds to strenuous exercise -- how muscles, blood circulation, breathing and body heat are affected. You will also see how these responses can be enhanced by training.

Your Body's Response to Exercise

Any type of exercise uses your muscles. Running, swimming, weightlifting -- any sport you can imagine -- uses different muscle groups to generate motion. In running and swimming, your muscles are working to accelerate your body and keep it moving. In weightlifting, your muscles are working to move a weight.

Exercise means muscle activity!

As you use your muscles, they begin to make demands on the rest of the body. In strenuous exercise, just about every system in your body either focuses its efforts on helping the muscles do their work, or it shuts down. For example, your heart beats faster during strenuous exercise so that it can pump more blood to the muscles, and your stomach shuts down during strenuous exercise so that it does not waste energy that the muscles can use.

When you exercise, your muscles act something like electric motors. Your muscles take in a source of energy and they use it to generate force. An electric motor uses electricity to supply its energy. Your muscles are biochemical motors, and they use a chemical called adenosine triphosphate (ATP) for their energy source. During the process of "burning" ATP, your muscles need three things:

- They need oxygen, because chemical reactions require ATP and oxygen is consumed to produce ATP.
- They need to eliminate metabolic wastes (carbon dioxide, lactic acid) that the chemical reactions generate.
- They need to get rid of heat. Just like an electric motor, a working muscle generates heat that it needs to get rid of.

In order to continue exercising, your muscles must continuously make ATP. To make this happen, your body must supply oxygen to the muscles and eliminate the waste products and heat. The more strenuous the exercise, the greater the demands of working muscle. If these needs are not met, then exercise will cease -- that is, you become exhausted and you won't be able to keep going.

To meet the needs of working muscle, the body has an orchestrated response involving the heart, blood vessels, nervous system, lungs, liver and skin. It really is an amazing system!

Let's examine each need and how it is met by the various systems of the body.

Exercise and ATP

For your muscles -- in fact, for every cell in your body -- the source of energy that keeps everything going is called ATP. **Adenosine triphosphate** (ATP) is the biochemical way to store and use energy.

The entire reaction that turns ATP into energy is a bit complicated, but here is a good summary:

- Chemically, ATP is an adenine nucleotide bound to three phosphates.
- There is a lot of energy stored in the bond between the second and third phosphate groups that can be used to fuel chemical reactions.
- When a cell needs energy, it breaks this bond to form **adenosine diphosphate (ADP)** and a free phosphate molecule.
- In some instances, the second phosphate group can also be broken to form **adenosine monophosphate (AMP)**.
- When the cell has excess energy, it stores this energy by forming ATP from ADP and phosphate.

ATP is required for the biochemical reactions involved in any muscle contraction. As the work of the muscle increases, more and more ATP gets consumed and must be replaced in order for the muscle to keep moving.

Because ATP is so important, the body has several different systems to create ATP. These systems work together in phases. The interesting thing is that different forms of exercise use different systems, so a sprinter is getting ATP in a completely different way from a marathon runner!

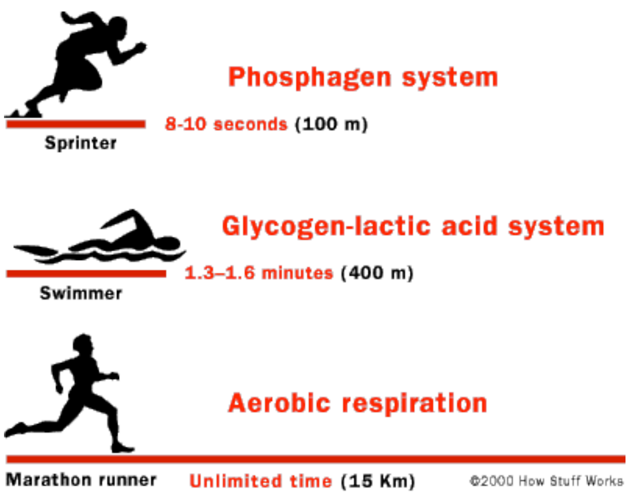
ATP comes from three different biochemical systems in the muscle, in this order:

1. phosphagen system
2. glycogen-lactic acid system
3. aerobic respiration

Now, let's look at each one in detail.

Exercise and the Phosphagen System

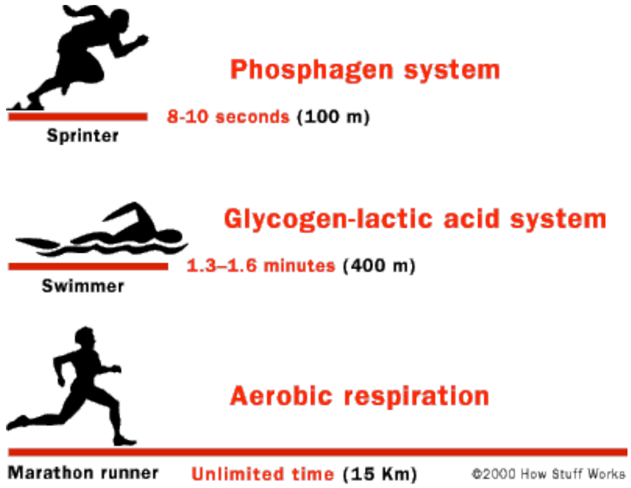
A muscle cell has some amount of ATP floating around that it can use immediately, but not very much -- only enough to last for about three seconds. To replenish the ATP levels quickly, muscle cells contain a high-energy phosphate compound called **creatine phosphate**. The phosphate group is removed from creatine phosphate by an enzyme called **creatine kinase**, and is transferred to ADP to form ATP. The cell turns ATP into ADP, and the phosphagen rapidly turns the ADP back into ATP. As the muscle continues to work, the creatine phosphate levels begin to decrease. Together, the ATP levels and creatine phosphate levels are called the **phosphagen system**. The phosphagen system can supply the energy needs of working muscle at a high rate, but only for 8 to 10 seconds.



Exercise and the Glycogen-Lactic Acid System

Muscles also have big reserves of a complex carbohydrate called **glycogen**. Glycogen is a chain of glucose molecules. A cell splits glycogen into glucose. Then the cell uses **anaerobic metabolism** (anaerobic means "without oxygen") to make ATP and a byproduct called **lactic acid** from the glucose.

About 12 chemical reactions take place to make ATP under this process, so it supplies ATP at a slower rate than the phosphagen system. The system can still act rapidly and produce enough ATP to last about 90 seconds. This system does not need oxygen, which is handy because it takes the heart and lungs some time to get their act together. It is also handy because the rapidly contracting muscle squeezes off its own blood vessels, depriving itself of oxygen-rich blood.



There is a definite limit to anerobic respiration because of the lactic acid. The acid is what makes your muscles hurt. Lactic acid builds up in the muscle tissue and causes the fatigue and soreness you feel in your exercising muscles.

Exercise and Aerobic Respiration

By two minutes of exercise, the body responds to supply working muscles with oxygen. When oxygen is present, glucose can be completely broken down into carbon dioxide and water in a process called **aerobic respiration**. The glucose can come from three different places:

- remaining glycogen supplies in the muscles
- breakdown of the liver's glycogen into glucose, which gets to working muscle through the bloodstream
- absorption of glucose from food in the intestine, which gets to working muscle through the bloodstream

Photo courtesy National Library of Medicine
Muscles of the human body

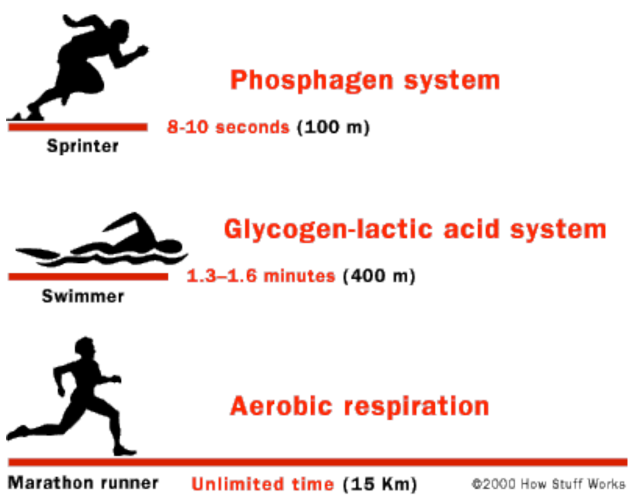
Aerobic respiration can also use fatty acids from fat reserves in muscle and the body to produce ATP. In extreme cases (like starvation), proteins can also be broken down into amino acids and used to make ATP. Aerobic respiration would use carbohydrates first, then fats and finally proteins, if necessary. Aerobic respiration takes even more chemical reactions to produce ATP than either of the above systems. Aerobic respiration produces ATP at the slowest rate of the three systems, but it can continue to supply ATP for several hours or longer, so long as the fuel supply lasts.

What Happens When You Exercise

So imagine that you start running. Here's what happens:

- The muscle cells burn off the ATP they have floating around in about 3 seconds.
- The phosphagen system kicks in and supplies energy for 8 to 10 seconds. This would be the major energy system used by the muscles of a 100-meter sprinter or weight lifter, where rapid acceleration, short-duration exercise occurs.
- If exercise continues longer, then the glycogen-lactic acid system kicks in. This would be true for short-distance exercises such as a 200- or 400-meter dash or 100-meter swim.
- Finally, if exercise continues, then aerobic respiration takes over. This would occur in endurance events such as an 800-meter dash, marathon run, rowing, cross-country skiing and distance skating.

When you start to look closely at how the human body works, it is truly an amazing machine!



Muscles and Oxygen

If you are going to be exercising for more than a couple of minutes, your body needs to get oxygen to the muscles or the muscles will stop working. Just how much oxygen your muscles will use depends on two processes: getting blood to the muscles and extracting oxygen from the blood into the muscle tissue. **Your working muscles can take oxygen out of the blood three times as well as your resting muscles.** Your body has several ways to increase the flow of oxygen-rich blood to working muscle:

- increased local blood flow to the working muscle
- diversion of blood flow from nonessential organs to the working muscle
- increased flow of blood from the heart (**cardiac output**)
- increased rate and depth of breathing
- increased unloading of oxygen from hemoglobin in working muscle

How strong are you?

You'd probably be amazed to learn how much force your body's joints and muscles actually support on a daily basis. This interactive segment from Discovery takes you inside the body and explains how much strength your bones and muscles really possess. Other activities let you explore even more of your body's systems to see exactly how they move you through your daily life.

These mechanisms can increase the blood flow to your working muscle by almost five times. That means that the amount of oxygen available to the working muscle can be increased by almost 15 times!

Let's examine more closely how blood flow to working muscle can be increased.

Exercise and Increased Blood Flow

Making the Pipe Bigger

As you exercise, the blood vessels in your muscles dilate and the blood flow is greater, just as more water flows through a fire hose than through a garden hose. Your body has an interesting way of making those vessels expand. As ATP gets used up in working muscle, the muscle produces several metabolic byproducts (such as adenosine, hydrogen ions and carbon dioxide). These byproducts leave the muscle cells and cause the capillaries (small, thin-walled blood vessels) within the muscle to expand or dilate (**vasodilation**). The increased blood flow delivers more oxygenated blood to the working muscle.

As you begin to exercise, blood from organs is diverted to the muscles.

Taking Blood from the Organs

When you begin to exercise, a remarkable diversion happens. Blood that would have gone to the stomach or the kidneys goes instead to the muscles, and the way that happens shows how the body's processes can sometimes override one another. As your muscles begin to work, the sympathetic nervous system, a part of the automatic or **autonomic nervous system** (that is, the brainstem and spinal cord) stimulates the nerves to the heart and blood vessels. This nervous stimulation causes those blood vessels (arteries and veins) to contract or constrict (**vasoconstriction**). This vasoconstriction reduces blood flow to tissues. Your muscles also get the command for vasoconstriction, but the metabolic byproducts produced within the muscle override this command and cause vasodilation, as we discussed above. Because the rest of the body gets the message to constrict the blood vessels and the muscles dilate their blood vessels, blood flow from nonessential organs (for example, stomach, intestines and kidney) is diverted to working muscle. This helps increase the delivery of oxygenated blood to working muscle further.

Exercising the Heart and Lungs

Making the Heart Pump Harder

Your heart, also a muscle, gets a workout during exercise, too, and its job is to get more blood out to the body's hard-working muscles. The heart's blood flow increases by about four or five times from that of its resting state. Your body does this by increasing the rate of your heartbeat and the amount of blood that comes through the heart and goes out to the rest of the body. The rate of blood pumped by the heart (**cardiac output**) is a product of the rate at which the heart beats (**heart rate**) and the volume of blood that the heart ejects with each beat (**stroke volume**). In a resting heart, the cardiac output is about 5 liters a minute (0.07 L x 70 beats/min = 4.9 L/min). As you begin to exercise, sympathetic nerves stimulate the heart to beat with more force and faster; the heart rate can increase about threefold. Also, the sympathetic nerve stimulation to the veins causes them to constrict. This, along with more blood being returned from the working muscles, increases the amount of blood returned to the heart (**venous return**). The increased venous return helps to increase the stroke volume by about 30 to 40 percent. When the heart is pumping at full force, the cardiac output is about 20-25 liters per minute.

Breathing Faster and Deeper

So far, we have talked about getting more blood to working muscle. Your lungs and the rest of your respiratory system need to provide more oxygen for the blood, too. The rate and depth of your breathing will increase because of these events:

- Sympathetic nerves stimulate the respiratory muscles to increase the rate of breathing.
- Metabolic byproducts from muscles (lactic acid, hydrogen ions, carbon dioxide) in the blood stimulate the respiratory centers in the brainstem, which, in turn, further stimulates the respiratory muscles.
- Slightly higher blood pressure, caused by the increased force of each heartbeat and by the elevated cardiac output, opens blood flow to more air sacs (**alveoli**) in the lungs. This increases the ventilation and allows more oxygen to enter the blood.

As the lungs absorb more oxygen and the blood flow to the muscles increases, your muscles have more oxygen.

Hemoglobin's Role in Exercise

Your body has increased the flow of oxygen-rich blood to your muscles, but your muscles still need to get the oxygen out of the blood. An exchange of oxygen and carbon dioxide is the key to this. A protein called **hemoglobin**, which is found in red blood cells, carries most of the oxygen in the blood. Hemoglobin can bind oxygen and/or carbon dioxide; the amount of oxygen bound to hemoglobin is determined by the oxygen concentration, carbon dioxide concentration and pH. Normally, hemoglobin works like this:

1. Hemoglobin in red blood cells entering the lungs has carbon dioxide bound to it.
2. In the lungs, oxygen concentration is high and carbon dioxide concentration is low due to breathing.
3. Hemoglobin binds oxygen and releases carbon dioxide.
4. Hemoglobin gets transported through the heart and blood vessels to the muscle.
5. In muscle, the carbon dioxide concentration is high and the oxygen concentration is low due to metabolism.
6. Hemoglobin releases oxygen and binds carbon dioxide.
7. Hemoglobin gets transported back to the lungs and the cycle repeats.

As you exercise, though, the metabolic activity is high, more acids (hydrogen ions, lactic acid) are produced and the local pH is lower than normal. The low pH reduces the attraction between oxygen and hemoglobin and causes the hemoglobin to release more oxygen than usual. This increases the oxygen delivered to the muscle.

Getting Rid of Waste

Your exercising body is using energy and producing waste, such as lactic acid, carbon dioxide, adenosine and hydrogen ions. Your muscles need to dump these metabolic wastes to continue exercise. All that extra blood that is flowing to the muscles and bringing more oxygen can also take the wastes away. The hemoglobin in the blood will carry away the carbon dioxide, for example.

Exercise and Body Heat

Your body heats up when you exercise, and it will show on your skin. Your skin feels hotter to the touch and may look flushed, and you sweat. Although those things let you know how much heat your body is giving off, they are actually the ways that the body cools itself.

Working muscle produces heat in two ways:

- The chemical energy used in muscles contracting is not efficiently turned into mechanical energy. (It is about 20 to 25 percent efficient.) The excess energy is lost as heat.
- The various metabolic reactions (anaerobic, aerobic) also produce heat.

Your body needs to remove this excess heat. The heat produced by exercising muscle causes blood vessels in the skin to dilate, which increases the blood flow to the skin. This elevated blood flow to the skin and the large surface area of the skin allows the excess heat to be lost to the surrounding air.

Also, receptors carry the message of excess heat to your body's thermostat, the **hypothalamus** in the brain. Nerve impulses from the hypothalamus stimulate sweat glands in the skin to produce sweat. The fluid for the sweat also comes from the increased skin blood flow. The sweat evaporates from the skin, removing heat and cooling the body. Evaporation of sweat removes fluid from the body, so it is important to maintain fluids for blood flow and sweat production by drinking water and/or sport drinks. Sports drinks also replace ions (sodium, potassium) that are lost in the sweat, and provide additional glucose to fuel anaerobic and aerobic respiration.

Heat Stroke

Evaporation of sweat is an important cooling system that can efficiently remove heat. However, if exercise is done in a hot, humid environment, then sweat does not evaporate. This reduces the efficiency of this system and the person is subject to **heat stroke**. Heat stroke is a life-threatening condition. Here are its symptoms:

- The core body temperature rises above 104 degrees F (40 degrees C)
- Sweating stops
- Heart rate increases
- Respiration increases
- Confusion, dizziness, nausea and headache occur

Heat stroke can cause a person to collapse, lose consciousness and even die. Emergency medical help involves these two steps: lowering the body temperature (removing clothing, spraying the person with cool mist, putting on ice packs, immersing the person in ice water) and replacing fluids, if possible.

You can avoid getting heat stroke by wearing shorts and other loose clothing, drinking plenty of water or sports drink and exercising in cool weather (below

82 degrees F or 28 degrees C).

Training Your Body

Your body can get more out of exercise and can exercise more easily with training. Athletes spend a great deal of time training. It allows the body to adapt its basic response to exercise and to improve athletic performance. Training can:

- make your muscles perform better
- match what you eat with what your body will use in energy
- improve the efficiency of oxygen delivery to working muscle
- get you used to the competition environment

Exercise Factors

If you exercise regularly or if you are an athlete in training, you are trying to make your muscles work better. You want to be stronger if you are a weightlifter, you want to be able to throw a blistering fast ball if you are a baseball pitcher or you want to be able to finish strong at the end of a 26-mile race if you are a marathon runner. Those three activities illustrate three major factors in muscle performance:

- strength
- power
- endurance

Muscle **strength** is the maximal force that a muscle can develop. Strength is directly related to the size (that is, the cross-sectional area) of the muscle. Muscle fibers are capable of developing a maximal force of 3 to 4 kg/cm^2 (average = 3.5 kg/cm^2) of muscle area. So, let's say that you have increased your muscle size from 100 to 150 cm^2, then the maximal resistance that you could lift could be increased from 350 kg (770 lb) to 525 kg (1,155 lb).

The **power** of muscle contraction is how fast the muscle can develop its maximum strength. Muscle power depends on strength and speed [power = (force x distance)/time]. A person can have extreme power from muscles (7,000 kg-m/min) for a short period of time (about 10 seconds) and then power reduces by 75 percent within 30 minutes; this aspect is important for sprinters because it gives them great acceleration. Muscle **endurance** is the capacity to generate or sustain maximal force repeatedly.

Resistance Training

But even if you train hard every day, you still might not be able to make your muscles perform as well as another person's. Athletes are not just made; they are born, too. Strength, power and endurance may be due in part to the distribution of fiber types within an individual's muscles. Muscles have a mixture of two basic types of fibers, **fast twitch** and **slow twitch**. Fast-twitch fibers are capable of developing greater forces and contacting faster and have greater anaerobic capacity. In contrast, slow-twitch fibers develop force slowly, can maintain contractions longer and have higher aerobic capacity. Your genes largely determine whether you have more of one kind of muscle fiber or another. Sprinters tend to have more fast twitch fibers. Marathon runners tend to have more slow twitch fibers. And the rest of us tend to have an equal distribution of both fiber types. It is not clear whether training can change the distribution of fiber types within an individual.

The training to improve strength, power and endurance of muscle performance is called **resistance training** (for example, free weights, jump-training and isometric training). Resistance training mostly increases the size of muscle fibers (**hypertrophy**). It is not clear whether training can increase the number of muscle fibers (**hyperplasia**). Muscle fibers get bigger by having more muscle protein content, and that is achieved by making new protein and decreasing the rate at which existing proteins are broken down. These proteins include contractile proteins as well as the enzymes that are involved in various metabolic reactions. By increasing the strength of muscles, resistance training can also increase the power of muscles. Increases in strength, diet and improved cardiovascular performance can increase muscle endurance.

Diet and Exercise

You can help your body to exercise better by eating the right foods. You know that muscle metabolism involves the phosphagen system, glycogen-lactic acid system and aerobic respiration. The major fuels used are glucose and glycogen. So, if you want to do well, whether you are competing or just exercising for well-being, you should try to increase the stores of glycogen in your liver and your muscles. Athletes eat solid, high-carbohydrate diets (breads, pasta) the night before competition, and liquid, high-glucose diets in the morning before competition. Sports drinks containing glucose are good to drink during competition to replace fluid and help to maintain blood glucose levels.

Cross Training

To become a world-class athlete or to get the most out of your exercise, you want your muscles to get the oxygen they need most efficiently. To do that you need to increase:

- cardiac output
- respiration
- the amount of oxygen carried by the blood

You can do this by resistance training, possibly in combination with **cross-training**, training for more than one sport at a time or for multiple fitness components (strength, endurance and flexibility) at the same time.

The main effects of training on the cardiac output appear to be an increase in stroke volume (that is, a larger heart) and a decrease in the resting heart rate. The increased stroke volume allows the heart to pump more blood with each beat. Because there is a limit to the maximum heart rate (180-190 beats/min), then a slower resting heart rate (50-60 beats/min in the trained athlete vs. the normal 70-80 beats/min) allows the heart to have a greater increase in heart rate during exercise. The greater increase in heart rate during exercise along with the larger volume increases cardiac output and blood flow to working muscle.

Training can help the respiratory system by decreasing the resting rate of breathing, increasing the respiration rate during exercise and increasing the volume of air exchanged with each breath (**tidal volume**). These changes allow the lungs to take in more air during exercise. Training can also boost the amount of oxygen that the working muscles take from the blood, which probably reflects the increases in metabolic enzymes.

You have probably heard about runners or cyclists who train in the mountains. This kind of training can actually increase the amount of oxygen carried by the blood forcing the body to develop more hemoglobin in the blood. Because there is less oxygen in high altitudes, the body responds by producing a hormone called erythropoietin (EPO), which causes the bone marrow to produce more red blood cells and more hemoglobin. Some athletes try to take a shortcut by injecting EPO directly into the bloodstream, but this is a dangerous practice. The International Olympic Committee has banned the use of EPO because it increases the thickness of the blood, which can lead to circulatory problems such as a heart attack or stroke.

Train Where You'll Exercise

If you are an athlete and you'll be competing in a place at a high altitude, as during the 1968 Olympics in Mexico City, then training at high altitudes would be helpful. If the competition is in a hot climate, then gradual periods of training in hot weather can allow the body to increase its efficiency in eliminating heat (increasing sweat production in the most-exposed areas of the body).

The body's reaction to exercise is a carefully orchestrated response of various systems (muscle, heart, blood vessels, lungs, nervous system and skin) designed to meet the needs of working muscles. These systems can be improved by training, thereby improving athletic performance.

For more information on exercise and related topics, check out the links on the next page.

More Information on Exercise

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