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**Sports Science**

Sports science is the study of how the human body adapts to training. Understanding sports science is the foundation required to build quality training plans based on how the body adapts to specific stimuli. This manual will cover physiology, biomechanics, and training theory.

**Physiology**

**Neuromuscular Physiology**

Neuromuscular physiology is the interaction between the muscles and nervous system. It examines muscle structure, fiber type, fiber arrangement, neural adaptations, and muscle contractions.

**Muscle Structure**

Muscles are composed of small fibers these fibers are covered in connective tissue. The fibers connect to nerve fibers and a blood supply. Muscle fibers are composed of multiple myofibrils which look like rods layered next to each other. The myofibrils are broken down into multiple sarcomeres which are the contractile unit of the muscle fiber. There are hundreds of sarcomeres lined together forming a myofibril. The sarcomere has multiple thick (myosin) filaments and thin (actin) filaments layered together. Small cross bridges connect the two filaments during a contraction in what is known as the sliding filament theory. A basic understanding reveals that the sarcomere has three distinct bands that are important in muscle contractions. First is the A-band which is the main portion of overlap between the actin and myosin filaments. The second band is the I-band. The I-band is composed of the actin filaments that connect each sarcomere together. The I-band has elastic titin filaments that connect the myosin to the Z-discs inside the I-band. These titin filaments provide resting tension in the sarcomere. The H-band is the middle space in the sarcomere between the two overlap zones. Each individual muscle fiber is wrapped in a sheath called endomysium. Multiple fibers together are wrapped in a sheath called perimysium. Fascia is the sheath that surrounds multiple fiber bundles. The muscle structure can be in figure 1.

![Figure 1: Muscle Structure](image)

When a muscle contracts, cross bridges form between the thick and thin filaments. Myosin heads on the thick filaments bind to the thin filaments. The H and I-bands contract, meaning there is more overlap between the thick and thin filaments. The sliding filament theory states that the sites on the actin filaments for the cross bridge links are closed in the myofibril's resting state until the nervous system transmits a strong enough signal that releases the necessary...
amount of neurotransmitter causing an increase in the sarcoplasm’s calcium ion concentration. Sarcoplasm is the cytoplasm of the muscle fibers. The increased concentration opens the cross bridge sites. The neurotransmitters cause the sarcoplasmic reticulum to release calcium ions into the sarcoplasm around the myofibril. The nerves that pass the signal to the sarcoplasmic reticulum are known as motor neurons. The myosin heads are energized by ATP losing a phosphate ion to become ADP. The myosin head rotates creating the increased overlap between the myosin and actin filaments. As a new molecule of ATP binds to the myosin head the cross bridge releases. The cycle repeats as long as the nerve continues to send a signal that keeps the calcium ion channels open. Multiple sarcomeres contracting together create a full muscle contraction. The cross bridge and motor neuron are depicted in figure 2 and 3.

Figure 2: Sliding filament model

Figure 3: Motor neuron
Aside from the contractile actin-myosin component there is a non-contractile component. The two non-contractile components are the parallel elastic component and series elastic component. The parallel components are composed of muscle sheaths and sarcolemma (myofibril membrane). The series components are the tendons. The parallel components create passive elasticity derived from muscle membranes. The series elastic component creates passive elasticity from tendons when a tensed muscle is stretched.

Figure 4: Elastic components

Muscle Fiber Type

Muscle fibers are normally characterized in two different categories, Slow and Fast Twitch fibers. Some muscle can be predominantly one fiber type or the other, but most muscles are mixture of the two fiber types. Slow twitch (ST), Type I, fibers are oxidative fibers. The fast twitch (FT) fibers are broken down into FTX or IIx (glycolytic) and FTA or IIa (oxidative-glycolytic). The ST fibers have a higher number of mitochondria, myoglobin, and large amount of capillaries making them great for aerobic activity. Type IIx fibers have a large amount glycolytic enzymes and low mitochondria density making them great for anaerobic work. These fibers are the least efficient and fatigue quickly. The Type IIa fibers are intermediate fibers that have characteristics of both IIx and I and are extremely adaptable. Fiber type make up in skeletal muscles is influenced by genetics, hormone levels, and training habits.

<table>
<thead>
<tr>
<th></th>
<th>Type I</th>
<th>Type IIA</th>
<th>Type IIx</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed of contraction</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Force capacity</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Fatigue resistance</strong></td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Mitochondrial content</strong></td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Aerobic capacity</strong></td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Anaerobic capacity</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

Figure 5: Fiber type

Muscle Fiber Arrangement

Muscle fibers can be arranged in parallel or pennate arrangements. The fiber arrangement influences the efficiency of a muscle pull. A parallel arrangement allows the muscle to apply force in the direction of the pull. The pennate arrangement prevents a muscle from applying force 100% in the direction of the muscle fiber, but allows more muscle fibers to apply force during a contraction. The more muscle fibers there are enhances the muscles pulling ability.
Muscles can affect either a single joint or multiple joints. The pectoralis muscle operates over a single joint and the hamstring operates over multiple joints.

The musculoskeletal system consists of more than just muscle fibers. Connective tissue is another part of the system that connects muscles and bones. Ligaments connect bone to bone and tendons connect muscles to muscles or muscles to bone. Ligaments are relatively inelastic. Tendons can have sheaths or not have sheaths. The sheath around tendons composes the parallel elastic component and the unsheathed tendon composes the series elastic component. The tendons do not exert their own force, but through their elasticity can transmit force that muscle produces when stretched. Fascia is the connective tissue that provides a protective sheath around muscles, bones, and joints.

**Neural Adaptations**

Large muscles produce more force, but muscle size is not the only determinate of force production. Motor unit recruitment from the nervous system is another determinate of force production. A motor unit is the combination of a muscle fiber and motor nerve. The more motor units the body can recruit the more force that can be produced. Motor units have a preferential recruitment pattern. ST motor units are recruited first. FT Ila and IIx have a high recruitment threshold. High threshold motor units become activated when a high force output is required. The body doesn’t initially have the ability to voluntarily recruit all the high threshold motor units that occur with training at a high stimulus. A high stimulus is large load or fast velocity. Repeated high stimulus training allows the body to recruit more motor units, but the body is an efficient organism and will only recruit the fibers needed to complete an activity. Therefore to fully recruit motor units a very high stimulus needs to be applied.
The speed of contraction can also be increased to produce not just high amounts of force but high amounts of force quickly (Rate of Force Development- RFD). The speed of a contraction will increase the more a movement pattern is trained. People commonly call this muscle memory but muscles cannot have memory because they lack memory cells. What is occurring is a specific nervous system pathway is becoming more efficient through the process of myelination. Myelin is the sheath that surrounds nerves similar to how fascia is the sheath that surrounds muscles or rubber around copper wires. As a motor pattern’s use is increased, the nerves continue to increase the myelin sheaths around the used nerves, creating more efficient paths as the nerves electric resistance decreases. The increased myelin around the used nerves allows the pathway to be used quicker and allows that motor pattern to be more familiar to the body (muscle memory). Neural adaptations occur first with the increased recruitment of motor units. This is why young athletes can get stronger quickly without body composition changes. Neural adaptations can occur within six weeks of starting a training regimen. Motor unit RFD takes much longer to train and hypertrophy (increase in muscle size) can take even longer to occur. FT fibers have greater ability to experience hypertrophy than ST fibers.
Muscle Contractions

The three most discussed muscle contractions are concentric, isometric and eccentric. Concentric contractions are when the muscle shortens during work. Isometric contractions are contractions where the muscle does not change length during the contraction. This contraction can be seen in the stabilization of a joint. Eccentric contractions are when the muscle resists lengthening as the muscle elongates. Eccentric contractions are the most powerful of the three contraction types. Eccentric contractions can produce as much as 140% of the force of a concentric contraction. The main function of an eccentric contraction is to stop or decelerate a muscle.
connective tissue, particularly tendons, have the ability to pre-stretch. Tendons’ sensory apparatus is known as the Golgi tendon apparatus that can monitor the stretch in a tendon and signal a muscle to contract. Excessive pre-stretch can also cause the Golgi tendon apparatus to reduce a muscle contraction’s force because the Golgi tendon is designed to protect the muscle from excessive force.

**Bioenergetics**

The body has 3 main energy systems/pathways that when properly understood allow trainers to develop proper sequencing of plans and applicable workouts based on the capabilities and limitations of each system. The three energy pathways: Adenosine triphosphate-phosphocreatine (ATP-CP), glycolysis (anaerobic), and oxidative-phosphorylation (aerobic). ATP is the main energy molecule in all these systems. It provides energy by a bond between the second and third phosphate atoms breaking in the ATP molecule to create ADP (adenosine diphosphate) +Pi (phosphate) + energy. The body has a ready-made supply of ATP available to muscle that will last for 1-2 seconds. After that period, ATP has to be resynthesized by one of the three pathways above.

![ATP](image)

**ATP-CP**

In this system creatine-phosphate is the energy rich molecule that restocks the ADP molecule with the additional phosphate. Creatine-kinase is the enzyme that breaks the phosphate atom off the CP molecule and adds it the ADP molecule. This system is also called the phosphagen or alactic system because it does not produce lactate as a waste product. CP stores can last upwards of 5 seconds before they are depleted and no longer can provide energy. So when this system is combined with the readily available ATP stores there is roughly 7 seconds of high intensity work that can be completed. To challenge this, 7-10 seconds of high intensity work needs to be conducted with either high force or high velocity. CP can only be restored during recovery from exercise. This systems takes a considerable amount of time to recover compared to the amount of time it lasts.

<table>
<thead>
<tr>
<th>Recovery Time</th>
<th>Percent Recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 seconds</td>
<td>50%</td>
</tr>
<tr>
<td>1 minute</td>
<td>75%</td>
</tr>
<tr>
<td>90 seconds</td>
<td>80%</td>
</tr>
<tr>
<td>3 minutes</td>
<td>98%</td>
</tr>
</tbody>
</table>

Table 1: ATP-CP recovery time
Based on the above table, training the phosphagen system requires recoveries of 2-3 minutes to allow work to continue to occur at the same intensity. Examples of ATP-CP specific workouts would be:

Table 2: ATP-CP example workouts

<table>
<thead>
<tr>
<th>Speed</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>8x30m sprints at 100% with 2 min recovery</td>
<td>Squat 4x4 at 85% of max effort with 2-3 min rest</td>
</tr>
</tbody>
</table>

Below is a graphical representation of the ATP-CP system.

![ATP-CP system](image)

**Anaerobic (Lactate) Glycolysis**

This is the second energy pathway. After the body has been challenged with 10 seconds of high intensity work this system kicks in and picks up the energy production. It can produce energy without the use of oxygen. In this system, glucose or glycogen is broken down into lactate and a hydrogen ion or lactic acid. For every turn of this system 1 glucose molecule is broken down to produce 2 ATP molecules, 2 lactate molecules, and 2 hydrogen ions. If glycogen is the initial substrate, 3 ATP molecules are produced. It is the acidity in the muscles from the hydrogen ions, not lactate, which halts muscle function after a period of time.
As seen in the above diagram, glucose is broken down to pyruvate to release 2 phosphagens to create 2 ATP molecules. This creates 2 pyruvates. The co-enzyme NAD absorbs the hydrogen ions formed as glucose releases phosphagen for ATP. NAD becomes NADH and pyruvate then accepts the additional hydrogen from NADH to become lactic acid. Lactic acid is the storehouse for the 2 hydrogen ions. The accumulation of hydrogen ions is the limiting factor in this energy system causing fatigue. The hydrogen ions occur because lactic acid is unstable and quickly breaks down into lactate + a hydrogen ion. When enough hydrogen ions accumulate the pH of the muscle changes and halts muscle function. The lactate can be recycled in the system and used as fuel. NADH can also be pulled into a cell’s mitochondria and recycle the hydrogen ions with oxygen in the aerobic pathway.

This system can last for up to 2 minutes, but fatigue (hydrogen ions) starts to accumulate at 45-60 seconds. Typical anaerobic runs are 300-800 meters at a high intensity. High quality anaerobic is very taxing on the central nervous system and muscles. Full recovery is needed to conduct quality anaerobic work. The rest can range from 5-30 minutes. The length of work is the determining factor for rest. The work to rest ratio for full recover is as high as 1:20. The goal is the removal of lactate from the muscles. Low intensity aerobic work at 60% of VO2 max or 65% max heart can help the body remove the lactate from the muscles. Less than full recovery can blend the anaerobic and aerobic energy systems.

Table 3: Example anaerobic glycolysis workouts

<table>
<thead>
<tr>
<th>Speed Endurance</th>
<th>Special Endurance</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x120m at 95% with 8 mins rest</td>
<td>3x300m at 90% with 12 mins rest</td>
<td>3x (5 pull ups, 10 pushups, 15 squats) with 6 mins rest</td>
</tr>
</tbody>
</table>

Aerobic (Oxidative) System

The third energy pathway is the aerobic energy system. ATP is produced in this system through oxidative phosphorylation. The aerobic energy system produces energy in three stages using three different fuel sources unlike glycolysis. In the aerobic energy system fats, carbohydrates, and proteins can be used for fuel. Exercise intensity determines which fuel is used for the aerobic system. Lower intensity exercise is more likely to use fats and high intensity
exercise is carbohydrate dominated. On a high fat/low carbohydrate diet, fats can provide the glucose for high intensity work through a process known as gluconeogenesis. The first stage is where pyruvate, amino acids, or fatty acids are turned into Acetyl-CoA. Pyruvate is the product of glycogen or glucose during glycolysis. Acetyl-CoA enters the Krebs cycle to begin stage two. The Krebs cycle produces NADH and FADH which carry electrons to the electron transport chain (ETC) in the mitochondria. It also produces guanosine triphosphate which can donate a phosphate to ADP and create ATP directly. The final stage of the aerobic energy system is the electron transport chain. NADH or FADH pass their additional electrons through the ETC to oxygen providing enough energy to allow ADP to be converted to ATP. The electron steps through different compounds releasing chemical energy through a proton gradient to create ATP. From every glucose molecule that is oxidized aerobically, 32 ATP are produced while glycogen produces 33-35 ATP. The by-product of this system is CO2 and water. The system needs oxygen to function. The oxygen molecules receive the electrons at the end of electron transport chain. Fats can enter the Krebs cycle as Acetyl-CoA through a process known as beta-oxidation.

The aerobic and anaerobic energy pathways are interdependent. Energy production from the two systems occurs on a spectrum. Factors determining energy contribution for the aerobic or anaerobic energy system are duration, intensity, and the body's ability to supply oxygen to the aerobic energy system. When less oxygen is supplied than needed to accept the hydrogen ions, then pyruvate accumulates and lactate is formed. The formation of lactate also causes an increase in muscle pH through the accumulation of hydrogen ions and that slows down all the energy systems. When exercise intensity is reduced, the lactate can be converted back to pyruvate and used in the aerobic pathway once oxygen consumption catches up. There are other factors, besides a lack of oxygen, including a rise in hormones that can increase glycolysis which will give a rise in lactate levels.

Generally steady-state work with a heart rate below 70% or under 60-80% VO2 max allows the body to use the aerobic energy system as its primary energy source. This work helps the body improve oxygen transport by stressing the system without accumulating lactate. At 60-80% of a maximum aerobic workload, lactate will start to accumulate. This point is commonly called the lactate threshold (LT). Training above this threshold for a short period of time can force the body
to become more efficient at recycling the lactate for fuel in the aerobic system. If running above the threshold is not prolonged for extended periods of time past the body’s ability to control the rate of lactate production, then the training can be successful. Example workouts:

Table 4: Example aerobic workouts

<table>
<thead>
<tr>
<th>Speed</th>
<th>Endurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>18x100m at 70% max effort with 60s recovery</td>
<td>45 min steady state run with 20 min slightly above LT</td>
</tr>
</tbody>
</table>

In summary, this is a breakdown of the energy system contributions over time.

![Figure 14: Energy system contributions over time](image)

**Cardiorespiratory**

The cardiovascular system is the transport system that carries oxygen and nutrients to skeletal muscles while removing waste products.

**Oxygen Delivery**

Not all air that is breathed in is used for respiration. A certain amount of air is lost to dead space in the respiratory system. The air used for respiration is known as alveolar ventilation. Lung capacity is the total of the lungs vital capacity (maximum inspiration) and the residual volume (the amount of gas in the lungs after expiration) this leaves the volume of alveolar ventilation. As gas enters the lungs it diffuses across alveolar membranes. Alveoli are small elastic sacs in the lungs that are the final branch in the respiratory system.

Partial pressure is a critical concept for gas diffusion across the alveoli membrane. There has to be a pressure gradient for gases to diffuse across the membrane. Partial pressure is the total pressure of gas multiplied by the percentage of that gas is one element. For example, the partial pressure of oxygen at sea level. The pressure at sea level for this example is 760 mm Hg

<table>
<thead>
<tr>
<th>Gas</th>
<th>Percentage</th>
<th>Partial Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>20%</td>
<td>0.2 x 760 mm Hg = 152 mm Hg</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>79.5%</td>
<td>0.795 x 760 mm Hg = 604 mm Hg</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>.5%</td>
<td>.005 x 760 mm Hg = 3.8 mm Hg</td>
</tr>
</tbody>
</table>
For respiration the partial pressure across one side of the membrane has to be less for gases to diffuse because the gas will move from a high pressure environment to a low pressure environment. Oxygen will diffuse across the alveoli membrane if the partial pressure inside the alveoli sac is higher than the partial pressure of O2 in the blood and CO2 will diffuse out of the blood if the partial pressure of CO2 is higher in the blood than the alveoli sac. During exercise the rate of gas diffusion can increase up to 30 times above resting values. Factors that affect the gas exchange are the alveoli membrane sac thickness, total surface area of the alveoli sac, blood saturation of the gas, blood temperature (this relatively stable). Blood saturation can be influenced by the amount of hemoglobin available to carry the O2 throughout the body. Exercise does not change diffusion capacity, but chronic exercise can increase lung surface area.

Circulatory System

Oxygen crosses the alveoli into the smallest blood vessels, called capillaries, and is carried in the plasma or by hemoglobin. A large majority of the oxygen is carried by hemoglobin, almost 99%. Capillaries are where all the exchanges of oxygen, carbon dioxide, and nutrients occur. The capillaries move the blood to venules then through veins to the heart. From the heart the blood is pumped out through arteries and the oxygen rich blood is pushed throughout the body. Once the blood becomes oxygen depleted it is moved back to the heart through veins and then is pumped to lungs to receive more oxygen. The left side of the heart pumps oxygen rich blood and the right side oxygen depleted blood.

Four oxygen molecules can be carried by one hemoglobin molecule. Blood hemoglobin saturation increases during exercise. The hemoglobin saturation percent is the amount of oxygen combined with hemoglobin versus the total oxygen capacity of the hemoglobin. Factors that affect hemoglobin saturation are blood temperature, oxygen partial pressure, blood pH, and CO2 partial pressure. So a decrease in blood pH, increase in tissue partial pressure, and tissue temperature increase can all cause oxygen to increase dissociate with hemoglobin and better diffuse into tissue. There is a final factor known as 2-3 DPG (2,3 Diphosphoglycerate), this enzyme causes more oxygen to dissociate from hemoglobin. Exercise at sea level does not cause a significant rise in 2-3 DPG levels, but at altitude exercise causes an increase in 2-3 DPG levels forcing more oxygen to dissociate from hemoglobin and diffuse into the tissue. Arteriovenous oxygen difference (avO2) is the amount of oxygen consumed by the tissue. During exercise the avO2 difference can increase up 3.5 times the resting rate. Training also increases the body’s ability to draw in air with an increase in diaphragm and abdominal strength.

Cardiac output increases during training to match the increased oxygen requirements of the body. Cardiac output is the heart rate (HR) x stroke volume (SV), amount of blood pumped by the heart. The output increases due to an increase in heart rate or stroke volume. Cardiac output is not drastically different at rest between trained and untrained individuals, but during exercise the cardiac output of trained individuals is significantly higher than untrained individuals.

Stroke volume reaches a maximal capacity at 40%-60% of a maximum aerobic workload. Stroke volume increases three ways; increased contraction strength, decrease in aortic pressure due to aortic dilation, and an increased venous return. Contraction strength increases with a higher circulation of hormones causing greater nerve stimulation. Venous return increases
because of venoconstriction, muscle pump, and respiratory pump. Venoconstriction increases blood flow by reducing the veins ability to store blood. Muscle pump is the process of skeletal muscles contracting to force blood back towards the heart. During sustain isometric contractions muscle pump does not occur. Respiratory pump increases blood flow by creating a change in pressure in the thoracic and abdominal cavity.

Heart rate increases in a linear fashion as workload increases. Training changes the heart rate for both exercise and rest. The parasympathetic and sympathetic nerve systems have the most pronounced effect on heart; both are part of the autonomic nervous system. The parasympathetic system serves to slow the heart rate and increase intestinal activity. The sympathetic system is the part of the nervous system that increases heart rate, constricts blood vessels, and raises blood pressure. The parasympathetic system increases activity at the sinoatrial node (SA) and atrioventricular node (AV). When the nodes receive a signal from the nervous system, the heart contracts. The SA node causes a contraction first followed by the AV node. The parasympathetic system causes the threshold for activation of the SA and AV nodes to increase which slows the heart rate. The sympathetic system increases SA and AV node activation. In general, the difference between parasympathetic and sympathetic response is known as heart rate variability (HRV). For training purposes, HRV is the difference in nervous system balance between para and sympathetic control of heart rate. A high HRV can be a sign of rest and relaxation while a low HRV can be a sign of stress or flight or fight response. Heart rate in general is influenced by age, body position, fitness level, and environmental factors.

Blood flow is another factor that changes in the cardiorespiratory system during exercise. During exercise the body also reorganizes blood flow away from inactive organs to skeletal muscles. Blood flow is affected by blood vessel resistance and pressure. Resistance is influenced by blood thickness (viscosity), vessel length and vessel diameter. The change in pressure is the systolic pressure minus the diastolic pressure. The systolic pressure is the contraction pressure and the diastolic pressure is the pressure when the heart is refilling with blood/relaxing. During rest, 20% of blood flow goes to skeletal muscles and during exercise up 90% of blood flow is pushed to the skeletal muscles by the arteries constricting blood flow to nonessential organs. During exercise, vasodilation occurs in the skeletal muscles to increase blood flow. This is a reflex that occurs naturally in the body. Blood flow to the brain remains relatively constant throughout.
Figure 15: VO2 max of a trained (athlete 1) and untrained (athlete 2) person in relation to LT threshold and running speed.

Oxygen consumption (VO2) of the body is the cardiac output multiplied avO2. VO2max is the maximum amount of oxygen consumption for the human body. VO2max training pace is generally reached in a two mile time trial. In terms of endurance training, there are many other factors besides just VO2max that affect performance including energy system and neuromuscular efficiency. Figure 15 shows the VO2max of a trained and untrained athlete. The graph shows that as fitness increases VO2max is reached at a faster speed with the lactate threshold being reached at a higher VO2max.
**Biomechanics**

Biomechanics is the study of mechanical principles applied to human movement. The study of biomechanics is important because it provides the basis for specific techniques taught in training.

**Basic Terminology**

Common terminology is important because it provides succinct language to use when discussing human movement.

**Anatomical Positions and Relationships**

Sagittal Plane: A vertical plane that runs front to back and divides the body into right and left sections.

Frontal (Coronal) Plane: A vertical plane that runs from left to right and divides the body from front to back.

Axial (Transverse) Plane: A horizontal plane that divides the body in upper and lower body sections.

Anterior: A term that relates to the proximity to the front of the body.

Posterior: A term that relates to the proximity to the rear of the body.

Medial: A term that relates to the proximity to the midline of the body.

Lateral: A term that relates to the proximity away from the midline of the body.

Proximal: A term that relates to the proximity toward the trunk.
Distal: A term that relates to the proximity away from the trunk.

**Joint Position and Movement**

![Anatomical Position](image)

**Joint Flexion:** Flexion is when the joint angle is less than the joint angle in the anatomical position. The knee joint is flexion during a quadriceps stretch.

**Joint Extension:** Extension for a joint is when the joint angle is close to or equal to the angle in the anatomical position. If a joint moves past the angle this is hyperextension and is normally associated with joint injury. The knee joint is in extension when standing.

**Joint Abduction:** When the joint is closer to the midline than the anatomical position.

**Joint Adduction:** When the joint is farther from the midline than the anatomical position.

**Joint Internal Rotation:** When a joint is rotated towards the midline of the body. Internal rotation of a joint can be known as inversion.

**Joint External Rotation:** When a joint is rotated away from the midline of the body. External rotation of a joint can be known as eversion.

**Flexion Movement:** A bending motion that decreases the angle between two parts. The elbow joint is in flexion during a bicep curl.

**Extension Movement:** The straightening movement the increases the angle between two parts. On the upward/concentric phase of a squat the hip is in extension.

**Rotation:** Occurs when a ball joint moves around an axis the travels through the bone connected to the joint.
Circumduction- Occurs when the distal end of the bone moves in a circle while the proximal end remains relatively stable

**Fundamental Mechanics Concepts**

**Forms of Motion**

Linear or translation motion occurs when all parts of the body travel the same distance in the same direction over the same period of time. One way of determining if something is experiencing linear motion is if the motion is in a straight line from the body and the line remains parallel to the previous position. Rectilinear motion is when the body follows a straight path and curvilinear motion is when the body follows a curved path.

Angular or rotation motion occurs when the body moves along a circular path so that all parts of the body travel the same angle, in the same direction, in the same time. The body rotates around a fixed axis during angular motion.

Most human motion is a combination of the two above forms of motion.

**Fundamental Terms**

**Force:** A body in a state of rest or motion can be changed by the action of another body. The pushing or pulling that other body exerts is termed force. Force can slow or stop a body in motion, accelerate an already moving body. Force has both a direction and magnitude.

**Mass and Inertia:** The quantity of matter of which a body is composed. Inertia is the body’s resistance to move. Inertia is directly related to a body’s mass. The greater the inertia of a body the harder it is to move.

**Center of Mass:** This is the point on the body where the resultant force of gravity acts on the body. This is where the mass of it is concentrated; it is the balance point of the mass, or its average location. The human body is capable of changing its center of mass based upon limb position in space.

**Internal and External Forces:** Internal forces are forces when any one part of the human body exerts forces on another part of the human body. For example the force a contracting muscle exerts on the bone or ligaments it is attached to. External forces are forces the body exerts on things not attached to it like the ground or a barbell.

**Kinematics vs Kinetics:** Kinematics is the study of motion without regard to forces. Kinematics looks at what is observable such as trajectories, displacements, velocities, and accelerations. Kinetics refers to the forces that cause motion. Kinetics covers forces, momentum, and impulse.

**Linear Kinematics**

Position refers to an object’s location in space. To accurately describe position a reference point is needed. For example limb position can be described from an environmental or anatomical reference point or in relation to another limb. This is why fundamental terms for biomechanics are so important; they provide the common language to reference positions from.

Distance and Displacement: Distance refers to the change in position of a body. Distance is the length of the path the body moved. Displacement is the distance in respect to direction. For example, if a body moves in a circle with a diameter of 100m the distance traveled is a 100m, but
the displacement is zero because the direction of travel had the body end up at the same starting point. If the path was a straight line then both the distance and displacement would be 100m.

Speed and Velocity: Speed is the rate at which a body moves from one point to another without respect to direction. Velocity is the rate of movement with respect to direction. Speed is the distance traveled divided by the time of travel. Velocity is the displacement divided by the time of travel. Instantaneous velocity is the velocity of a body at a specific point in time. Instantaneous velocity is important for bar speed. Average velocity is velocity over a longer period of time. This is important for evaluation of running performance.

Acceleration: Acceleration is the rate at which velocity changes with respect to time. Speeding up is positive acceleration and slowing down is negative acceleration or deceleration. Acceleration can be viewed either instantaneously or as an average.

Newton’s Laws: Linear Kinetics

First Law: Law of Inertia

A body will maintain a state of constant motion unless acted on by an external force. A body at rest will stay rest and a body in motion will stay in motion. Remember a body’s resistance to motion is related to its mass. The greater the mass the more resistance it is to change. Many sports techniques are based around overcoming a body’s inertia. The first law is also seen with bodies coming to rest without anything seemingly acting on them. The invisible forces such as friction and gravity are the forces that prevent perpetual motion in sports.

Second Law: Law of Acceleration

This law explains the relationship between force, mass, and acceleration. In this law mass will accelerate proportional to the amount of force applied to it in the direction the force is applied.

\[ F = ma \]

Equation 1: Force

In the above equation, \( F \) is force, \( m \) is mass, and \( a \) is acceleration. At the simplest level everything in training involves force generation and application so this concept is fundamental to training. Momentum is another part of the second law. Momentum refers to the product of mass and velocity.

\[ M = mv \]

Equation 2: Momentum

It is the quantity of motion for a body. For example a 260 pound linebacker moving to make a tackle at 20 mph will hit harder than a 260 pound linebacker moving at 10 mph. The greater velocity gives the first linebacker more momentum. It is less risky to get tackled by a 130 pound cross country runner moving at 20 mph though because of the decreased mass. Momentum is important because it can be transferred. Based on the conservation of momentum, the momentum of closed systems will stay constant. This means that in a collision an object can transfer its momentum to another object. This is seen in football tackles or the throwing of an object. Impulse is when a force acts over an interval in time. The amount momentum produced is directly related to the impulse. In sports this means applying large amounts of force over a long
period of time. For example in Olympic weightlifting, the clean, the goal is to apply force throughout the entire pull movement. It is easier to apply a greater impulse when the initial velocity of an object is low. When an object is moving at a high velocity the time to apply a large force is short creating small impulses. Impulse is most important during acceleration, but not at high velocities. Trying to impart a large force when the velocity is already high is normally misguided and will likely cause a decrease in velocity.

Third Law: Law of Action and Reaction

Every action produces an equal and opposite reaction. For example when a runner’s foot hits the ground and puts force into the ground the ground puts force, but into the runner’s foot this is known as ground reaction forces. This is a very important point when looking at technique. It means that for every change in technique there is going to be a secondary effect. For example if an athlete drops his or her back in the Olympic weightlifting movement the snatch, the center of mass will change which changes the athlete’s stability, this an internal reaction force. Internal reaction forces can enhance ground reaction forces. For example, the arm swing in a standing broad jump increases the downward forces, which then increases the ground reaction forces.

Work, Energy, and Power

Work is equal to the product of a force’s magnitude and the distance the force causes a body to move in the direction the force is being applied. For a force to qualify as having done work then there needs to be a displacement.

\[ W = Fd \]

Equation 3: Work

Mechanical energy refers to the capacity of a physical system to do work. Inherently every system has energy as Einstein famously related energy directly to mass through \( E=mc^2 \). In biomechanics there are three main types of energy, potential, kinetic, and elastic. Potential energy is the body’s capacity for work based on its position in space. The higher something is above the ground the greater the potential energy. Potential energy in this case is generated from the force the Earth’s gravitational field exerts on it. Kinetic energy is the energy a body has from its motion. Kinetic energy is related to a body’s mass and velocity.

\[ K = \frac{1}{2}mv^2 \]

Equation 4: Kinetic energy

Strain energy is the energy a body can store based on the deformation of tissue. This is a type of potential energy where the force creating the energy is something other than gravity. This type of energy can be seen in the body’s stretch shortening cycle. The Law of Conservation of Energy states that although energy can convert forms, it cannot be created or destroyed.

Work-Energy Relationship: The work-energy relationship indicates that energy is the capacity to do work. Work can be a means to transfer energy from one object to another. For example an object in motion has the capability to do work through its kinetic energy. An object’s potential energy has the capability do work based on its position. For example with a bow and
arrow, when the string is drawn back the string contains potential energy. Once the string is released that potential energy is converted to the kinetic energy of arrow. The equation is:

\[ Fd = 0.5mv^2 + Wd \]

Equation 4: Work energy

Power: Power is the amount of work done taking time into account. Power is how quickly or how slowly work is done, a work/time ratio. Power is a primary factor for success in sports.

\[ P = \frac{W}{t} \text{ or } P = \frac{Fd}{t} \]

Equation 5: Power

Angular Kinematics
Axis of Rotation: For rotation to be stable the axis must pass through the body’s center of mass.

Angular Displacement: This is measured in size of the angle or number of revolutions rotated.

Angular Velocity: This is the angular displacement per unit of time. It is the speed of rotation. In a rigid body all units rotate at the same speed because they transverse the same angle.

Angular and Linear Velocity Relationship: All points on a rigid body have the same angular velocity but not linear velocity. Since velocity is measured as distance covered over time, the points farther away from the axis of rotation have a faster linear velocity.

Angular Kinetics
Torque is the angular equivalent of force; it is the rotational force. Torque is the distance from the axis (radius) multiplied by the force.

Rotational Inertia is known as moment of inertia. Just like inertia in linear kinetics is a body’s resistance to motion, in angular kinetics moment of inertia is a body’s resistance to rotation. The farther a body’s mass is distributed from the center of mass the larger the moment inertia.

Newton’s second law: In the angular world a rotating body will accelerate rotationally to a magnitude proportional to the amount of torque applied to it. Systems with a greater moment of inertia are harder to accelerate. An example is, it is harder to move a body under the bar in the Olympic movement the snatch if the bar has moved farther out from the body and its center mass. The farther away the bar moves from the body the greater the moment of inertia.

Conservation of angular momentum: Angular momentum will stay constant unless a body is acted on by an external torque. An internal momentum change will cause another internal momentum change to keep the value constant.

Transfer of angular momentum: Angular momentum can be transferred which will allow the body to slow, stop, or reverse its rotation. Hinged moment is when one end of a moving body is stopped, the other end of the body will continue to move about the axis created by the stopped end.
Posture, Stability, and Kinesiological Concerns

Posture
Proper posture is prerequisite for maximal force production. The proper positioning of the core of the body allows for the most optimal application of force.

Postural Stability and Alignment
  Stability: When a force is applied to an elastic body that is not properly stabilized the body becomes distorted rather than displacement occurring. This means that forces meant to cause displacement of an entire system are absorbed as angular movements. Force in athletic events needs to be applied from stable positions to produce efficient movement and maximal displacements. If the body is not properly stabilized, distortion and angular movements occur in the body, absorbing and wasting these forces.

  Alignment: Proper alignment involves position of the head, spine and pelvis with the stabilization of the appropriate muscle to establish a base. The head needs to be aligned with cervical spine in most movements so that the associated muscles are not overused. The spine must be stabilized in correct alignment (what is commonly called a neutral arch) to best accept the load it receives from the legs and gravity. The pelvis needs to be positioned to allow proper force production and leg position in a movement. Pelvic misalignment can cause harmful stiffening or multilink strategies. Improper head alignment can impair limb function. Refer to the above example where the head being out of position in an Olympic lift can change the bar position through an action/re-action cycle. Pelvic and head alignment can have major impacts on muscle recruitment patterns.

Stability
  Base of support: The farther a body’s center of mass from the base of support the more unstable the body becomes. A body cannot be stable when the center of mass is outside the base of support. Single support is when only one foot contacts the ground like running. Double support is when both feet contact the ground like a squat. Height of the center of mass above the base of support also affects stability. The higher the center of mass is above a base of support the more unstable a system is.

Types of Stability
  Static Stability is when a body is immobile or stationary and the center of mass is somewhere above the base of support and no external forces are applied.

  Dynamic Stability is when the body continually experiences a pattern of stability and instability with the base of support continually relocating itself. For example when running the body is stable when a foot is in contact with the ground and the center of mass is over the foot. The body is unstable as the center of mass continues moving forward and is not stable again until the next foot strike. This is dynamic stability.

Stability Preservation
Stiffening Strategies: When the body senses instability the muscles contract isometrically to stabilize the body.
Multilink Strategies: When the body senses instability body part positions are changed to rebalance the center of mass to achieve stability.

Grounding Strategies: When the body experiences excessive forward rotation it can quicken the body’s stride to regain stability or lengthen a stride to counter rotation.

**Kinesiological Concerns**

Firing order: Joints near the core (proximal joints) like the hips and shoulders are capable of producing large amounts of force because they are connected to larger muscles. However, they typically move slower than distal joints like the wrist or ankle. The larger joints are better at overcoming inertia and the distal joints should contribute after inertia has been overcome. The sequencing of joints is referred to as the firing order and should go proximal to distal. For example when throwing a baseball the movement originates in the hips, then shoulder, and finally the wrist with the ball release.

Use all the available joints to complete movements because typically every joint can contribute force to a movement. The technique needs to incorporate all the available joints. For example if the squat is conducted with an athlete shifting to his or her toes, the hip joint isn’t used to its fullest affect so to properly conduct a squat the athlete should sit back on his or her heels.

Joints are not just force producers, but are force transmitter. The number one force transmitter in the body is the core. The core transmits force from the hips in many movements to the shoulders. It allows forces to move proximal to distal. Stabilization of the joint is important for this force transmission. Proper alignment also keeps the force from dissipating in the joint instead of being transmitted farther downstream.

**Correcting Errors**

Errors may not appear at a low velocity or low force, but only at high velocity or high force reps where time becomes a constraint and reflexes are more of a factor. In these cases it is important to correct initial body position because errors will compound. If the set position in a clean is not established properly the first and second pull will likely contain errors. These can be hard to see at first because the movement occurs so fast so it is much easier have a proper set position to reduce movement errors. It is normally best to backtrack to correct an error. If multiple errors occur in a movement and the first error is fixed, then there is a high probability the other errors will disappear because they were the result of the body compensating for the first error.
**Training Theory**

Training theory is the encompassment of all the sports sciences including: anatomy, biomechanics, genetics, nutrition, pedagogy, physiology, and psychology to properly apply stimuli to improve performance. More succinctly it is the body of science that examines how the body reacts to exercise and how the exercise can be planned and administered.

**Fundamental Terms and Concepts**

**General Adaptation Syndrome**

Han’s Selye’s general adaption syndrome is a concept adopted in training theory from mainstream science. According to Selye, the body is always attempting to maintain homeostasis. There are three phases to a stress response. The alarm stage is the body’s initial reaction where the fight or flight response is activated. The resistance stage is when the stress level is likely eradicated or reduced. The body allocates energy to repair the damaged muscle tissue. If the stress is prolonged the exhaustion stage is entered. The adaptive energy is depleted and the body can no longer adapt to the stress creating health problems.

A sport specific model of Selye’s general adaption syndrome is Matveyev’s model of periodization. When stress is initially applied, fatigue decreases fitness levels. After a period of recovery/rest the body completes the adaptation prior stimulus. A new stimulus is applied once the body rests and recovers to a superior fitness level known as super compensation.

![Matveyev’s Model](image)

**Figure 18: Matveyev’s Supercompensation**

There are six basic principles that are the basis of successful training designed with a considerable scientific backing.

**Six Principles**

Stimulus and Adaptation: How the body reacts to stress (stimulus) in a way that better prepares it to deal with a similar stress at a later point in time. Training is a planned, progressive series of
stresses. It takes longer for the body to adapt to some stresses than it does others. Adapting to a strength workout may not happen as fast as adapting to an endurance workout, which must be taken into account during the planning process. Some stimuli can be progressed faster than others. An example of a stimulus and adaptation is a reduced rest heart rate following an endurance program or increased muscle fiber diameter after a period of strength training. Adaptation rates vary based on genetics, sex, age, training age, fitness level, motivation, capacity, and health. The variation in adaption rates is biovariability.

Individualization: Stimuli should be individually tailored because of biovariability to create optimal performance. Individualization is not just about a stimulus but also applies to biomechanics. Creating ability groups better segregates workouts based on individual performances, thus ensuring no one is pushed too far beyond their fitness level. Workouts should be scaled down for individuals joining the regimen midway through. It is important to consider training history when changing an individual’s fitness plan. Multiple workouts in a day only benefit individuals who are fit enough to adapt, and not overtrain. Fair is not equal, equal is not fair.

Overload: Applying an excessively difficult load to an unadapted body. Load can be determined by intensity, volume, density, and duration. Intensity refers to the percent of a maximal performance for the exercise being performed. Intensity is not determined by fatigue. Volume can be measured in repetitions performed, total weight lifted, or total distance run. Density refers to the amount of recovery between bouts of exercise in relations to the time to complete the activity. Duration is that time a person is actually engaged in an activity. If the stimulus is too weak, then the adaptation may not be positive creating a de-training effect. If the stimulus is too strong, the body will not adapt and cause overtraining. This overtraining creates an unfit illusion, which would likely cause the coach to push the athlete even harder. The stimulus should be systematic and progressive.

Rest and Recovery: Rest is the time required for a person to recover from the depleted post training state to a point of super adaption/compensation. 48 to 72 hours may be required to recover from an intense strength training workout where the muscle tissue is damaged. An intense anaerobic or aerobic workout that depletes muscle and liver glycogen stores may take up to a week to recover from. Do not assume the athlete will get proper rest outside of training. Rest and recovery should be planned and included. To accomplish rest and recovery easily, follow a hard/easy day to day schedule. Rest does not equate to zero activity. Alternating anaerobic with aerobic energy systems on different days will allow the body to rest and recover which ever system that is not in use. The fitness-fatigue shows that performance due to a training stimulus will not be expressed until the fatigue is decreased.

Figure 19: Fitness-fatigue model
Reversibility: Loss of adaption due to a lack of stimulus or inadequate stimulus. If the training stimulus decreases for a given period of time, the fitness level will drop off. The length of time to see a decrease in adaptations depends on the adaptation. Reversibility is important to understand with designing a taper. Below is chart created by USTFCCCA Coaches Education Program based off the removal of a training stimulus:

<table>
<thead>
<tr>
<th>Days</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Beta-endorphin and adrenaline levels drop. Mood is affected negatively.</td>
</tr>
<tr>
<td>3-5</td>
<td>Muscles lose elasticity. Aerobic capabilities drop off 5% by the fifth day off.</td>
</tr>
<tr>
<td>7-9</td>
<td>Body's ability to use oxygen (VO2 max) drops by 10%. Less oxygenated blood is pumped with each beat.</td>
</tr>
<tr>
<td>10</td>
<td>Body's metabolic rate begins to drop. Eat less or you'll gain weight.</td>
</tr>
<tr>
<td>11-13</td>
<td>Maximum heart rate and cardiac output decline by 15%. Muscle tone sees first appreciable loss.</td>
</tr>
<tr>
<td>14-16</td>
<td>Mitochondrial activity (energy production) in muscle cells begins to decrease rapidly. Loss of muscle mass, strength and metabolic rate occurs.</td>
</tr>
<tr>
<td>17-19</td>
<td>Body becomes less efficient at thermoregulation. You are forced to spend excess energy cooling off.</td>
</tr>
<tr>
<td>20-21</td>
<td>VO2 max has dropped by about 20%.</td>
</tr>
<tr>
<td>22-25</td>
<td>10-15% loss of muscle mass and that lost mass is replaced by fat.</td>
</tr>
<tr>
<td>27-29</td>
<td>Muscle strength drops by as much as 30%.</td>
</tr>
</tbody>
</table>

Specificity: Specific training stimuli result in specific adaptations. Training needs to be designed to stress a system peculiar to the desired test at the intensity and duration of the test. To create a better runner, running should be the stimulus not an alternate exercise. It takes on average 21-28 days for the body to completely adapt to a stimulus. If a workout is worth doing, it is worth doing more than once to completely allow the body to fully adapt to it. A workout never returned to might as well not have been done.

**Training Components**

Training can be broken into 5 major components based on neuromuscular performance. These components are speed, strength, endurance, coordination and flexibility. These are different than the 10 or 11 components of health and fitness. The biomotor abilities are neuromuscular performance markers, and a majority of the 10 health and fitness components are subsets of those markers.

**Speed**

Speed is traditionally defined as the ability to move the body and/or its parts quickly. There are a few subsets of the term speed that need defined. Speed can apply to any event. Average speed is the event length divided by the completion time.

Absolute/Maximum Speed: This involves the alactic (ATP-CP) energy system. This is the maximum achievable velocity in an event. In running absolute speed is achieved between 30m to 70m in an all-out effort. Top speed cannot be maintained longer than 30m and after 70m
deceleration occurs which corresponds to the depletion of ATP in the ATP-CP system. In weight training, speed is viewed as bar speed. Normal speed strength training has bar speeds of 1-1.5 m/s and has loads under 50% of an athlete’s maximum.

Acceleration: This is the rate of speed increases. Acceleration is a cross between speed and strength. It can refer to the body, a body part, or implement.

Speed Endurance: The ability to maintain a specific pace. Speed endurance in longer events like a 5 mile is different from speed endurance in a 400m therefore it can be termed event specific speed. The required endurance depends on the event, its intensity and duration, and the energy system requirements of the event.

Optimal Speed: The speed necessary to complete an event in the shortest amount of time. Not every event is an absolute speed event. Optimal speed is a combination of event specific endurance, speed endurance, and pacing. The concept of speed reserve comes into play here. Speed reserve is the athlete’s maximum performance at a distance less than the racing distance and the time to complete that distance during the primary event. The greater the speed reserve the less muscle tension and fatigue affects performance

Strength
Strength is the production of force.

Absolute Strength: Ability to produce large amounts of forces regardless of the movement speed. Heavy weight exercises like squats are an example. The exercise is relatively slow but produces large amounts of force.

Power: Ability to produce force quickly. Power movements usually involve high movement speeds but still require some resistance to be overcome. Examples are plyometrics, Olympic lifts, or weighted sprints. Optimal power in the clean movement is normally achieved at an 80% load rather than 100% load.

General Strength: Ability to overcome body weight and effectively manage movement in space.

Reactive Strength: Ability to produce force and elastic energy using the body’s stretch reflex/stretch shortening cycle. An example would be depth jumps.

Endurance
The capacity to maintain a degree of speed or force in the presence of fatigue.

Aerobic Endurance: The ability to produce ample amounts of energy using the aerobic energy system. Activities that improve aerobic fitness require the body to consume oxygen. The aerobic energy system uses oxygen, glucose, and fatty acids to produce energy. It is very efficient at producing energy but cannot keep up with the demands of high intensity activity. When the threshold of intensity is reached, the anaerobic energy system is activated. Aerobic Endurance is usually stressed beyond 10 minutes of work. Events between 2 to 10 minutes are usually a combination of aerobic and anaerobic endurance.
Anaerobic Endurance: The ability to produce ample energy for use in the glycolytic energy system. Activities that are anaerobic are high enough in intensity to cause the aerobic energy system to fail at providing energy for the activity. The body is forced into a state of oxygen debt and acidosis. The glycolytic energy system uses glucose or glycogen to create energy without oxygen. It provides energy for a period of up to 2 minutes of intense work. The by-product of this energy system is lactic acid. The system needs to be recovered after the 2 minute window to be used again. Another anaerobic energy system is the creatine-phosphate system. It provides the most energy for the most intense work. It only last 7 seconds, then needs to be recovered.

Work Capacity: The ability to withstand high loads of training. Work capacity is different from aerobic and anaerobic fitness because it can be applied to speed, strength and coordination work.

Coordination
The in sync function of a muscle or groups of muscles. Coordination includes the ability to spatially orient oneself, kinesthetically differentiate, react, keep rhythms, and maintain balance. Coordination develops before puberty and regresses during puberty. It involves the rhythmic activation of agonists and relaxation of antagonists. This can be seen in the third pull of Olympic weightlifting. The body quickly contracts to complete the second the pull then relaxes just as fast to drop under the bar and complete the third pull.

Agility: The ability to perform un-patterned or irregular movements quickly and accurately. Starting, stopping, and changing direction are examples.

Mobility: The ability to display large ranges of movement while accomplishing technical tasks. This is different than dynamic flexibility because of the technical demand. Walking over hurdles is an example.

Balance: Ability to remain stable. Balance can be static and dynamic. Standing on one leg is static balance and running is an example of dynamic balance.

Flexibility
Flexibility is the amplitude of movement. Flexibility is optimized to the individual. It is also specific from muscle to muscle and event to event. Research has shown that stretching/flexibility does not necessarily decrease injury. Studies have shown a decrease in injury rate with increased flexibility, no change in injury rate, and an increase in injury rate with increased flexibility.

Static: The ability to attain large ranges of motion in the joints from static positions. It normally takes 2 minutes of holding a stretch to create change in static flexibility. This is why yoga is so effective. Never stretch a cold muscle. It is like putting a rubber band in the freezer then trying to stretch it.

Dynamic: The ability to move through large ranges of motion. It is different than static flexibility because motion is involved.
**Training Design**

**General to Specific Training**
Training should progress from general to specific.

General training is that which improves overall fitness. General is the foundation for specific training. General training can include: agility, balance, fitness, strength, and should result in an increase in work capacity.

Specific training is that which is directly related to a competitive event. Specific training can occur once there is a base level of fitness. It is event specific and can address individual strength and weaknesses.

**Simple to Complex Training**
Training should progress from simple movements to more complex movements over time. An oversimplified weight room example is doing general strength for a cycle (calisthenics), progressing to squats and deadlifts for a cycle, and then progressing into Olympic lifts the next cycle. Complex movements place more stress on the body especially during skill acquisition.

**Volume and Intensity**
Volume and intensity have an inverse relationship. If volume is high then intensity should be low and vice versa.

![Volume and intensity relationship](image)

**Variance**
Creating variety among the monthly plans, to eliminate staleness, enhance adaptation, and prevent injury. If every workout is completely different, however, the body will never fully adapt to a stress which is a desired outcome. Prominent plan to plan variation and progression is a must.

**Training Grouping Principles**
Each training day should have a theme. Group similar training stimuli together. Speed and power, speed and strength, skill and speed, work capacity (aerobic and general strength) are all examples of groupings. Do not group drastically different stimuli together, like aerobic running and power work. This creates an interference effect which impedes adaptation because the
desired results are so different. They are likely to cancel each other and decrease the athlete’s performance.

**Multilateral Training**
The philosophy of developing all the components of fitness in a planned balance. This creates a complete athlete and is important to a successful training program. The plan should not exist between the main 5 components alone, but also the subcomponents. The areas don’t have to be addressed equally, but are based on the demands of the job. Each component should be addressed daily, but they don’t have to be addressed equally.

**Multisystem Training**
The philosophy of developing all the body’s systems in a planned balance. The balance of the systems need not to be equal. The balance is determined by the demands of the specific training event, time of year, and specific individual’s ability.

**Planning and Organizing Training**
Periodization is one of the early attempts at planning and organizing training. It is a concept developed in the 1950s by a Russian scientist, Lev Pavlovich Matveyev. This concept is analytic-synthetic concept. The idea is to train parts then those parts create a better complete athlete. The traditional model as it is known starts with high volume, low intensity training then progresses to low volume, high intensity training.

![Figure 1: Matveyev Model](image)

Matveyev’s concept is a very linear model that was developed from looking at the training plans developmental athletes. The concept is based on logic and statistics not the specific biological adaptation time frames. In Matveyev’s concept the fitness is built through general methods early on that combine during the transition phase to produce results in the competition phase. Here all the necessary fitness is achieved during the prep phase and then just maintained in the competition phase. Matveyev treats all the components independently and states they all operate based on the above picture. The adaptation process here is known as the complex principle where all the components were trained in parallel during a microcycle with no respect to how the components interact. The training process was the sum of the components. The graph also shows
that quality technique is unimportant early on in training. Instead of breaking down the traditional model this manual will cover Yuri Verkoshansky’s Sports Training Theory (STT) that looks at the biological adaptation process. The essence of planning training is to increase the motor potential of an athlete’s neuromuscular components and the ability to use that potential. The fundamental blocks in the STT concept are the microcycle, main adaptation cycle, and a large training cycle.

Main Adaptation Cycle (MAC)
The main adaptation cycle is a specific block of training/time that is designed to help an athlete realize his or her actual adaptation potential (AAP). The AAP is the energy reserve that allows an athlete to achieve a relatively stable adaption to workloads requiring maximum intensity. A key point is the AAP shows that adaptations are not indefinite, but have limit strongly influence by genetics. AAP can be viewed as genetic potential. A MAC is designed to achieve a relatively stable morphological change that allows the athlete to progress to a higher level of specific work capacity. MACs need to be specifically planned. In a MAC the training loads have specific aims that involve specific energy systems or other functional capabilities to achieve a specific objective. Keys to specific planning are knowledge of the athlete’s current functional capacities and knowledge of the body’s adaptive reactions to stimuli. To properly plan a MAC the trainer needs to predict the body’s response to a given stimuli and ensure the plan is design to allow that response. The STT concept is backward planning. The training goal is selected then the type of training, volume, and organization are determined to achieve the end state. Multiple MACs can be strung together to create an annual plan where a MAC builds on the previous one allowing the athlete to train at a high level.

Blocks A, B, and C
These are the next components of the STT concept. Block A is the basic phase. The block is oriented on creating adaptations to allow the body to increase the specific work regimen it undertakes. The main focus is to increase the body’s motor potential. This block is not just general work but still has a focus of the specific requirements of the end state. Block B is the special phase and is focused on the developing the body’s ability to execute at competition speed and get the body accustom to its new potential. Block C is the conclusion of the adaptation cycle. In block C the body exploits its full potential in competition. Curves in the graph above for
Blocks A, B, and C represent the different priorities of each phase not the volume. They represent a gradual increase in intensity of specific work. Notice that the blocks overlap to create a smooth transition between phases. There is neither a preparation or competition phase in this concept because that implies the training between the two is not connected and that improvement is not seen in the competition phase only an expression of fitness. The length of the blocks should be determined by the time of adaptation. A general rule of thumb is it takes 21-28 days to adapt to a strength stimulus and 29-30 days to adapt to an endurance stimulus. 70% of the adaptation to a specific endurance stimulus can occur in the first 10 days. The layering of phases should occur such that each phase builds on the abilities trained in previous phase. For example, acceleration training precedes speed training.

Figure 23: Phasing training blocks

**Microcycle**
A microcycle (MC) is group of training sessions designed to produce a specific adaption. The minimum number of sessions in a microcycle is two different types of sessions. A microcycle typically last 5-10 days. The microcycle is the synthesis and interaction of the different training components to create long term adaptation. It should be designed so the loads for different training methods allow the desired adaptation to occur. Rest needs to be managed appropriately during the MC to allow glycogen replenishment, protein synthesis, and increase hormonal response. This can be managed by varying the functional capacities being challenged between workouts. The MC should contain heavy load days followed by restoration days to allow the body ample time to adapt to the heavy load. Recovery varies based on the system stressed. Microcycles should not be independent blocks but tied together to accomplish the specific goals of a training block.

**Training Day**
The training day usually consists of 2 to 3 training units. The day is organized based on the day prior and the day after. There can be multiple training sessions in a day. The day should have a theme like endurance, speed, or strength and all the units should support the theme.
**Training Session**
A training session is the combination of training units executed in one solid block of time. A training session can be one unit or a combination of units. A training session is organized based on the athlete’s short term adaptations to training units so that they build on each other. Units can be linked together based on neuromuscular demand, metabolic demand, duration and rhythm.

**Training Unit**
A block of training dedicated to a specific training component like speed, strength, endurance, flexibility or coordination. Units have specifically determined loads, intensities, exercises, recovery periods, and densities designed to meet the end state of the unit.
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