APPLIED MILITARY PHYSIOLOGY

LEADERS HANDBOOK TO EXERCISE SCIENCE
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PREFACE

As of November 2010, nearly 14.5 percent of Army Soldiers in a brigade combat team are unable to deploy by the unit’s latest arrival date in theater, or LAD. That number is up from a little over 10 percent in 2007. By 2012, it’s expected the number will be as high as 16 percent, said LTG Thomas P. Bostick, the Army’s deputy chief of staff, G-1. LTG Bostick said medical issues are a prime factor in the increase of non-deployable Soldiers. About 68 percent of those medical injuries are musculoskeletal issues, including knees, backs or muscles, for instance (23).

Recently the Army implemented a new physical training program called Physical Readiness Training (PRT). This physical training program is designed to improve soldiers' physical capability for military operations. The purposes of PRT are to improve physical fitness, prevent injuries, progressively train soldiers, and develop soldiers' self-confidence and discipline. In three military field studies, the overall adjusted risk of injury was 1.5-1.8 times higher in groups of soldiers performing traditional military physical training programs when compared with groups using a PRT program (19).

In efforts to reduce these musculoskeletal injuries while simultaneously taking an enterprise approach to support training of a 21st century army the Army should look to educate their leaders in the proper understanding of body responses and adaptations to training. Currently, our Army does not have a publication or document which gives leaders basic principles in how the body works. Not only is there a reliance on the medical community to educate Soldiers but there is a heavy reliance on our education system (Secondary School, Colleges and Universities) to meet this requirement before our Soldiers join the Army.

In order to enable, assist and improve our Army leaders in the management of combat power, we have developed this handbook which will help to educate commanders and leaders in Applied Military Physiology and the understanding of body responses and adaptations to training.

This handbook is designed for Commanders and Leaders who implement and supervise Army Physical Readiness Training (PRT). It is intended to compliment current publication TC 3-22.20, by providing more information on the basics of military physiology and the responses and adaptations that happen during different activities of Physical Readiness Training. Additionally this handbook may stimulate discussion and make recommendations for further advancement of the PRT program as designed to meet the needs of an Army in the era of persistent conflict. Leaders will have access to a document which may broaden their knowledge and comprehension for each element of training in order to answer the “So What” of PRT.

This handbook was made for educational use and may generate further discussion that may help to stimulate the basis of doctrine and policy. The opinions or statements made herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.
Introduction

Effects of physical readiness training and physical adaptations that take place afterwards depend on many different factors. Some of these aspects of exercise are fixed (genetics) and some of them are variables that depend on technique (biomechanics), adaptations that happen within the body (physiology and motor-learning), and adaptations that occur in the Soldier’s mind (psycho-social milieu). The social acceptance of unhealthy behavior has a huge impact on the way our new recruits think and feel towards exercise and training.

The current data says that only 22% of our population exercises three times per week for at least 20 minutes, while 24% of the US population does not exercise at all. During past twenty years (1991-2011) the obesity rates have skyrocketed while memberships in health clubs have seen tremendous rise in numbers. Since 1991, there has been a significant decrease in physical education participation in American public schools.

On one hand, we (as a society) are engaging in activity; however the adherence rates after 20 weeks of training are not consistent. On the other hand we are overindulging in toxic food, rich in calories, fat, sodium and sugar. It seems that many are confusing the physical activity, which is anything above sedentary level of doing nothing, with physical exercise, which includes raising one’s heart rate above metabolic resting level.

“What we were finding was that the soldiers we’re getting in today’s Army are not in as good shape as they used to be,” said Lt. Gen. Mark Hertling, who oversees basic training for the Army. “This is not just an Army issue. This is a national issue.”(5) In the most recent letter to the forces, the new Chief of Staff- General Dempsey, re-enforces the importance of fitness as one of the qualities that are the most important in today’s Army.

As a result, it is harder for recruits to reach Army fitness standards, and more are getting injured along the way. The percentage of male recruits who failed the most basic fitness test at one training center rose from just 1 in 25 in 2000 to more than 5 in 25 in 2006, up 16% in just 6 years. The percentages were even higher for women (5).

These physical training injury reports are vastly spread across the US Army as a result of training as well as the combat deployments.

In 2006 one of the Army’s elite Ranger Companies tried to find a solution to the volume of injuries sustained consistently during mission cycles. Company Commander, Major Ivezaj, knew that these injuries were connected to the specificity of physical preparation needed to sustain the special operations mission demands. His men are some of the toughest US Army light infantry raid force. Their Army Physical Fitness Test Scores were off the charts; however the number of lower back and knee injuries skyrocketed mostly caused by hard landings during parachuting and carrying heavy loads during combat raids where each man is required to sprint several flights of stairs (with equipment) and engage in various battle tasks such as hand to hand combat, climbing over obstacles, jumping, or dragging/carrying another person or object. With help from the US Army World Class Athlete Program (WCAP) MAJ Ivezaj, enlisted the help of strength and conditioning coach Matt Wenning, a world class power lifter with ability to teach and produce results. After a few workouts with Matt, the Rangers knew that they found their answer in resistance training as he introduced them to steady “diet” of Presses, Squats, and Deadlifts, with individual focus on their weak areas in order to eliminate the injury. As a result most men reported positive feedback and more effectiveness during training and combat, as well as a significant decline in injuries. This decline can be attributed to major adaptations associated with weight lifting such as increases in power, strength, and bone density. (8)
The Rangers experience was a great way of addressing the issue of focusing on the specificity of physical demands of the mission at hand and training according to those occupational tasks as oppose to training for Army Physical Fitness Test.

These issues have been studied by the Army’s Physical Fitness School in Fort Jackson, SC, for past decade. As a result of these studies, numerous training reports, and field implementations, the US Army published Physical Readiness Training (PRT) Manual (TC 3.22-20) focusing on combat related fitness tasks. The findings from the field were stunning. According to the Journal of Strength and Conditioning Research (Knapick et al), when compared to the traditional physical fitness training the subjects that participated in the new PRT showed significantly less percentage of injuries and greater levels of fitness when conducting occupational military tasks.

In short, the new manual implements something we always preached “Train as you will fight”. The PRT approach is based on individual combat soldier tasks (sprinting, jumping, crouching, climbing, pushing and other strength demanding tasks while wearing combat kit). Furthermore, the requirement of endurance events (patrols and road marches under load) still exists. The greatness of the new PRT manual is that it does not focus on the specificity of one task but provides balanced approach to physical readiness training allowing training across multiple modalities of fitness. This is a significant advance because leaders can now prepare their soldiers for unknown and unforeseeable tasks of combat by training to make necessary physical adaptations at their home base, prior to and during mission execution (if the situation allows).

Training must be correctly supervised by leaders who are responsible for preventing injuries and assisting Soldiers in gaining the most out of physical exercise. Leaders are responsible to ensure that Soldiers understand not only the execution of physical readiness training but must continue to educate and develop Soldiers in the understanding of how PRT meets the demands of Full Spectrum Operations. Along with the execution of PRT leaders must work to enhance Soldiers understanding of the factors that affect physical performance such as physiological adaptations, biomechanics of exercise, and motor learning skills. Commanders and Leaders should have a working knowledge base in basic body responses and adaptations to the Army Physical Readiness Training (PRT). PRT must be planned, executed in an efficient manner (proper technique) while intensely focused on meeting the demand of Full Spectrum Operations.
The Cardiovascular System

1-2. The heart is a pump, which is around the size of your fist, which contracts and produces pressure that moves blood through the blood vessels around the body. The right side of the heart pumps oxygen-depleted blood to the lungs in a pathway called the pulmonary circuit, and the left side pumps oxygen rich blood to all the tissues in the body using a pathway called the systemic circuit.

Cardiac muscle is collectively called the myocardium or myocardial muscle. Myocardial thickness at various locations in the heart varies according to the amount of stress placed on it. The left ventricle is the most powerful of the four heart chambers. This chamber must contract to generate sufficient pressure to pump blood through the entire body. When a person is sitting or standing, the left ventricle must contract with enough force to overcome the effect of gravity, which tends to pool blood in the lower extremities.

The left ventricle of the heart, must produce enough force to pump blood to the systemic circulation. The left ventricle has a greater thickness of its muscular wall compared to the other heart chambers. With more vigorous exercise, the working muscles’ need for blood increases considerably which in turn increases the demand on the left ventricle to deliver blood to exercising muscles.

Myocardial muscle is different than skeletal muscle in many ways. Cardiac muscle fibers are anatomically interconnected end to end by intercalated disks. These disks are structured to both help anchor individual cells together during muscle contraction and allow rapid transmission of the electrical signals which contract the heart together as one unit. The ability of the myocardium to contract as a single unit depends on initiation and propagation of an electrical signal through the heart, the cardiac conduction system. (38)

Figure 1-1   Anatomy of the Heart (Image from http://www.education.science-thi.org/edu_ana/images/heart-anatomy03.jpg)
Cardiac Conduction System

1-3. The body generates electricity in both the brain called electrical impulses. The cardiac conduction system is a series of specialized fibers located within the cardiac muscle tissue which has the unique responsibility to generate your heartbeat.

The cardiac muscle has the distinctive ability to produce its own electrical signal, called spontaneous rhythmicity. This allows the cardiac muscle to contract without any external stimulation. The contraction is rhythmic, in part because of the anatomical pairing of the conduction cells through gap junctions. There are four main components of the cardiac conduction system: (38)

3. Atrioventricular Bundle – The AV bundle travels along the ventricular septum and then sends right and left bundle branches into both ventricles. These branches send the impulse toward the apex of the heart and then outward. Each bundle branch subdivides into many smaller ones that spread throughout the entire ventricular wall.

1. Sinoatrial (SA) Node - The impulse for normal heart contractions is initiated in the SA Node and is known as the heart’s pacemaker. The SA node is a group of specialized cardiac muscle fibers located in the upper posterior wall of the right atrium. The electrical impulse generated by the SA node spreads through both atria and reaches the atrioventricular (AV) node.

2. Atrioventricular (AV) Node - The AV node conducts the electrical impulse from the atria into the ventricles. A .13 seconds delay allows blood from the atria to completely empty into the ventricles to maximize ventricular filling before the ventricles contract. While most blood moves passively from the atria to the ventricles, active contraction of the atria completes the process, often called the “atrial kick.”

4. Purkinje Fibers - The terminal branches of the AV bundle are the Purkinje fibers. They transmit the impulse through the ventricles approximately six times faster than through the rest of the cardiac conduction system.
**Vascular System**

1-4. There are different types of blood vessels in the circulatory system, with the exception of the pulmonary artery (which carries oxygen depleted blood from the heart to the lungs), arteries carry oxygen rich blood away from the heart and to the rest of the body. Anatomically arteries have thick walls. Because arteries receive blood being pumped from the heart, there usually is sufficient pressure in the arteries to move blood through the arteries and arterioles.

Except for the pulmonary vein (which carries oxygen rich blood from the lungs to the heart), veins carry oxygen depleted blood from the body’s tissues back to the heart. Vein walls tend to be thinner than arteries. Blood moves through veins as a result of contraction of skeletal muscles. As you move your arms, legs, and torso, your muscles contract, and those movements massage the blood through your veins. The contraction of skeletal muscle provides a type of kneading action to squeeze the blood through. The blood moves through the vein a little bit at a time. There are valves inside the veins that keep blood from flowing backward. The valves open in the direction that the blood is moving, and then shut once the blood passes through to keep the blood heading toward the heart.

![Vascular System Diagram](image)

1. Blood is pumped from the left side of the heart into the aorta, the largest artery in the body.
2. From the aorta, arteries branch into smaller vessels called arterioles, which further branch into capillaries.
3. The capillaries have walls that are one cell thick through which oxygen and nutrients can easily pass. Through capillaries, oxygen and nutrients are delivered to the tissues, and carbon dioxide and waste are picked up from the tissues and taken back to the heart.
4. The capillaries branch into bigger vessels called venules, and then into veins.
5. From the veins the blood enters the right side of the heart and is pumped to the lungs.

Every time your heart pumps, you can feel a pulse. People often measure the number of times their heart beats per minute (often called heart rate), to gauge their exercise intensity. When people say they are “taking their pulse” they are referring to their heart rate. The easiest places to take your heart rate are your radial and carotid arteries. The radial
artery is located on the inside of your wrist just below your thumb, and the carotid artery can be found along the neck. Resting heart rates in adults tend to be between 60 and 85 beats per minute. However, extended endurance training can lower resting heart rate to 35 beats per minute or lower. The amount of blood that is pumped with each heartbeat is called stroke volume. The product of stroke volume and heart rate is cardiac output, which is the amount of blood pumped per minute.

**Blood pressure** is the pressure applied by the blood on the vessel walls, and usually refers to arterial blood pressure. The two separate numbers given are **systolic blood pressure (SBP)** and the **diastolic blood pressure (DBP)**. The higher number is the SBP as it represents the highest pressure in the artery that occurs during ventricular systole. The contraction of the ventricles pushes the blood through the arteries with a tremendous force and that force exerts high pressure on the arterial walls. The lower number is the DBP and represents the lowest pressure in the artery, corresponding to ventricular diastole when the ventricle is filling.

**Movement of Blood (Hemodynamics)**

Blood flows from a region within the vessel of high pressure to a region within the vessel with lower pressure. This process is commonly called a pressure gradient. The pressure gradient across the entire cardiovascular system is approximately 100 mmHg (millimeters of mercury). Blood flow can increase by either an increase in the pressure difference or a decrease in resistance, or a combination of the two. Changing resistance has a larger effect on blood flow. **Vasoconstriction** occurs when the radius of the blood vessel decreases resulting in decreasing blood flow. **Vasodilation** occurs when the radius of the vessels increases which results in increasing blood flow. These small changes in blood vessel radius called vasoconstriction and vasodilation help regulate the blood flow to organs. This enables the cardiovascular system to channel blood to areas most needed throughout the body.

Distribution of blood to the various body tissues varies quite a bit depending on the immediate needs of a specific tissue. When the body is resting under normal conditions, the most metabolically active tissues receive the greatest blood supply. The liver and kidneys combine to receive almost half the blood being circulated, and resting skeletal muscles receive on about 15% to 20%.

While conducting exercise, the body sends blood to the areas to meet the greatest requirement. During heavy bouts of exercise or activity, muscles receive up to 80% or more of the available blood. This redistribution, along with increases in cardiac output allows up to 25 times more blood flow to active muscles.

Some examples of this redistribution would be after a person eats a big meal and when the digestive system is full it receives more of the available cardiac output than when the digestive system is empty. In a similar way, during increasing environmental heat stress, skin blood flow increases to a greater extent as the body attempts to maintain normal temperature. The cardiovascular system responds accordingly to redistribute blood, whether it is to the exercising muscle to match metabolism, for digestion, or to facilitate thermoregulation.

**Blood Volume**

Most of the blood volume normally resides in the venous side of the system. The average blood volume of a person is around 5-6 liters for men and 4-5 liters for women. The total volume of blood in the body depends on the body size and conditioning level of the person. Greater blood volumes are typically seen with persons who have greater lean body mass and elevated levels of endurance training. The changes on the arterial side of the system actually control blood flow to the tissues. In resting conditions, the blood volume is dispersed around the body. The venous system has great capacity to hold blood volume. There is little vascular smooth muscle in the veins, and they are very elastic. The venous system uses its large blood storage capacity to rapidly distribute needed blood back to the heart (venous return) and to the arterial side of the system. (38)

The veins have an anatomical uniqueness of having one way vales which allow blood to flow in only one direction. This prevents backflow and pooling of blood in the lower body. These vales also work in concert with the skeletal muscle pump which mechanically compresses due to skeletal muscle contraction pushing blood volume in the veins back toward the heart.
Blood Composition

Blood is typically composed of plasma, red blood cells, white blood cells and platelets. Plasma normally accounts for about 55 to 60% of total blood volume but can decrease by 10% of its normal amount or more with intense exercise in heat. Plasma can also increase by 10% or more with endurance training or acclimation to heat. Around 40-45% of blood is formed elements consisting of red blood cells, white blood cells and platelets. Red blood cells account for 99% of these formed elements while white blood cells and platelets make up less than 1%. (26)

![Blood Components](image)

The percentage of total blood volume composed of cells or formed elements is referred to as the hematocrit. \[ \text{Hematocrit} = \frac{\% \text{ Formed Elements}}{\% \text{ Total blood volume}} \]

Blood platelets play a very important role in the body and are used in blood clotting. The ability for the blood to clot prevents the body from excessive blood loss. Oxygen is primarily bound to Hemoglobin which is composed of both a protein (globin) and a pigment (heme). Heme contains iron, which binds oxygen and allows for the red blood cells to transport oxygen throughout the body.
The Respiratory System

1-5. The respiratory system and cardiovascular system combine to provide an effective delivery system which transports oxygen to and removes carbon dioxide from tissues. There are four separate processes involved in the respiratory system. These processes are Pulmonary Ventilation (Breathing), Pulmonary Diffusion, Transport of Oxygen and Carbon Dioxide in the Blood, and Gas Exchange at the Muscle.

Pulmonary Ventilation (Breathing)

Breathing is the process of moving air in and out of the lungs. Air is brought to the lungs typically through the nose although the mouth must also be used when the demand for air exceeds the amount that can comfortably be brought through the nose. When air enters the nose it becomes warmed and humidified as it travels through the nasal cavity. This movement proceeds to filter out all but the tiniest particles, minimizing irritation and the threat of respiratory infections.

Inspiration is an active process during resting and exercise, with the goal of increasing the volume of the lungs. When the lungs expand, the volumes of the lungs increase while the pressure within the lungs decrease. With the pressure of the lungs inside being now less than the pressure outside the lungs, air rushes into the lungs to reduce the pressure difference.

Expiration at rest is normally a passive process. The inspiratory muscles and diaphragm relax and the elastic tissue of the lungs recoils, returning the thoracic cage to its smaller, normal dimensions. This increases the pressure in the lungs and forces air out. During exercise or force breathing expiration becomes an active process dependant on accessory muscle actions (internal intercostals actively pull the ribs down).

Pulmonary Diffusion

Simply explained is the exchange of oxygen and carbon dioxide between the lungs and the blood and it serves two major functions. One function is to replenish the blood’s oxygen supply, which is depleted at the muscle tissue level as it is use for oxidative energy production. After the muscles create energy (ATP), the severely depleted de-oxygenated blood is pumped through the heart and returns to the lungs to become saturated with oxygen at its full carrying capacity. This blood now leaving the lungs returning to the heart has a rich supply of oxygen to deliver to the required muscle tissues. Another function is to remove carbon dioxide from returning blood. Carbon dioxide’s diffusion ability is twenty times greater than oxygen so it can diffuse across the lung more rapidly. (28)

Transport of Oxygen and Carbon Dioxide in the Blood

Oxygen is primarily transported bound to hemoglobin. Hemoglobin is a protein which is inside each of the body’s 4 to 6 billion red blood cells. This special protein permits the blood to transport oxygen at greater carrying rates. Enhancement to hemoglobin’s ability to unload oxygen occurs when the pressure of oxygen decreases, temperature rises, or blood becomes more acidic (pH decreases).

Carbon dioxide relies on the blood for transportation. The majority of carbon dioxide produced by the active muscle is transported back to the lungs in the form of bicarbonate ions. This transportation prevents the formation of carbonic acid, which can cause hydrogen ions to accumulate and increase blood acidity (lower the pH). Much smaller amounts of carbon dioxide are either dissolved in the plasma or bound to hemoglobin.

Capillary Diffusion

Capillary Diffusion is the exchange of oxygen and carbon dioxide between the blood and the muscle tissue. The arterial-venous oxygen difference is the difference in the oxygen content of arterial and mixed venous blood throughout the body. This measure reflects the amount of oxygen taken up by the tissues. Oxygen delivery to the tissues depends on oxygen content of the blood, blood flow to the tissues, and local conditions such as tissue temperature and pressure of oxygen. (38)
So What?

Respiratory system controls our breathing. Air moves via a pressure gradient. As we inhale, oxygen is brought into the lungs, where it passes through alveoli and passes into the capillaries. Once at the capillaries, the oxygen enters the muscle tissue. From the muscle tissue, Carbon dioxide and waste from the oxygen depleted blood pass through the capillaries back to the alveoli in the lungs. When we exhale, these waste products and carbon dioxide are released into the air.
**Energy for Exercise**

1-6. Energy is the fuel needed to make the muscles move for activity, and we get that energy from the breakdown of food. However food energy can’t be used directly by the muscles. Instead, the energy released from the breakdown of food is used to make a biochemical compound called adenosine triphosphate (ATP). ATP is made and stored in small amounts in muscle and other cells. The breakdown of ATP releases energy that your muscles can use to contract and make you move. ATP is the only compound in the body that can provide this immediate source of energy. Therefore, for muscles to contract during exercise, a supply of ATP must be available.

The body uses three systems in muscle cells to produce ATP.

1. The ATP-Phosphocreatine (PCr) system
2. The Glycolytic System
3. The Oxidative System

The first two systems of ATP-PCr and glycolytic do not require oxygen and are called the anaerobic “without oxygen” system. The third system requires oxygen and is called the aerobic “with oxygen” system. The aerobic system is the primary system for developing cardiorespiratory endurance, which is why we need to get oxygen to the muscles.

**Anaerobic Energy Production**

**ATP-PCr system**—The simplest of the energy systems and is a very rapid process which takes place during such an activity like sprinting. ATP is maintained at a relatively constant level, but PCr declines steadily as it is used to replenish the depleted ATP. At exhaustion, however both ATP and PCr levels are lows and are unable to provide energy for further muscle contraction and relaxation. The combination of ATP and PCr stores can sustain the muscles’ energy needs for only 3 to 15 seconds during an all out sprint. Beyond that time, muscles rely on other processes for ATP formation (Glycolytic and Oxidative systems). Note that the ATP-PCr system can create energy in the presence of oxygen but does not require oxygen to produce ATP.

**Glycolytic System**—Most of the anaerobic ATP production in muscle occurs during glycolysis, the process that breaks down carbohydrates in cells. In addition to ATP production, glycolysis often results in the formation of lactic acid. Because of this lactic acid by product, this pathway for ATP production is often called the lactic acid system. This system can use only carbohydrates as an energy source. Carbohydrates are supplied to muscles from blood sugar (glucose) and from muscle stores of glucose called glycogen. The anaerobic energy pathway provides ATP at the beginning of exercise and for short term (30-60 seconds) high-intensity exercise. For exercise that is intense and less than 2 minutes in duration, such as a 60 to 80 second sprint primarily relies on this system. During this type of intense exercise, muscles produce large amounts of lactic acid because the lactic acid system is operating at high speed.

**Aerobic Energy Production**

**Oxidative System**—After about a minute of high-intensity exercise, anaerobic production of ATP begins to decrease, and aerobic production of ATP start to increase. The aerobic system needs oxygen for the chemical reactions to make ATP. Activities of Daily living and many types of exercise depend on ATP production for the aerobic system. Whereas the anaerobic system uses only carbohydrates as a food source, aerobic metabolism can use fats, carbohydrates, and protein to produce ATP. However, for a healthy person who eats a balanced diet, proteins have a limited role during exercise since carbohydrates and fats are the main fuel broken down during aerobic ATP production. During prolonged exercise (longer than 20 minutes), there is a gradual shift from carbohydrates to fat as an energy source. (38, 32)
Energy Continuum – In reality, many types of exercise use both of anaerobic and aerobic systems. Anaerobic energy production is dominant during short term exercise, and aerobic energy production is greatest during long term exercise. For example, a Soldier who is required to move under fire by running fast under load, jumping, bounding, crawling, pushing, pulling, squatting, rolling, stopping, starting, changing direction, and getting up/down uses anaerobic energy sources almost exclusively. Boxing, (exercise of 2-3 minutes’ duration) is an example of an exercise duration that uses almost an equal amount of aerobic and anaerobic energy sources. At the other end of the energy continuum, running a marathon uses mostly aerobic production of ATP, because the exercise involves 2 or more hours of continuous activity.
Muscle Structure and Function:

1-7. There are about 600 skeletal muscles in the human body, and their primary function is to provide force for physical movement. When the muscles shorten or lengthen during a muscle action, they apply force to the bones, causing the body to move. The skeletal muscles also are responsible for maintaining posture and help regulate body temperature through the mechanism of shivering (generating heat production).

Muscle Structure

Skeletal muscle is a collection of long, thin cells called fibers. These fibers are surrounded by a dense layer of connective tissue called fascia that holds the individual fibers together and separates muscle from surrounding tissues. Muscles are attached to bones by connective tissues known as tendons. Muscular action causes the tendons to pull on the bones, thereby causing movement. Muscles cannot push the bones as they can only pull them.

Muscle Function

Muscle actions are regulated by electrical signals from motor nerves. Motor Nerves originate in the spinal cord and send messages to individual muscles throughout the body. A motor nerve and an individual muscle fiber make contact at a neuromuscular junction. Each motor nerve branches and then connects with numerous individual muscle fibers. (32)
Motor Units

There are two different types of motor neurons. There are alpha motor neurons and gamma motor neurons. Different types of motor units have different properties. Motor units obey a simple “all or none law” which simply is when the motor neuron fires the muscle fibers contract. Motor units have different number of muscle fibers to allow for the fractionated movement in muscles. If the body just had one motor neuron innervating just one muscle although it would be simple in understanding it would result in forceful contractions which lack coordination and any fractionated movement from the muscles. (22)

Alpha motor neurons can be defined as a motor neuron and all the muscle fibers it innervates.

Small motor unit muscles allow for fine and very fine control of movement. Examples of this would be small diameter motor units which innervate the finger, facial and eye muscles. Slow units typically have small diameter nerves innervating muscle fibers. These small diameter nerves conduct impulses slower than large diameter nerves.

Large motor unit muscles allow for gross and large control of movement. Examples of this would be large diameter motor units which innervate the hamstrings and quadriceps muscles. Fast units typically have large diameter nerves innervating the muscle fibers. These large diameter nerves are able to conduct impulses faster than that of small diameter nerves. This faster impulse conduction allows for the faster contraction of the muscle fibers.

Mixed Muscle- There is very few types of muscles in the body that just have one type of motor unit. Therefore most of the muscles in the body have a lot of different types of units in them and are often called mixed muscles. (22)
A normal neuron is able to conduct an impulse at around 60-70 meters per second. As we age, neurons lose the ability to conduct impulses and often lower to around 50-55 meters per second. These velocities are dependent on whether it is sensory or motor fibers.

**Gamma motor neurons** are motor neurons located inside the muscle spindle and have the sole responsibility to keep the muscle spindle aligned with the muscle. There is no force production generated from these gamma motor neurons but they are co-activated simultaneously with the alpha motor neuron. (22)

**Muscle Exercise**

1-9. **Isotonic** (also called dynamic) exercise results in movement of a body part at a joint. Most exercise or sports are isotonic. For example, lifting a dumbbell involves movement of the forearm and is therefore classified as an isotonic exercise.

**Isometric** (also called static) exercise requires the development of muscular tension but results in no movement of body parts. An example of isometric exercise is pressing the palms of the hands together. Although there is tension within the muscles of the arms and chest, the arms do not move. Isometric exercises are an excellent way to develop strength during the early stages of an injury rehabilitation program.

**Isokinetic** exercises are performed at a constant velocity where the speed of the muscle shortening or lengthening is regulated at a fixed, controlled rate. This is generally accomplished by using a machine that provides an accommodating resistance throughout the full range of motion. (32)

**Muscle Actions**

1-10. Muscle actions can similarly be classified as isometric, concentric, or eccentric, depending on the activity the muscle needs to perform.

(a) **Isometric muscle action:** are static and do not involve any joint movement. An isometric muscle action occurs during isometric exercises.

(b) **Concentric muscle action:** Causes movement of the body part against resistance or gravity and occurs when the muscle shortens. Concentric muscle actions can be performed

(c) **Eccentric muscle action:** control movement with resistance or gravity -lengthens. The downward or lowering phase of the bicep curl is controlled as the biceps muscle lengthens. The muscle is developing tension, but the force developed is not great enough to prevent the weight from being lowered. (32)
Individual Variations in Fiber Type

Not all the muscles in the body have the same percentage of type I, IIa and IIx fibers. The numbers of muscle fibers in a person’s arm and leg muscles have similar fiber compositions. This relationship means that if a person has a larger percentage of type I muscle fibers in their upper arm there would be a larger percentage of type I muscle fibers in the leg muscles. In the soleus muscle there is a predominance of type I fibers for all people.

Genetics plays the most important factor in determining which type of alpha motor neurons innervates our individual muscle fibers and changes little from childhood to middle age.

Recruitment of Motor Units and Force Generation

There are two ways that a muscle is able to generate force. First, way is going to get more motor units or the second way is having the motor units fire faster. It’s not really about how much, how many or how fast but how motor units organize to work together to generate the required force.

Henneman’s Size Principle has to deal with the order in which the body recruits motor units for any movement. The body recruits motor units from small to large no matter which type of movement. No matter if you lift 150 lbs or you lift a pencil the body recruits motor units from small to large. The difference is when you lift a pencil the movement does not require additional motor units whereas when lifting 150 lbs there becomes an immediate demand for additional

Types of Muscle Fibers

Slow-Twitch Fibers (Type I) these fibers contract slowly and produce small amounts of force although, these fibers are highly resistant to fatigue. Slow-twitch fibers appear red or darker in color because of the numerous capillaries that supply the fibers. They have the capacity to produce large quantities of ATP aerobically, which makes them ideally suited for a low-intensity, prolonged

Intermediate Fibers (Type IIa) have a combination of characteristics found in fast and slow-twitch fibers. They contract rapidly, produce great force, and resist fatigue because they have a well-developed aerobic capacity. These fibers contract more quickly and produce more force than slow-twitch fibers, but they contract more slowly and produce less force than fast-twitch fibers. They are slightly redder in appearance than fast-twitch fibers but are not as red as the slow twitch fibers.

Fast-Twitch Fibers (Type IIx) contract rapidly and generate great amounts of force, but fatigue quickly. These fibers have a low aerobic capacity and appear white because they are supplied by only a few capillaries. Fast-twitch fibers are well equipped to produce ATP anaerobically, but only for a short time. With their ability to shorten rapidly and produce large amounts of force, fast twitch muscles are used during activities requiring rapid or forceful movement, such as jumping, sprinting and weight lifting.
motor units in order to conduct the lift. The body follows this principle because it needs to coordinate the movement through fractionated muscle activation. Additionally, this principle helps in the prevention of possible injury to the body. (22)

**Rate Coding (Frequency of motor unit firing)-**

An example of this would be like a rope in a tug of war. Say for instance a one side of a rope is tied to a wall and the other side of the rope has a group of Soldiers ready to pull on the rope. Say that each Soldier represents different motor units and as a group would collectively be a muscle like the calf muscle. When each individual Soldier attempts to pull on the rope by themselves they would each have a different amount of force generated because each Soldier is a different size motor unit. In order to produce the maximum amount of force to pull the rope, the Soldiers recruit additional Soldiers (motor units) to pull the rope. Once there are no more Soldiers (motor units) to pull on the rope, then everyone pulls as many times or as fast as they can. This firing as fast as Soldiers can produce overlap thus increases the amount of force that can be produced. (22)

<table>
<thead>
<tr>
<th>So What?</th>
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<td>Speed and strength events are characterized by a higher percentage of fast twitch (type II) fibers while endurance events are characterized by a higher percentage of slow twitch (type I) fibers. The fiber types are genetically determined for each individual but through the use of endurance and strength training we may cause a change to therefore allow shifting some of the type II x/b into type II a.</td>
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Chapter 2  
**Strength and Mobility Activities**

2-1. The purpose of strength and mobility activities is to improve functional strength, postural alignment, and body mechanics as they relate to the performance of WTBDs.

The muscular strength is determined by two main physiological factors. The first and the primary factor is the size of the muscle – the larger the muscle the greater the force produced. Second factor is the number of the muscle fibers recruited during contraction – the more muscle fibers that are stimulated the greater the force produced. This aspect of muscular strength is regulated by nervous system, which means that we control how much effort is to be exerted to get the work done. Early adaptations to the strength training consist of neural factors and body’s ability to recruit more muscle fibers, while long term adaptations consist of muscle hypertrophy or growth of muscle fibers. Additionally, strength and mobility training exercises described in the TC 3.22-20 (Army Physical Readiness Training) are anaerobic in nature, which means that muscles do not use oxygen to produce energy. Instead the energy is produced through the two anaerobic systems (ATP-PCr and Glycolytic system), which are able to sustain up to two minutes of high intensity exercise. As adaptations to these strength training (anaerobic) activities our system also alters the energy systems making them more efficient and it allows control over the rate of effort through pacing to ensure that muscles are not prematurely exhausted.
Physiological changes that occur during battle specific training drills are designed to impact specific muscle groups and even individual motor units within the specific muscle. Unfortunately, the old Army Physical Fitness Test could not analyze all of the important activities needed to succeed in the battlefield and reduce the chance of injury. These specific combat fitness requirements are best described by a field reports from Soldiers returning from combat.

- Stepping up with weight (box jumps, lunge)
- Jumping (learning hip and knee extension/explosion)
- Throwing or propelling weight (weight training - overhead lifts, squats, medicine ball throws, explosive hip movement)
- Digging and carrying awkward shaped objects for unknown time and distance
- Sprinting in 40-60 lbs of gear (explosiveness, short sprints)
- Wrestling/subduing enemy combatants on stairs, a hillside, or in enclosed spaces (explosive power)
- Swinging sledgehammers/Hooley tools for breaching (explosive power and hip movement)
- Crawling in 40-60 lbs of gear (flexibility, range of motion in all joints)
- Walking on tops of exterior walls, negotiating rooftops, jumping down on unstable terrain (agility, accuracy, balance)

This is considerable because the old style of Army physical fitness testing (2 mile run - to measure aerobic endurance; two minutes of push-ups and two minutes of sit-ups - to measure anaerobic endurance) drove the way we conducted physical training; however, these three drills did not correlate significantly with the above mentioned Soldier combat requirements.

In order to meet the physical demands of the battlefield and reduce the raising injury rates the newly published Training Circular 3-22.20 addresses those battle requirements through a series of drills and movements which consist of the following:

- The Push-up drill
- Sit-up Drill and Core Strengthening
- Climbing Drills performed on a high (pull-up) bar
- The Strength Training exercises using strength training equipment
- Callisthenic and Plyometric exercises, designed to functionally train the agility, coordination and the total-body muscular strength and endurance.

### The Push-up drills

2-2. In an earlier time the push-up was largely regarded as a measure of a man's strength and fitness. In more modern times much of this reputation has been passed on to the bench-press which measures the upper body strength through one repetition maximum lift. According to recent study the push-up and the bench press exercise do not correlate well and training for one event will not result in improvement of the other.

The fact is that the push up move is still one of the greatest exercise progressions ever invented. It requires endurance of the shoulder, arm, and chest muscle. A perfect military push-up is slow and deep with a body absolutely perfectly straight and taut; however the push up move can start from the modified position (pushing against a wall or fixed object above ground), moving into horizontal position, and gradually, with incorporation
of elevating the feet from the floor ending at a point where the person is eventually in a handstand ("handstand push-up").

**Response**: According to TC 3.22-20 the Push-up Sit-up Development (PSD) promotes muscular endurance without the repetitive motions that often lead to overuse injuries. They improve mobility by progressively moving the major joints through a full, controlled range of motion.

**Adaptations**: Done correctly, the push-up is a super demanding whole body movement—it engages as many stabilizers as possible. As mentioned above the push-up is more a family of movements than a single exercise.

First of all this exercise builds mobility in the arms and shoulders while engaging the core muscles which stabilize the body in the plank position. The more difficult types of push-up incorporate balance and strength of biceps, triceps, chest muscles, hand, and fingers (grip). Plyometric push-ups (handstand and clapping pushups) are an incredibly powerful stimulus, as they require rapid firing of shoulder stabilizers while maintaining a relatively heavy and dynamic load. During the Army physical fitness test the push up event is used to measure the endurance of the chest shoulder and triceps muscle; however in its progression this exercise can be used to develop so much more of practical strength needed during everyday operations.

**Sit-up and Core strengthening drills**

2-3. For decades we have used the traditional sit-up as a way of developing the abdominal strength and as a level of measurement of the endurance of the abdominal and hip flexor muscles; however, the violent nature of the traditional sit-ups put tremendous amount of pressure on the lower back and is linked to a large number of lower back injuries. In an effort to solve this problem the U.S. Navy SEALS abandoned the sit-up in favor of the crunch and found a rather steep rise in running times. The rise in running time was eventually traced back to weak hip flexors which are developed with the traditional sit up. In order to rectify this problem the Navy SEALS decided to implement the device called ABMAT, a mat like apparatus, which allows for traditional sit-up while protecting the lower back. More importantly this trial of different abdominal exercise by the Navy confirmed the importance of the hip flexor muscles in the dynamic training. Abdominal exercise alone will not get us there. Since core serves as a muscle group that transfers power from lower body to upper body and the other way around we must incorporate as many hip extension movements into core training instead of focusing only on the abdominal muscle group.

**Response**: Sit up drill improves torso strength and stability and are crucial for operational demands. Keeping your midsection tight and having the ability to powerfully alter midsection positioning improves power output and control in almost all functional and athletic movements.

The core training is not to be confused with abdominal muscle training. Core training works abdominal muscles, hip flexors, lower back muscles, and it also includes glutes and hamstrings and everything in between. Even some of the upper body muscles such as connective tissue on the bottom of the latissimus dorsi involved during performance of plank position. These particular muscles are crucial during transfer of power from lower body to upper body for the performance that requires pulling or climbing.

**Adaptations**: Core development exercises directly impact the development of abdominal and hip flexor muscles. Traditional sit up with feet anchored generally increases the rate at which sit-ups can be performed, which intensifies the metabolic demand but also shifts the recruitment more to the hip flexors. An increase in capillary density ensures that increased amounts of oxygen can be delivered to your working muscles, while increased muscle glycogen stores provide more energy for repeated contractions. There is also development of an improved tolerance to the discomfort caused by lactic acid. Lactic acid is a by-product of anaerobic metabolism and is thought to be one of the causes of the burning sensation you feel in your muscles when...
performing muscular endurance workouts. The increased blood flow to your working muscles slows the build-up of lactic acid while working out and also speeds its dissipation at the end of your efforts.

Climbing Drills

2-4. Climbing involves the whole body movement often referred to as kipping. Kipping demands coordination and agility. It is plyometric and it requires flexibility of the shoulders, allows for rapid cycle time, and in totality represents an essential, unique, and powerful core to extremity motor recruitment pattern.

Response:

The purpose of the Climbing Drills is to improve upper body and trunk strength, and the ability to climb and negotiate obstacles. Success in climbing and surmounting obstacles depends on both conditioning and technique. These drills include exercises that condition the muscles of the body that are predominant in climbing. The entire body is involved during climbing by helping to change or stabilize position. The hands and feet act as anchor points and initiate movement to the next position. The abdominal and back muscles stabilize the body's position. The arms push and pull upward with assistance from the much stronger legs.

Adaptations: Climbing involves the whole body movement, they are plyometric with demand for coordination and ability. Climbing drills as described in TC 3.22-20 require flexibility of the shoulders and represent unique and powerful core to extremity motor recruitment pattern. As a result the strength gains are predominantly in shoulder, arms, abdominal and back muscles.

The Strength Training exercises using weight training equipment

2-5. Many of us believe that strength and power are interrelated terms and often assume that they are one and the same. Based on the popularity of strength training combined with aggressive marketing strategies many would assume that strength will dominate; however, practical application of combination of skill, coordination, and agility can neutralize the strength advantage. In short a stronger person is not necessarily more powerful.

Strength is defined as maximum force developed during muscle contraction. It depends on the ability of muscles to generate force and the ability of nervous system to activate large number of muscle fibers.

Power is amount of work per unit of time. Work is the force required to move an object multiplied by the distance moved. Strength can help increase the power by making it easier to move the object, or to move it further. Power is increased by doing the work in shorter time, therefore involving both strength and speed. Increasing one without the other limits one's abilities. Many of us focus on increasing strength because it is easier and probably a lot more fun. Speed training alone requires improved coordination, efficiency of movement, and necessary timing. In order to improve speed one must conduct endless hours of repetition drills, yet gains might be modest. The most recommended way of training is to incorporate the elements of strength and power into task specific training focusing on optimal sequence of the events.

Response: Weight-training programs specifically designed to improve strength and programs designed to improve endurance differ in the number of repetitions and the amount of weight lifted.

Adaptations: As noted earlier strength training increases muscular strength by altering muscle fiber recruitment and then by increasing in muscle size. These positive changes are reflected in body composition and flexibility. Performing weight training exercises through the full range of motion results in improved flexibility. In most cases resistance training results in increased muscle mass and loss of body fat.
Plyometric and Callisthenic Drills

2-6. The term plyometrics can be used to include both depth Jumping and hopping and bounding drills. The plyometrics equipment requirements are simple, danger is low and the benefits are high. The leaders should begin with moderation, use good judgment, and communicate with their Soldiers in order to prevent injuries and improve performance. Because of the intensity the plyometrics should not be done more than twice per week in order to allow muscles to recover and adopt.

Response: Calisthenic and plyometric exercises are designed to functionally train agility, coordination, and the lower-body muscular strength and endurance needed to successfully perform WTBDs. High explosive events such as sprints and jumps require more engagement from fast twitch fibers. This means that in order to be successful in training our muscles we must incorporate exercises that includes explosive training.

Adaptations: Plyometric drills are very dynamic movements which use gravitational force, on to the body and the contractibility and elasticity of muscle tissue to increase the force or stress on related muscles. The basic concept of plyometric exercises involves the stretch reflex mechanism and the storage of elastic energy.

When you do a high number of repetitions with a moderate weight, some myofibril growth occurs, but the body also sends a signal to increase the size and number of mitochondria, the power motors inside all the cells. As these mitochondria multiply to handle endurance demands of high rep workout, the supply of sarcoplasm also increases to make the muscles function more efficiently. As a result one will build size and endurance by boosting the volume of sarcoplasm.

A workout of heavy weights and low repetitions causes microtears in myofibrils. These tears trigger your immune system to send white blood cells to clear away damaged cell fragments, preparing the site for rebuilding. At the same time the body experiences a boost in human growth hormone, which activates dormant stem cells and makes it easier to for the body to use amino acids in protein (hence the reason why one should consume a nutritious meal after working out). The stem cells and amino acids work together to grow new filaments or fuse with the existing filaments, therefore making muscles denser, larger and stronger.

TOP: ALLERUZZO.M/U.S. ARMY Soldier doing bicep curls using a barbell made from spare car parts in Mosul, BOTTOM: BAKER, F./U.S. ARMY Army Spc. David Helton lifts weights on the single bench that serves as the gymnasium at Combat Outpost Apache in Wardak province, Afghanistan.
**Stretch Reflex** - When the Soldier lands on the ground during a plyometric exercise, a stretch occurs in the involved muscle fibers. Proprioceptors within the muscle tissues instantly sense this stretch and send a message to the spinal cord through afferent or sensory neuron. The spinal cord immediately sends a message back to the muscle fiber via an efferent motorneuron instructing the contraction to prevent an overstretch. This phenomena is called the stretch reflex and it is a protection mechanism which is built in the body for prevention of injuries to muscle tissues. Plyometric drills and training can make adaptations to the body to emit sensor signals in a shorter time period which cause the affected muscle to react more quickly. The action of plyometric jumping involves an initial eccentric contraction, followed immediately by a concentric contraction, or shortening of the muscle during the take off. This means that the athlete falls back to the ground from a previous jump, absorbs the gravitational force on the body during the stretch of the eccentric contraction and immediately returns to the jump phase by initiating a concentric contraction. (17)

**Elastic Energy** - Hochmuth (1974) stated that, "a body movement, requiring an extremely high end velocity can best be achieved by starting it with a movement in the opposite direction. The braking of the opposite movement creates positive acceleration power for the original movement." (18) For example, as a Soldier employs the use of a battering ram in the breaching of a door, the first movement is in the reverse direction of the forward swing. This backward movement and later forward movement puts a stretch on the involved muscle groups. This stretch stores kinetic energy in the muscle and creates a greater concentric contraction as the battering ram is swung forward. The prestretch is often referred to as loading the muscle.

**Key point** is that plyometrics should be supplemented with both a strength program and a running program. Power includes the elements of speed and strength and plyometrics help to integrate the two. Because these type of workouts require muscle fibers to lengthen (eccentric contraction) before contracting again many Soldiers may experience soreness which may linger for several days.

The basis for application of these plyometric drills are drawn from the experience of the Indiana University Track and Field team which generally use the guideline of about 100 jumps in one workout (4 repeats of 6 drills). The important aspect of plyometrics is that each drill must be done at full speed in order to gain the most benefit from this type of activity. Sample Plyometric hopping and bounding workout can be set up as follows (3-5 rounds):

---

**PLYOMETRIC DRILLS**

- **Double Leg Hopping**
  - L
  - R
  - L
  - R
  - L
  - R

- **Single Leg Hopping**
  - L
  - R
  - L
  - R
  - L
  - R

- **Skipping**
  - (Long Hop – Short Bound)
  - R
  - L
  - R
  - L
  - R
  - L

- **Bounding**
  - R
  - L
  - R
  - L
  - R
  - L

- **Hop – Bound**
  - R
  - L
  - R
  - L

- **Run- Run- Bound**
  - R
  - L
  - R
  - L
  - R
  - L
  - R

Adapted from Dr. Phil Henson, Theories of High Level Performance, Plyometric Training, Lecture and Handout, June 2010, at Indiana University, Bloomington, IN
Chapter 3   Endurance and Mobility

3-1  Cardiorespiratory endurance is the ability to execute aerobic exercises, such as running for an extended period of time. **Aerobic** exercise is commonly described as exercises that primarily use the aerobic energy system (with oxygen) and that are designed to improve cardiorespiratory fitness. **Anaerobic** exercise is commonly described as exercises that primarily use anaerobic energy system (without oxygen) and that are designed to improve short term and high intensity exercise.

The cardiorespiratory system is composed of the cardiovascular system (the heart and blood vessels) and the respiratory system (the lungs and muscles involved in respiration). In concert, these systems deliver oxygen and nutrients throughout the body and remove waste products (e.g. CO2 etc) from tissues. Exercise challenges the cardiorespiratory system because it increases the demand for oxygen and nutrients in the working muscle.

The most important measurement of cardiorespiratory fitness is VO2max, or maximal aerobic capacity, which is the maximum amount of oxygen the body can take in and use during exercise. In simple terms, VO2max is a measure of the endurance of both the cardiorespiratory system and exercising skeletal muscles.

One of the most highly used field tests for VO2 max is the 12 minute run test or the 1.5 mile run test both develop by Dr. Kenneth Cooper. Both these tests have shown high correlation to the VO2 max tests administered in laboratory settings using direct measurements. The Army has recently changed the APFT run test from 2 miles to 1.5 which will result in more valuable data on the on the capacity of the Soldier to perform endurance work. (2)

3-2  **Factors affecting VO2max**

**Level of conditioning**- Initial state of conditioning will determine how much VO2max will increase for example the higher the initial value, the smaller the expected increase

**Heredity**- Accounts for 25-50% of the variation in VO2max and largely explains an individual’s response to training. There is a genetic ceiling for VO2 max in which you can only increase it to a certain point.

**Sex**- Women have a lower VO2max compared to men. Lower muscle mass and lower blood volume are some reasons for this. Highly condition female athletes have VO2max values about 10% lower than their male counterparts. Most of the difference is due to females having a smaller heart size and lower blood volume.

**Individual responsiveness**- There are high responders and low responders to endurance training which is a genetic phenomenon

**Physiological factors**- The ability of the heart to pump blood (contractility) and the oxygen-carrying capacity of the blood (hemoglobin content). The ability of the working muscles to accept a large blood supply (amount of capillarization within a muscle). The ability of the muscle cells to extract oxygen from the capillary blood and use it to produce energy (number of mitochondria and aerobic enzymes). (38, 32)

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**So What?**

VO2 max is a measure of your body’s ability to take up and utilize oxygen during maximum exercise. The 12 minute run test or 1.5 mile run test is a field expedient way to measure a Soldier’s maximum oxygen consumption rate (VO2max). The results of the 1.5 mile run test give commanders and leaders a reliable measurement of cardio respiratory fitness for each one of their Soldiers.
Cardiorespiratory Responses and Adaptations to Acute Exercise

3-3. During an exercise session and after a regular workout your cardiorespiratory system undergoes several responses and adaptations.

**Responses** are the changes that occur during and immediately following exercise. For example, your increased heart rate and heavy breathing after you run up a hill or climb flights of stairs is a response.

**Adaptations** are the changes you will see over time while adhering to the Physical Readiness Training program or specified regular exercise program. For example, your ability to run up a hill, foot march for 20 km with load, sprint or climb flights of stairs without getting winded after a few weeks of regular PRT is the human body's adaptation to the aerobic or anaerobic training.

3-4. **General Adaptations**

**Aerobic Training**-
The body adapts to aerobic training resulting in improved central and peripheral blood flow and enhancement of the capacity of muscle fibers to generate ATP.

**Anaerobic Training**-
The body adapts to anaerobic training resulting in increased short term, high-intensity endurance capacity and increased anaerobic metabolic function. Another adaptation is the increased tolerance for acid-base imbalances during highly intense efforts. (22)

3-5. **Cardiovascular Adaptations to Training**

**Heart Size Adaptation**
The left ventricle of the heart changes significantly in response to endurance training. The internal dimensions (size) of the left ventricle increase as an adaptation to an increase in ventricular filling which is secondary to the increase in plasma volume and diastolic filling time. The left ventricular wall thickness and mass increase allows for greater contractility

**Stroke Volume**
Endurance training increases Stroke Volume at rest and during submaximal and maximal exercise intensity levels. Increases in end diastolic volume are caused by an increase in blood plasma and greater diastolic filling time (lower heart rate) which leads to increased stroke volume. An increased ventricular filling or often called "pre-load" results in the production of greater contractility by the ventricles. Another adaptation is the reduced systemic vascular resistance often called “after-load”.

**Heart Rate**
A decrease in resting heart rate and a relative decrease in heart rate at any given submaximal exercise intensity are common adaptations which result from endurance training.

**Cardiac Output**
Cardiac output is the volume of blood pumped by the heart in the time interval of one minute. The adaptation from endurance training allows for the maximum cardiac output increase due mostly to an increase in stroke volume. Cardiac output has been shown to increase at maximal exercise and is largely responsible for the increase in VO2max. Cardiac Output \( (Q) \) is equal to the stroke volume times the heart rate. This formula is described as: \( (38,22,17) \)

\[
Q = \text{Stroke Volume} \times \text{Heart rate}
\]
**Blood Flow** - Through *Angiogenesis* (physiological process involving the growth of new blood vessels from pre-existing vessels), there is increased capillarization of trained muscles. There is also an adaptation resulting in the greater recruitment of existing capillaries in trained muscles in order to effectively extract more oxygen. Another adaptation is the increased effectiveness of blood flow redistribution from areas of inactivity such as the stomach.

**Blood Pressure**
Blood pressure is reduced at rest and during submaximal exercise but not during maximal exercise. The largest reduction is typically seen in the systolic pressure, particularly in hypertensive subjects.

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**3-6  Respiratory Adaptations to Endurance Training**

There are minimal effects on lung structure and function at rest due to endurance training. There is an increase in pulmonary ventilation (rate which gas enters or leaves the lung) during maximal exercise through both increased tidal volume (normal volume of normal inspiration) and respiratory rate. Pulmonary diffusion increases at maximal exercise due to increased ventilation and lung perfusion. The Arterial-Venous Oxygen difference increases with training, reflecting increased extraction of oxygen at the tissues (26).
Responses and Adaptations to Specific Endurance and Mobility Activities

3-7 30:60s and 60:120s

Responses- When Soldiers sprint for 30 and 60 seconds, their heart rate, cardiac output, increases in direct proportion to the increase in intensity until near maximal exercise is achieved. Stroke volume increases with increasing intensity and through increases in the heart’s degree of contractility. The overall blood pressure (Mean Arterial Pressure) increases substantially during exercise as systolic blood pressure increases directly proportionally to the exercise intensity. However, diastolic blood pressure remains relatively unchanged during the exercise. The mean arterial blood pressure has to increase during exercise to facilitate the increase of blood flow which aid in substrate delivery to working muscles.

Adaptations- The body will adapt to sprint training in a few ways. Soldiers will notice improved sprinting performance, anaerobic capacity and anaerobic power. Sprint training also enhances muscle strength development which allows a Soldier to perform the same workload (sprint) with less effort. Other adaptations of the body are an increase in oxidative and glycolytic enzymes in working muscles, small increase in blood buffering capacity and the activation of additional fast twitch (Type II) muscle fibers.

Active Recovery- When Soldiers walk for 60 or 120 seconds following their 30 and 60 sprints, the body is able to flush out and remove metabolic waste products by actively maintaining blood flow through the active muscles.

*30:60s 30 second sprints are around 95% Anaerobic and 5% Aerobic.
*60:120s 60 second sprints are around 90% Anaerobic and 10% Aerobic.

3-8 300-yard Shuttle Run (SR)

Responses: Planting feet and changing direction, bending the trunk and squatting while alternating hand touches in touching the ground, Soldier familiarization with knowing relative body location (kinesthetic awareness)

Adaptations: Increased agility through increased muscular strength and power to decelerate and then accelerate in a different direction. Soldier will increase flexibility and balance while also developing relative kinesthetic awareness of the body.

3-9 Hill Repeats (HR)

Uphill

Responses- First, moving the body uphill against gravity involves muscle shortening, or concentric contractions. Anaerobic capacity as measured by the maximal or peak oxygen deficit is greater during uphill running than during horizontal running. Uphill running forces proper knee lift, which is essential for driving the legs downward and back for more force. Hill sprinting forces a Soldier to dorsi-flex their foot while running. The closer the toes are brought to the shin, the more force they can apply on ground contact. An example of this would be to think of dorsi-flexing as loading the foot, then unloading it into the ground, pushing a Soldier forward. During uphill repeats at 10% grade the muscles in the lower extremities are around 73% activated. (36) There is a higher peak oxygen deficit during uphill running compared with horizontal running, due in part to increased activation of skeletal muscle in the lower extremity. As uphill running intensity increases, heart rate increases proportionately, up to maximal heart rate. Stroke Volume increases proportionately with increasing uphill exercise intensity but usually achieves its maximal value at around 40-60% of VO2 max in untrained Soldiers. The body responds in increases in heart rate and stroke volume combine to produce the product of cardiac output. (38)
Adaptations- Increased capacity of the ATP-PC system which provides enough energy for very short explosive types of exercise lasting only a few seconds. There is increased ability to oxidize glycogen without oxygen. Energy can be provided in this manner for up to 45 seconds and plays a particular role in all Warrior Tasks and Battle Drills. Concentric muscle contractions during sprint hill training lead to increase in muscle strength and running economy.

Downhill

Responses-Moving the body downhill primarily involves muscle tension development that resists muscle lengthening, or eccentric contractions. During downhill running the body performs a series of eccentric contractions in every foot strike to the ground which results in the breakdown of skeletal muscle in the legs. In the upper quadriceps, there is extraordinary amount of force (can be up to three times body weight) which passes through the muscles particularly as the foot hits the ground. The initial muscle contraction is not strong enough to overcome this force so the muscle is stretched in an eccentric contraction for a quick instant, every time either foot strikes the ground. Muscles were not designed for repetitive eccentric contractions and are vulnerable to damage when forced to contract in this way. During downhill running the muscles act as brakes and heat up just as brakes do when continually used.

Adaptations-Since there is a longer period of negative work for the knee extensors and ankle flexors, through the eccentric muscle contractions this results in greater muscle damage. These eccentric contractions will for many Soldiers may result in experienced delayed onset of muscle soreness (DOMS) which typically subsides 1-3 days after conducting the downhill repeats. Through repeated bouts of downhill training (eccentric muscle contractions) the elastic elements of the muscle are strengthened, reduces the severity of muscle damage, reduces the amount of strength loss, decreases the sensation of soreness and tenderness after downhill running. A Soldier can develop leg speed (fast leg movement) while staying relaxed and subjecting the body to anaerobic threshold conditions.

3-10 Ability Group Run (AGR) Ability group runs train Soldiers in groups of near-equal ability to sustain running for improvement in aerobic endurance.

Responses- Primarily stimulates Soldier’s slow twitch skeletal muscle motor units because the motor neurons are more responsive to lower-intensity activity than those of fast twitch motor units.

Adaptations-Improvements often occur in the oxidative metabolic capabilities of cardiac muscle and in those skeletal muscle cells that are activated. Adaptations also include decrease in heart rate while performing the same workload. The ability group run setting fosters a natural competitive spirit while encouraging group members to relax and work together as a group.

3-11 Unit Formation Run (UFR) Unit formation runs are based on a time and distance that can be achieved with unit integrity and a display of unit cohesion.

Responses- During a unit formation run most all Soldiers will run at a submaximal pace (anywhere from around 55% to 75% of their maximum heart rate). Unit formation runs primarily stimulates a Soldier’s slow twitch skeletal muscle motor units because the motor neurons are more responsive to lower-intensity activity than those of fast twitch motor units.

Adaptations-Unit formation runs (aerobic training) improve the oxidative breakdown of fuels through the special proteins called mitochondrial oxidative enzymes. Aerobic training increases the activity of these important enzymes. Running in a formation run provides a stimulus for improving joint and tendon strength without the excessive impact stress that would result at faster paces.
3-12 **Release Run (RR)**

Release runs combine the benefits of formation running and individual performance at higher training intensities. Soldiers will run in formation to a specified time (no more than 15 minutes), then are released to run as fast as they can back to the starting point.

**Responses** - During the first phase of the release run, the body primarily works using the aerobic system while maintaining a running pace which is less than the maximum of which an individual is capable (Submaximal). When Soldiers are released to run as fast as they can to the start point, the immediate response on the body is proportional to the increased exercise intensity. Increased responses of heart rate, stroke volume, oxygen uptake, cardiac output, all will be present. Some Soldiers with lower aerobic capacity thresholds will exhibit higher amounts of fatigue and may produce greater amounts of lactate.

**Adaptations** - Typical adaptations consist of an increase in capillarization (development of a capillary network) for a given cross sectional area of muscle. This increase allows for further improvement for blood to move through the capillary network which enhancing the exchange of oxygen and carbon dioxide between the blood and muscle fibers. Another adaptation is the increase of aerobic energy production which improves the ability for muscle to generated ATP.

3-13 **Terrain Run (TR)** Terrain running applies the *Train as you will fight* principle to PRT. Running through local training areas, over hills, and around obstacles improves mobility, endurance, and the ability to stop, start, and change direction.

**Responses** - In order to meet the exercise demands of the Terrain Run the body will react uniquely to the challenges which specific terrain dictates. By running through local training areas, over hills, around obstacles, starting, stopping, and changing direction the body responds by the increase in recruitment of motor units, stroke volume, and moves towards an elevated state of awareness. It has been commonly known, that with the changing of terrain goes the changing of tactics and employment possibilities. Thus, having variety in terrain runs certainly play a very important role in the meeting the training demands for full spectrum operations.

**Adaptations** - The effects of these runs through terrain allows for greater muscular strength and power allowing Soldier improvement in deceleration and then acceleration in a different direction. Although responses may be greater in some Soldiers than others, endurance improvements are the increase in blood flow to muscle. This increase is attributable to the improved capillary supply.

3-14 **Foot March (FM)** Foot marching as a movement component of maneuver, is a critical Soldier physical requirement. Regular foot marching prepares Soldiers to successfully move under load.

**Responses** - It has been shown that during load carriage there is a phasic activation of the abdominal muscles that serves to increase inter-abdominal pressure. Inter-abdominal pressure increases with an increase in the speed of walking and an increase in the load carried. This may be partly due to an increase in the trunk angle that normally occurs during heavy load carriage and may serve to relieve pressure on the spine. Different physiological factors may come into play as a function of the severity and/or duration of the road march. Abdominal strength was found to be the best single predictor of road marching performance. (21) Studies conducted on treadmills for short periods of time show that energy cost increases in a systematic manner, with increases in body mass, load mass, velocity, grade, or a combination of these items. Studies have shown that the energy cost of prolonged (≥2 h) load carriage at a constant speed increases over time at higher loads, or speeds or both. Energy cost also increases over time during downhill walking with loads. Whether or not energy expenditure increases over time is important, because the individual carrying the load might become more easily fatigued if energy cost does increase. (20)

**Adaptations** - Neither running nor resistance training alone improves foot march speed, suggesting that both aerobic capacity and muscle strength must be trained to improve road marching capability. When regular road
marching with loads (at least twice a month) is included in a training program that also involves running and resistance training, Soldiers are able to march faster than if training is not included. (20) After a 30-day preparatory training period, Soldiers can march 12 miles in less than 3 hours loaded to about 60 pounds, when energy expenditure at that rate would cause exhaustion in 2.5 hours for soldiers who have not received special training. (15)

**SO WHAT?**

Studies have shown relationships between foot march trip completion times and aerobic capacity, back and lower body strength, and fat-free mass. More recent studies, generally confirm that aerobic fitness, fat-free mass, and leg/back strength are important physiological factors associated with load carriage performance and changes in load carriage performance. These studies provide clues as to the components of physical fitness that should be trained to improve load carriage and performance.

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Adapted from Knapik & Reynolds, 1997; Load Carriage in Military Operations

Effects of terrain on energy cost. Energy cost increases about 8% on a dirt road and about 24% for moving through light brush. Much heavier brush requiring the use of arms and more lifting of the legs to move over downed trees and brush can increase energy cost by 60%. Going through swampy land or walking on sand almost doubles energy cost. Walking in snow without the use of snowshoes can considerably increase energy cost 3 or 4 times, depending on the depth and quality of the snow. This increase in energy cost with deeper snow is presumably because of the extra energy needed to raise the legs. Numbers after the snow estimates are the depth of depression the shoe makes in the snow.
Due to nature of our profession the lower body has to withstand some amazingly large forces that take toll on the back and abdominal muscles, hips, thighs, knees, lower legs and ankles. For instance when running, the hip absorbs a force that is approximately six times greater than the body weight while a Soldier who is conducting Parachute Landing Fall “PLF” with extra equipment sustains vertical forces that are drastically higher than the body weight. During training most Soldiers experience at least some kind of negligible injury which does not result in significant recovery and time off duty; however, recent study has shown a significant rise in chronic injuries which leave our Soldiers sidelined for long periods of time. These signs and symptoms should not be ignored as the condition of the Soldier may worsen with continuation of training, but they should be reported to unit chain of command, Medical personnel in order to be properly evaluated by a treating physician. In most cases these injuries can be reduced and often times prevented through appropriate training, timely recognition and proper care. Compiled below is a list of some of the most common injuries sustained during army physical readiness training and with each injury there is a recommendation for prevention.

4-2 Lower Back Strain

According to Zemper (39) more than 40 percent of weight room injuries were technique related lower back injuries. Although this information does not represent the military population but thousands of college football players, it brings out the fact that the good technique is the key to the prevention of injuries. Strains are often caused by a sudden stretch or contraction of the lower back muscles (figure); weak abdominal muscles; and tight low back and hip muscles.

Symptoms:

- Pain when lower back muscles are contracted; pain when rising from sitting down; pain when bending forward or arching back; pain when twisting at the waist.
- In severe cases a person may exhibit moderate or severe tenderness over site of injury, lump or indentation where the muscle is torn, back weakness, and bruising.

Prevention:

Soldiers should conduct exercise to strengthen and stretch lower back, abdominal, and hip muscles using proper technique. This good technique refers to proper back management. When lifting heavy loads off the ground (i.e. deadlifts, powercleans) it is imperative that the lifter’s back is arched in order to assume the load. Failure to properly arch the back results in high pressure on the inter-vertebrae disks with ligaments and fasciae doing most of the lift, instead of relying on the muscles. This figure illustrates the load on the inter vertebrae disks when 50 kg is lifted.

Figure 4.2 * This figure illustrates the load on the inter vertebrae disks when 50 kg is lifted using proper and improper technique. (image retrieved from: *An Introduction to Olympic Style Weightlifting* by John M. Cissik, 2nd Edition)
4-3  Patellar Tendinitis

The knee is probably the second most common injury to lower back and the patellar tendinitis is one of the most common chronic knee injuries. It consists of an inflammation of the tendon that attaches the kneecap to the tibia - lower leg bone( see figure bellow). Causes of this condition are usually forceful contractions of the quadriceps muscles; weak and inflexible quadriceps, hamstrings, and calf muscles.

![Image of knee anatomy](image)

Figure 4.3 - Patellar Tendinitis: Image retrieved from Sport First Aid, A coach's guide to the care and prevention of athletic injuries, by Melinda J. Flegel, Fourth Edition, 2008, Human Kinetics, Pages 187-226

Symptoms:
- Pain from the bottom of the patella to the top of the tibia; pain with running and jumping activities; pain when forcefully straightening the knee
- In severe cases: localized swelling, thickening of the patellar tendon, tenderness between the knee cap and upper tibia

Prevention:
Conduct physical exercise that strengthen the quadriceps such as squats and lunges; Conduct all exercise through the full range of motion; stretch the quadriceps, hamstrings, and calf; perform an adequate aerobic or cardiovascular warm-up before activity.
The indicative of this injury is a stretch or tear of the muscles located high on the front of the thigh or pelvis (figure). Main cause of this strain/tear is the forceful contraction or stretch of the muscles as well as the weak or inflexible hip and thigh muscles.

**Figure 4.4 – Hip Flexor Strain/Tear: Image retrieved from Sport First Aid, A coach’s guide to the care and prevention of athletic injuries, by Melinda J. Flegel, Fourth Edition, 2008, Human Kinetics, Pages 187-226**

**Symptoms:**
- Pain in the front of the thigh; pain when trying to raise thigh forward; pain when running; heard or felt a pop
- Moderate or severe tenderness over the front of the hip; lump where the muscle is torn; hip and thigh weakness; bruising and swelling; limping

**Prevention:**
Perform an adequate aerobic or cardiovascular warm up before exercise bout. Conduct hip and thigh strengthening and stretching exercises.
4-5  Iliotibial Band (ITB) Strain

Manifested by stretch or irritation of the connective tissue along the outer the thigh that attaches to the outside of the knee. It typically occurs over time and it is caused by the weak or inflexible thigh and hip muscles. Other causes include running in the same direction on a track or constantly running on the sloped edge of a road.

Figure 4.5- Iliotibial Band (ITB) Strain: Image retrieved from Sport First Aid, A coach’s guide to the care and prevention of athletic injuries, by Melinda J. Flegel, Fourth Edition, 2008, Human Kinetics, Pages 187-226

Signs and symptoms
- Pain outside of the knee; pain with jumping, biking, or using stairs
- Moderate to severe point tenderness along outside of the knee; swelling; limping

Prevention
Begin exercise bout by warming up with cardiovascular or aerobic type activity. Conduct exercises that improve strength and flexibility of the hip, thigh, hamstring, and calf muscle. Finally, avoid running the same direction on a track or constantly running the slope edge of the road (hill running).

4-6  Shin Splints

This is a chronic injury that results in stretch, tear, or irritation of the shin muscles, tendons, or bone covering (figure). The most common cause of the shin splints is constant running on an uneven or unyielding (hard) surface. Forceful contractions or stretching of the shin muscle and faulty foot mechanics that fail to absorb the shock contribute to this condition as well as worn out shoes with inadequate arch support. Other causes include weak or inflexible shin muscles, thight calf muscles, and tight Achilles tendon.
Signs and symptoms:
- Pain on the inside and outside of the tibia; pain with running and jumping activities; pain at rest
- Moderate to severe tenderness over the site of injury; swelling; decrease ability to run or jump

Prevention
Conduct exercise that target lower leg muscles and stretch the calf and Achilles tendon. Warm-up before activity using cardiovascular type exercise. Use appropriate increments for increasing training intensity (no greater than 10% per week). Instruct Soldiers to have their feet evaluated and measured by qualified personnel (local specialty running store) for the right type of running shoe as some soldiers may need additional arch support.

Tibial Stress Fracture
Breaks or cracks in tibia that occur over time. Main cause is constant running or jumping on an uneven or unyielding (hard) surface and sudden increase in the intensity of these two types of exercise. Second, faulty foot mechanics that fail to absorb shock allowing tibia to absorb most of the force induced by running. Other causes include shoes with inadequate arch support, worn out athletic shoes, and sometimes amenorrhea (lack of menstrual period caused by anorexia).

Signs and symptoms
- Pain along the front of the shin; pain with walking; pain at rest; moderate to severe pain when running or jumping
- Moderate to severe tenderness over the site of injury; pain when tibia is pressed above or below the site of injury; swelling; decreased ability to run or jump; limping

Prevention
Use appropriate increments when increasing training intensity (for running and jumping specific exercise). Instruct Soldiers to have their feet evaluated and measured by qualified personnel (local specialty running store) for the right type of running shoe as some soldiers may need additional arch support. Conduct training on shock absorbing and even surfaces such as grass or dirt.
**Achilles Tendinitis**

Manifested by stretch, tear, or irritation to the tendon that attaches the calf muscles to the heel (figure)

This condition is usually caused by repeated forceful contraction or stretch of the calf muscle and participation in repetitive stressful activity that requires going up on the toes.

![Achilles Tendon](image)

**Figure 4.7 – Achilles Tendinitis: Image retrieved from Sport First Aid, A coach’s guide to the care and prevention of athletic injuries, by Melinda J. Flegel, Fourth Edition, 2008, Human Kinetics, Pages 187-226**

**Signs and symptoms**
- Pain between the heel and lower calf; pain when running or jumping; pain when pointing foot down; pain when foot is stretched up towards shin
- Slight point tenderness; swelling; thickening of the tendon; decreased ability to run or jump; limping

**Prevention**
Conduct exercises that strengthen and stretch the Achilles tendon and calf. Perform adequate aerobic or cardiovascular warm up before activity.
4-8 Plantar Fasciitis

Manifested by stretching or inflammation of the tissue that connects to the heel and toes. (figure)
This condition is caused by the following: flat feet, high arches, shoes with inadequate arch support, tight calf muscles, and increasing running intensity too fast and too soon.

![Plantar fasciitis](image)

Signs and symptoms
- Pain along the arch or near the bottom of the heel; pain when running or jumping
- Feeling of muscle tightness or weakness; pain with walking; slight point tenderness; swelling; decreased ability to push off with the foot or point the foot down; arch may flatten out

Prevention
Incorporate exercises that stretch the calf, Achilles tendon, and plantar fascia. Conduct adequate aerobic or cardiovascular warm up before activity. Use appropriate increments for increasing training intensity when training for running or jumping (no more than 10% increase per week). Instruct Soldiers to have their feet evaluated and measured by qualified personnel (local specialty running store) for the right type of running shoes. Some soldiers may need additional arch support.

4-9 Other Injuries and conditions

Muscle Soreness

Most common result of hard training is acute muscle soreness which results from an accumulation of the end products of exercise in the muscles (edema). This sensation usually disappears within minutes or hours after exercise bout.

The more serious conditions such as Delayed Onset Muscle Soreness (DOMS) is felt 12 to 48 hours after a strenuous bout of primarily eccentric exercise such as downhill running. Causes include structural damage to muscle cells and inflammatory reactions within the muscles.
Prevention

In order to avoid DOMS start of the training bout should be done at low intensity with a gradual increase. One should reduce eccentric component of muscle action during early training. Certain supplements such as antioxidants and fish oil may help with the recovery.

Exercise induced Vomiting

Common discomfort associated with resistance training is nausea and vomiting. One of the most common Causes of Exercise induced sickness is Gastrophageal reflux brought on by the valsalva maneuver - holding your breath while you push hard. Other causes include dehydration and heat exhaustion during exercise. This can induce sickness because of the increased effort which is causing loss of fluids (through sweat) that are not replaced.

Over hydration - Hyponutremia can result in exercise induced sickness as well. Hyponatremia is caused by over hydration which causes a sudden drop in concentration of sodium in the blood. For some reason people that take anti-inflammatory medications like Motrin, Advil, or Aleve may be more at risk of hyponatremia.

Prevention

The key to avoid exercise induced vomiting is to BREATHE during exercise. Additionally ensure proper levels of hydration but ensure that you drink to thirst to prevent hyponatremia.

Rhabdomyolysis (Rhabdo)

Our old way of physical training required long efforts of aerobic endurance; however the new physical readiness training which was based on the combat requirements entail highly explosive type of training which can have drastic impact on anyone. One of the most serious conditions is the rhabdomyolysis, which can be defined as the breaking down of muscle fiber into the blood stream. This can happen with someone new to explosive type of strength training (i.e. cross training) and can be hazardous and even lethal.

Rhabdo is a breakdown of muscle cell contents that results in the release of muscle fiber contents into the bloodstream. Eccentric muscle contractions, in which muscles attempt to shorten while they are being stretched, seem to significantly increase tension on muscle cell membranes, and it is this tension that appears to break them down. Potassium is normally in high concentrations inside muscles; when it is found in high concentrations in the blood, it is a good indicator of rhabdo. Sodium and calcium also move from outside the muscles inward and start building up inside the muscle cells, causing very painful swelling that can lead to compartment syndrome, which requires urgent surgery to slice open the membranes to relieve the pressure.

When everything is working properly, the extra potassium would probably be filtered out of the blood by the kidneys. But with the onset of rhabdo the amount of potassium is overwhelming and that extra volume is complicated by yet another player called myoglobin. Myoglobin is another resident inside the muscle cells that acts as a warehouse for oxygen. When myoglobin leaks out with the potassium and makes its way to the kidneys, it breaks down into a toxic chemical called ferrihemate, which damages kidney cells. This damage prevents the kidneys from working properly and can be permanent. The extra potassium can peak at such high levels in the blood that heart function is altered; arrhythmia is a common consequence, and eventually the heart may fail completely if the potassium levels are not controlled.

Prevention:

Know your Soldiers and their abilities. Increase the training intensity gradually as described in TC 3-22.20. Evaluate training sessions and conduct follow up on personnel after strenuous training events. The timely response by medical personnel for this condition is the key to a full recovery.
In the military setting we have the way of making our Soldiers adhere to constant regime of exercise but we must be smart during development of our physical training plans. Ignoring planning factors such as Frequency, Intensity, Time/duration and mode/Type (FITT) can contribute to decrease in physical and emotional well being (34). It appears that in order to improve fitness (cardiovascular and strength) in general public the approach should be mild to moderate. Another words the perfect balance of physical and emotional well being comes from a physical training that is reasonable, yet action oriented, specific, and measurable. In order to influence performance commanders and leaders should ensure that physical training goals are focused with directed (specific) activity, mobilizing effort (resources, time), increasing persistence (close/constant supervision), and ever changing in terms of adopting the kind of activities to keep or discard. No unit in the US Army can afford the “all or nothing” approach to our physical training where we have part of the unit that trains and adheres to the developed PRT plan and those individuals who are not conducting training because they simply cannot keep up or because they must take care of mission requirements. It is up to leaders to incorporate flexible programs that emphasize success, provide make-up strategies, and determine what is acceptable to miss. Conversely, we also must stay cognizant of Soldiers that over-exercise, ignore injuries and show signs and symptoms that may lead to destruction. Bottom line we must get to know our Soldiers and their abilities and have to pay close attention during all phases of physical training plan.

In order to reach optimal physiological adaptation from the PRT we must build a good plan that incorporates good aerobic and anaerobic endurance base, followed by toughening (hard training) phase during which time we implement maximum training volume and intensity in order to reach optimum performance, followed by sustaining phase which is meant to preserve the fitness levels. It is during the toughening part that our Soldiers may exhibit the symptoms of overloading such as mood disturbances, medical illness, muscle soreness, as well as sleep disturbances and loss of appetite. Numerous studies show that rapid increase in training, regardless of the activity, has direct correlation to personal mood changes (34, 21). These factors have direct impact on the morale of unit and the best approach to hard training is to increase the loads and distances gradually.

The benefits of physical training have high impact on physical aspect of our well being and it has a huge impact in reduction of heart disease, hypertension and diabetes, as well as psychological factors such as depression, anxiety and overall emotional well-being. All of these factors have a direct impact on the morale of the Soldiers and can be maintained at healthy levels with proper implementation of physical training.

Physiological variable can influence many aspects of exercise and physical performance as different factors such as anxiety, depression and personality can have a significant impact on the physical readiness of our forces. For instance studies show that personality trait such as extroversion has high correlation with physical strength during six weeks of resistance/strength training. (34)

On the other hand our psychological adaptations that occur during PRT will have direct impact on our perception of fatigue.

Dr Timothy Noakes’ Central Governor Theory defines fatigue as most of the physiological events that occur during exercise as well as the brain control that allows maintenance of constant homeostasis and prevention of catastrophe. (29)

Many athletes tend to agree with Dr. Noakes including former Olympian and a triathlete Samantha Mcglone, who uses an interesting way of explaining the Central Governor Model. While supporting Dr. Noakes’ theory she states that the sensation of fatigue is experienced during long endurance events because the brain is telling the muscles to shut down the muscle fiber recruitment when the oxygen reserves start getting low in order to preserve the oxygen and protect the heart from damage. This reduction in neural recruitment can be
defined as fatigue, however there are always “emergency reserves”. Mcglone makes an interesting analogy by comparing this sensation to the gas light coming on in a car. Although the car is low on gas there is a buffer that allows the car to keep going for a significant amount of miles before reaching complete empty. She states that similarly the endurance athletes can override the bodily warning signs using the sheer force of will throughout the race for long periods of time that they are literally running on empty. As a result we see complete meltdowns 400 meters away from the finish. The fact is that those athletes were near catastrophe long before that finish line and when the brain senses that the end is near it registers and stops pushing while allowing for the peripheral breakdown to occur. As an encouragement to other athletes she claims that if you can remove yourself from the immediacy of sensation and look at the pain as an objective signal, like that gas indicating light, it becomes much easier to grit your teeth and get to the finish line. The pain is not defined as a bad thing but a suggestion that the body needs to slow down and get some fuel and liquids in as soon as possible. (25)

Colonel Friedel, US Army, (10) indicates many causes of fatigue as defined by the military. In his paper he states: At least six categories of militarily-relevant fatigue can be described: intensively demanding tasks (“overtraining” or “overload”), prolonged wakefulness, circadian disruptions, psychosocial distractors, environmental strain, and metabolic limiters. There are at least three major categories of mechanisms of the performance degradation: insufficient fuel, damage or pre-damage afferent limiters, and central mechanisms. (10) In order to improve performance he suggests that training individuals and leaders in “mindfulness” and psychological resilience is one of the keys to overcoming a psychologically challenging (stressful) situation, as demonstrated with mental resilience of individuals who respond well to crisis. For example, learning to think “warm thoughts” in the cold, as currently practiced by extreme cold water swimmers, may help overcome the brutal environmental conditions.

Figure 5.1 – Colonel Friedel, Causes of fatigue
The Central Governor Model provides us with an explanation on how an individual Soldier can endure the process of attending some of the toughest training events that the US Army has to offer such as Special Forces Selection and Qualification Courses or Ranger School. All of these schools test the Soldier’s will power over long periods of time, lasting several weeks or more. It would be impossible to complete a single day in one of these training/selection events without our brain’s ability to override the symptoms of discomfort, maintain the balance (homeostasis), and continuing its pacing strategy although the distance and time on most events are undeclared. Not knowing how far and how long a candidate has to go during the road march or an endurance run makes it really challenging because the pacing strategy becomes harder. According to the old cardiovascular/anaerobic model of fatigue no one would be able to sustain such activity as peripheral fatigue would settle in and reduce the ability of exercise muscles. The truth is that these training events are very physical in nature but the true test objective is to select the Soldiers that exhibit the strongest mental attributes. In another words the US Army is selecting its elite troops based on the mental aptitude, pain tolerance, and physical ability as dictated by the brain. This is an explicit test of one’s central governor. Dr. Noakes theory seems to have a better way of explaining many phenomena that occur with the endurance athletes and service members alike, allowing for completion of physically and mentally demanding events where quitting is not an option. A key to success achieved by soldiers and athletes is that fatigue, physical or mental, will not be observed as long as the individual’s brain is allowed to self-regulate the intensity of exercise. Carefully devised and implemented physical readiness training plan will produce psychological adaptations needed to overcome hard training events and will ensure more resilience of our Soldiers on the battlefield.
Discussion

There are many factors which affect the ability to perform physical activity required by our profession. Some of these factors such as genetics are fixed. We inherit body build, skeletal size, hormonal potential for growth in size and muscularity, and the proportion of slow and fast twitch fibers which determine speed and endurance. Other factors such as physiology, biomechanics, and motor-learning help us understand how to utilize physical training in order to produce strength and endurance and reduce chance of injury.

Physiology and motor-learning encompass the multiple facets of the function of the human body. When applied to physical readiness training, it involves knowledge of the requirements for responses and adaptations to the various events, the changes which occur with conditioning and the measurement of these changes and an understanding of the specificity of training adaptations.

Biomechanics includes understanding of the correct movement patterns (technique) so as to apply muscular force to the skeletal system. The movement skills of each exercise must be major focus during teaching, coaching, and supervision of training.

Other factors that affect performance can be described by the Psycho-Social Milieu which is the environment and attitude of our parents and society, which determines our attitudes and drive toward training and performance. As we have indicated in the introduction the social problems associated with lack of physical activity, improper nutrition, and excessive weight gain, have had a major impact on the new recruits in terms of injuries and inability to adapt to physical demands of military occupation.

Implementation of the new PRT Manual is a crucial step in the positive direction in order to overcome physical challenges we face as a rapid deployment force. Therefore it is absolutely necessary to understand the scientific reasoning behind physical training.

It is no secret that after nine years of war the best way to approach conditioning of our Soldiers is to tailor our physical training to the demands of battlefield. This training is not specific to a single task but it is a rather a combination of movement to include running, jumping, marching, crawling and climbing, amongst many. The closer our conditioning comes to simulating the demands of these warrior tasks, the greater the conditioning carryover to our mission readiness will be. How do we accomplish this?

As indicated in the TC 3-22.20 our training plan must be comprised of four different phases: Initial, Toughening, Sustaining, and Re-training phase. These increments of training are designed to help commander reach that goal by designing a training plan for his Soldiers to fight, survive, and be resilient on the battlefield. They mirror the different phases of the physical readiness training strategy and can be referred to as the micro-cycles of the long term training plan.

I. Initial - this phase should be focused on the aerobic and anaerobic endurance base in order to allow the Soldier to get in shape without placing undue physical and emotional stress of training. This type of training includes running drills with gradual increase from week to week; foot marching; and strength training through conditioning drills that emphasize muscular endurance (body weight resistance exercise such as push up, sit up, pull-up, squat, lunge and hip strengthening exercise).

II. In the toughening phase of physical training we recommend the combination of various running drills as well as strength training and plyometric drills, which focus on speed, power and agility. As a result different energy systems will overlap considerably and compliment each other. Improving anaerobic system will never hurt the other, and will probably help. During this phase Soldiers can be introduced to more intense type of exercise such as interval runs, all out sprints, an occasional distance runs, foot marching and climbing exercises with combat kit, and weight resistance training focusing on large muscle groups as described in TC 3.20-22.
III. Since sustaining phase of training is closest to or during mission execution, leaders should incorporate all occupational specific tasks as well as warrior skills to include foot marching/patrolling, marksmanship training, climbing, jumping, pushing, and hand to hand combat. By this phase Soldiers should be conditioned enough to conduct high-intensity cross-training during daily physical training as the situation permits.

IV. Re-training is usually a phase during which Soldiers are re-assessed (usually following blocked leave) and re-trained properly in order to reach maximum physical performance.

In sports specific training plans coaches focus of the task at hand, therefore runners must run, swimmers must swim and bikers must bike. Specificity of conditioning is a term used to describe the specific adaptations that take place physically from a particular activity. To produce these adaptations in our Soldiers we must design a well-planned training program to incorporate various combat tasks and executing each one with maximum intensity as we would in combat environment. We cannot predict one specific physical task but have to train for a variety of skills. Physical Readiness is Commander’s program and he must tailor his fitness goals to directly correlate with the unit’s mission and its ability to conduct full spectrum operations.

In order to improve coordination, core strength and conditioning during phase II and III many units across the Army have implemented the Cross-Fit as the sole physical readiness training program. These workouts have a considerable amount of variance or unpredictability to best mimic the often unforeseeable challenges that combat, sport, and survival demand. The fundamentals of the Cross-Fit method are to incorporate a blend of the following basic fitness elements into daily workout schedule: Nutrition, Metabolic Conditioning, Gymnastics, Weightlifting and throwing, and Sport.

The focus is on maximizing neural response, developing power while cross-training with multiple training modalities, and constant training and practice with functional movements. As they say in the cross-fit circles “routine is the enemy”. (11)
Because of safety factors of CrossFit (especially during weight-lifting workouts) many have criticized this fitness program. In 2006 a United States Navy sailor suffered injuries while performing a CrossFit workout claimed that CrossFit caused rhabdomyolysis which nearly killed him. (Mitchell) According to Dr. Stuart McGill, a professor of spine biomechanics at the University of Waterloo, the risk of injury from some CrossFit exercises outweighs their benefits when they are performed with poor form in timed workouts. He added there are similar risks in other exercise programs but noted that CrossFit's online community enables athletes to follow the program without proper guidance, increasing the risk. (6)

In the other hand there are many supporters of the program from the science community such as Dr. Tony Webster of the Pacific Institute for Sports Medicine at Camosun College in Victoria, British Columbia who suggests that CrossFit can be used "safely and sensibly" and further describes it as a vigorous exercise safe for general public. The editors of PureHealth MD writing for Discovery Health Channel found CrossFit "equals better fitness and stronger muscles in a more reasonable amount of time" and "a well-rounded and very efficient way to achieve a higher level of fitness". (33)

In order to test the efficacy of the Cross Fit program, One study conducted, (30) measured the change in level of physical fitness (defined as an athletes' work capacity across broad time periods and modal domains) of fourteen athletes during eight-weeks of physical training utilizing the Cross Fit program. The fourteen athletes were all students at the Command and General Staff College, and were a mix of men and women with varying levels of physical fitness and Cross Fit experience. The athletes were given an initial assessment made-up of four physical evaluations (the APFT, and three Cross Fit benchmark workouts) that tested their ability to perform a variety of functional movements across modalities and for differing periods of time. During the six-week training period athletes were required to attend a minimum of four, one hour, training sessions per week. Over the course of the study, every athlete experienced an increase in their work capacity, measured in terms of power output, with an average increase of 20% (range 14-28%). The results from the dead-lift, shoulder press, back squat, push-up and sit-up assessments shoved significant improvement (21% average increase in work output) despite limited number of training sessions devoted specifically to these exercises. These results lead us to the conclusion that generalized training can prepare athletes for unknown and unknowable events, a crucial capability in combat, and can produce improvement in specialized events despite non-specialized training. (30) Certain military installations (Fort Bragg, Fort Hood, Fort Polk, Fort Knox, Fort Meade, Fort Leavenworth, the Pentagon and the United States Military Academy) have recognized this as the functional fitness program and their Soldiers have the ability to perform daily work-outs with proper equipment in safely supervised environment.

The Cross Fit approach to training can yield tremendous results as training tasks of weight lifting and throwing, gymnastics and metabolic conditioning force Soldiers to keep learning new tasks and therefore keep making adaptations within muscular-skeletal and nervous system.

Cross Fit program in particular may or may not be suited for wide implementation across all of the units in the military; however some of the general principles are well designed and despite the study's findings possible influenced by the Hawthorne effect and lack of using a control group there may be some many important lessons from this popular fitness trend.

Nutrition must be the molecular foundations for fitness and health. Study data on resistance training show that ingestion of 40 grams of mixed amino acids and 40g of essential amino acids cause net protein synthesis (37). What this means is that a normal, well balanced, meal taken within 45 minutes after work out is sufficient for protein synthesis and therefore will facilitate muscle fiber growth (hypertrophy) and recovery. This is especially significant in training of new recruits who are new to resistance training, because the studies with the untrained subjects showed higher protein synthesis and protein breakdown after resistance exercise than those who were trained (31). These studies coincide with the Cross Fit dietary guidelines, which are as follows: Protein should be lean and varied and account for about 30% of your total caloric load. Carbohydrates should
be predominantly low-glycemic and account for about 40% of your total caloric load. Fat should be predominantly monounsaturated and account for about 30% of your total caloric load.

The workout pattern does not put more emphasis on one fundamental over the other but rather insists that all elements are incorporated at the same time. This approach allows Soldiers to experience multiple responses and adaptations as they learn and incorporate new drills during physical readiness training. The example of all of these exercises can be found in the Army Physical Readiness Training Manual and are classified as follows:

Metabolic Conditioning – Participate in activities such as running (and where available: rowing, cycling, and swimming) in order to build capacity in each of three metabolic (energy producing) pathways, beginning with aerobic, then lactic acid, and then phosphocreatine (PCr) pathways.

Gymnastics - establish functional capacity for body control and range of motion in terms of basic body weight resistance exercise such as push-ups, sit-ups, dips, air squats, and pull-ups (core and climbing drills).

Weightlifting and throwing - develop ability to control external objects and produce power through weight bearing exercises that incorporate Bench press, Dead-lifts, Kettle-Bells and Dum-bell lifts, Squats, and Push presses.

Sport – Motor Learning is the ability to learn a variety of complex motor skills and it plays a large role in determining soldier’s ability and performance (physical and cognitive). Sport applies fitness in competitive atmosphere with more randomized movements and skill mastery. For our purpose the sport equates to combat mission execution and therefore it takes its rightful spot at the top of the pyramid. The culmination of the training plan and successful execution, without injuries, is the goal.

The key take-away from this type of training is the idea to blend elements of strength and mobility drills in sets that combine to a dramatic metabolic challenge. An example would be to perform five reps of a moderately heavy back squat or bench press followed immediately by a set of max reps pull-ups repeated three to five times. On other occasions we can take five or six elements balanced between weightlifting, metabolic conditioning, and gymnastics and combine them in a single circuit, which can be execute in three rounds without a break. Routines like this can be created forever and most importantly they can be created utilizing the exercise sets as described in the strength and mobility chapter of TC 3.22-20 (Army PRT).

Gains and improvements attributed to this type of training can be explained as neural adaptations to resistance exercise. According to Hakkinen, early increases in strength training during the first weeks of heavy resistance strength training in previously untrained healthy male and female subjects may be explained largely by neural factors with a gradually increasing contribution from muscular hypertrophy as training proceeds. Strength training may lead to specific adaptations in the faculatory and/or inhibitory neural pathways acting at various levels in the nervous system (12).

The benefits of using this approach to physical training regime are enormous in terms of strength, power and anaerobic endurance. Units can come up with their own cross-training plan by following the same ideology and using the strength and mobility principles as described in the Army Readiness Training (TC 3-22.20). Incorporation of Conditioning Drills (Aerobic and Anaerobic), Push-up and Sit-up drills, Climbing drills, and Strength and conditioning drills into a single exercise bout can and will yield productive results.
Recommendations

Our recommendation is to synchronize our existing research and findings in the field of applied military physiology. This can be done by enhancing relationships between research organizations such as United States Research Institute of Environmental Medicine (USARIEM) and conventional army units. USARIEM is an internationally recognized center of excellence for Warfighter health and performance. The research studies conducted by scientists from four research divisions, working in concert with one another, as well as other world-class scientists from government, industry and academia should more timely find its way into the hands of the Army leader who can apply research findings to better their organization.

Currently the Borden Institute publishes many exceptional reports, studies, publications and books dealing with issues such as Load Carriage in Military Operations, Water Requirements and Soldier Hydration.

It would be of great interest to find current publications and curriculum that are taught to Soldiers at the U.S Army Medical Department Center and School. By taking the experienced medical instructors best practices this handbook could further strengthened to explain basic physiology principles to commanders and leaders.

While creating this handbook many additional ideas were presented which might be further investigated to create a better handbook. Further areas which may strengthen this handbook include the topics of exercise in hot and cold environments, overview of the nervous system, nutrition, effects of altitude (responses and adaptations, operational and mission planning concerns) and ergogenic aids such as mechanical aids, pharmacological aids, physiological aids, nutritional aids, and psychological aids.

Future recommendations and enhancements of this handbook will help to enable, assist and improve our Army leaders in the management of combat power. By educating commanders and leaders in Applied Military Physiology and the understanding of body responses and adaptations to training we can better meet the training demands of Full Spectrum Operations.
References


