Kinesiology of Exercise

Based on the Work of Dr. Michael Yessis

Biomechanical Considerations of Exercise

KinX Learning

Kinesiology of Exercise eBooks by KinX Learning

Published by KinX Learning

www.kinxlearning.com

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Part 1 – Biomechanics and Kinesiology

Biomechanics and Kinesiology

The most accurate way to determine the key joint actions and muscles involved in a strength exercise is to analyze biomechanically and kinesiologically, the movements that are performed. By doing this you can also determine the effectiveness of the exercise in relation to muscle involvement and function. Only in this way can you determine which joint actions and muscles play a major role and if the exercise is effective and safe.

In books and magazines exercises are usually described in very general terms. As a result it leads to misunderstandings. An exercise analysis, however, answers questions such as: If the exercise is effective, why is it effective? What is the role of each joint action? What is the role of the different muscles that are involved? With this information it is possible to determine which actions can be changed to make the technique more effective? Also, how can joint, body, or limb movements be changed to bring in greater involvement of specific muscles? How can specific actions be made more powerful? Should the exercise be modified? If the answer is yes, how can this be done? Most sources of standard instruction fail to address important points such as these.

There is a lack of agreement in regard to exercises and their execution among iron sport athletes, strength and conditioning coaches, athletes, personal trainers, and people who are involved in fitness programs. There is often disagreement when identifying the key actions and the exact execution that is needed to ensure safety and produce maximum strength or muscle involvement.

Nor is there conformity as to how each joint action involves specific muscles. Instead, we see articles espousing the opinions of exercisers, personal trainers, and celebrities which are often at odds with one another's views.

You have probably read articles dealing with certain issues, as for instance, whether the bar should be pulled down in front or behind the head when doing the lat pull-down. Or, if the arms should be raised shoulder level or completely overhead when doing the lateral or front arm raise, or if you should hold your breath on the exertion phase of a lift.

From biomechanics and kinesiology, that also incorporate pertinent physiological factors, we can come up with definitive answers to resolve these issues. These answers are based on science and facts, not opinion, as is often being done.

Biomechanics is the study of movement, more specifically, the movement (technique) involved in a strength exercise, or in execution of a sports skill. It deals mainly with physical factors such as speed, mass, acceleration, levers, force, and the physical functions of the movement. Some think of biomechanics as the science of movement based on principles derived from physics and anatomy. It explains the “why” and “how” of a movement and strategies to improve it through scientifically-based modifications.

Kinesiology is the study of human motion which deals mainly with the muscles and their functions. It describes movement, which muscles are involved in the movement, and how exactly they are involved. It explores the muscular involvement in strength exercises and sports technique while biomechanics looks at the physical factors involved in the movement.

By applying basic scientific laws it is possible to come up with accurate descriptions not only of what should take place in the exercise, but also the roles that key joint actions and muscles play. By studying the physical characteristics of the human body and the principles of mechanical physics, you will be able to better apply the information to your workouts or to those of your charges. You will have the basis for selecting and using specific exercises and movements to produce the results desired. Biomechanics and, to a limited extent, kinesiology are relatively new to the fitness and sports fields but are very important emerging sciences. They help to determine what exercises a person should do, how the workouts should be conducted, how effective the exercise execution is and if the exercises you use are safe. Biomechanics shows you the way to do exercises most effectively while kinesiology tells you which muscles are involved in the particular actions that take place in the exercise.

Are You Seeing What You See?

At first glance the title to this section may appear silly, but it is not. I have found that after years of conducting biomechanical analyses of exercises and sports skills that most people are not capable of recognizing what they see in a captured picture or a live movement. It appears that each individual's attention is drawn to certain elements and his/her focus gets concentrated on these elements.

As a result, each person sees something different when looking at the same picture or movement. Even the police have discovered this to be true when they question people who are at the scene of an accident. Witnesses will invariably give different versions of what happened in the accident.

Because of this, it is necessary to learn how to look more in depth at how an exercise is executed and how you should focus on certain key elements. This ability is necessary before you can determine what is needed to make effective changes or corrections in technique to ensure safety and effective development.

Keep in mind that most books and magazine articles dealing with strength exercises give only the superficial features of the exercise. They do not bring out in detail how the muscles are being worked or exactly how the exercises should be done. For example, when doing the seated row, do the elbows stay out to the sides, or in close to the sides of the body? Can the exercise be done either way for the same muscle development? Many authors state that doing the shrug exercise is effective for development of the trapezius. Is this an accurate statement? In doing the shrug exercise, should the shoulders be raised as high as possible or should the range of motion be relatively small?

What is perhaps equally important is how much weight should be used or the ROM of the exercise. Through what range of motion should the lateral arm raises be done to maximally contract the deltoids? Which range of motion is most effective for development of the supraspinatus? Knowing the answers to these and many other similar questions enables you to correctly execute and evaluate an exercise. To be able to analyze an exercise, you must have a thorough understanding of the exercise. You should know not only which muscles are involved, but how they are involved. In addition, you must know how the exercise should be executed in order to involve a particular muscle or part of a muscle and the mechanical aspects of execution. This includes speed of execution, exact pathway of the limb or body part involved, where and how much force should be applied to execute the movement, the correct body position and so on. When you have this information, you can fully and accurately evaluate an exercise. This is what this book can do for you.

When you watch an exercise video or DVD it is difficult to pick up all the key elements of the exercise. It is necessary to freeze-frame the DVD and then advance it, frame by frame, so that you can see exactly what takes place in the various joints that are involved. If this technology is not available to you, then viewing it in slow motion is beneficial. In this case it may be necessary to look at it several times. Each time you look at the pictures, look at a different body part to get more precise details.

For example, if you are watching someone do a squat, you may start by concentrating on the lower body. Do the heels stay in contact with the ground throughout the full execution? Do the knees stay over the feet? Do the hips move backward during the descent?

After this you should look at the trunk and upper body to see if the spine is maintained in its normal curvature, if the head and vision is focused directly in front, if the bar is resting securely on the upper back, and so on. As you become proficient in picking out the different aspects of execution, your eyes will become trained to see these elements quickly.

Also effective is to have sequence pictures of an exercise. As your eyes move from one frame to the next you can check each joint to see exactly what is occurring. If needed, you can look back several frames and then ahead several frames to see the total movement. This is the only way that you can tell exactly what is occurring and if the execution is effective in relation to muscle development, and joint safety.

All too often we have a tendency to look at the muscular development or facial or body features of the exerciser, rather than looking at how the exercise is done. Keep in mind that photographers are usually more concerned with the aesthetics of the picture rather than accuracy of exercise execution.

As a result, they often put the model in a position that is not most conducive to the best execution. This in turn makes understanding the exercise more difficult! But even when the photography is accurate, very often the pictures do not match the exercise description!

To improve your ability to see exactly what is taking place during execution of an exercise, practice with others so that you can compare what you see with other people. The more you practice the more you can develop your expertise in this area. This ability does not come automatically; it must be learned just as you learn any other skill. When you develop this ability you will be able to make the needed changes to improve exercise execution.

To help you in your sport or practice, look at some of the pictures and explanations or descriptions in the more popular sports and fitness magazines. Analyze the statements in relation to the information presented in this book to give you a better understanding of what takes place in the exercise execution. You will also be able to better evaluate much of what you read and see in the literature, both popular and "scientific".

Part 2 – Muscle Function and Roles

Muscle Action/Function

Before going into detailed analyses of the exercises and the muscles involved it is necessary to have a good understanding of how the muscles function. It is important to have good comprehension of the different kinds of muscular contractions as well as the different dynamic and static regimes in which the muscles must operate during execution of strength and explosive exercises. This will enable you to effectively evaluate the exercises and exercise execution.

Roles Which Muscles Play

1. **Prime Mover, Agonist, or Muscle Most Involved.** A muscle is called a prime mover, agonist, or muscle most involved when it is the main muscle involved in a concentric contraction. For example, in the biceps curl the biceps brachialis and brachioradialis are agonists for elbow flexion. Many muscles are prime movers in more than one action, as for example, the biceps is also a prime mover in forearm supination.

2. **Assistant Mover.** An assistant mover usually plays a secondary role to the prime mover muscles involved. However, at times the secondary muscles play the main role in certain ranges of motion or in other exercises. Usually secondary or assistant muscles are not as powerful in the movement as the main agonists or prime movers. An example is the pronator teres in elbow flexion. It is a prime mover in pronation and an assistant in elbow flexion.

3. **Antagonist.** An antagonist muscle is one which has an action directly opposite that of the agonist. When an agonist undergoes a concentric contraction, the antagonist undergoes an eccentric contraction to guide the movement and to stabilize the joint. These are very important roles of antagonists. As the movement goes through the full range of motion, the antagonist muscle develops greater tension as the ROM increases and then stops the movement before it goes beyond the normal range of motion (ROM). It should be noted that the role of antagonist and agonist can change depending upon the action taking place. For example, in the biceps curl, the biceps is a prime mover while the triceps is the antagonist. When the triceps is involved in elbow extension it becomes a prime mover and the biceps becomes its antagonist. Thus, we see how one muscle can serve different functions.

During a muscular contraction, especially when the weights are very heavy, both the agonist and antagonist, undergo contraction (known as cocontraction). This is needed to stabilize or hold the joint in place while the action occurs. When the resistance is very light, the agonist and especially the antagonist are not strongly contracted.

The antagonist undergoes a strong eccentric contraction mainly to slow down and stop movement before there is injury to the joint. When the weights are very heavy, both agonist and antagonist are under contraction. In this case the antagonist contracts eccentrically and lengthens to make the movement possible.

4. **Stabilization.** When a muscle acts as a stabilizer it steadies or holds a limb and/or body part in place. It anchors the bone so that the prime mover has a firm base against which to contract, i.e., for the muscle to pull from or against. Stabilization is very important in all movements in order to have precise movements of the limb or body part.

Note that many people call for development of the stabilizer muscles. However, there are no such muscles in the body. At one time or another, all muscles can function as stabilizers. Exactly which muscles are involved is dependent upon the exact movement and the prime muscles used in executing the exercise.

The muscle acting as a stabilizer is usually under an isometric contraction to hold the bone (limb) in place. At times there may be slight movement of the limb or body part but it is still considered stabilization. For example, in the knee extension exercise with Active Cords, in which you hold the thigh up at about a 60 degree angle and then extend the leg, there may be some slight natural movement of the thigh. However, the thigh is still considered to be stabilized by the hip joint muscles.

When doing an overhead press, the quadriceps muscle of the thigh and especially the erector spinae muscle of the lower back contract to hold the body and trunk erect as you raise the weights overhead. If these muscles did not contract your body would not be stable and as a result, you would be susceptible to injury.

You would also not have a firm base against which the muscles could contract. Breath holding at this time also contributes greatly to stabilizing the trunk. Thus the muscles and breathing play an important role in stabilization when doing strength exercises, especially when the weights are heavy. Because of the isometric contraction used in stabilization, the muscles involved can become fairly well developed. However, this does not mean that you should ignore other exercises and exercise regimes to strengthen the muscles involved. Keep in mind that the isometric contraction is not as effective as the concentric in developing strength, mass, or definition.

5. **Synergy.** Because the term synergy has been used in so many different ways in the popular press, its meaning has become somewhat diffused. In the field of exercise it should be used in two ways. One is helping synergy in which two muscles contract simultaneously to produce one movement for which they are suited, while their other actions cancel each other out. For example, in the sit-up, when the internal and external obliques contract, they have a tendency to not only perform spinal flexion but to rotate the shoulders. In order to prevent the shoulder movement, the internal and external obliques cancel out their rotational action and the resultant force is used for spinal flexion.

Second is true synergy in which a different muscle contracts to stop the secondary action of another muscle. For example, the biceps brachii is both a supinator of the forearm and a flexor of the elbow joint. Thus, in elbow flexion, the pronator quadratus comes into play to cancel the supinating tendency of the biceps so that only flexion occurs. The pronator teres also comes into play, but since it is a flexor of the elbow it acts as a helping synergist.

Synergy can also be used synonymously with the term neutralizer. In other words, a muscle acts as a neutralizer when it contracts to counteract or neutralize an undesirable action of another muscle during its contraction.

Types of Muscle Contractions

1. Concentric Strength. In a concentric contraction the muscles shorten and produce movement. Concentric strength is sometimes known as overcoming strength. In other words, when the muscle contracts, it overcomes the resistance and puts the object or your body into motion.

An example is the biceps curl. When you contract the biceps and other elbow flexor muscles, you get movement of the forearm which raises the weight held in the hand. Concentric strength is usually measured by the maximum amount of weight that can be overcome in one repetition.

2. Eccentric Strength. In an eccentric contraction (often known as a yielding contraction), the muscle lengthens (stretches back to its original length) as it contracts. The more the muscle lengthens or the faster it is stretched the greater the tension that is developed. The eccentric contraction plays a very important role in controlling and stopping movement and in preparing the muscles for an explosive type contraction.

For example, when you return to the initial position in the biceps curl exercise, the same muscles are involved. The biceps and other elbow joint flexors remain under an increasing eccentric tension type contraction when they lengthen as you lower the weight.

Since gravity is the force involved in lowering the weight, the eccentric contraction counteracts the pull of gravity to guide the movement. The intensity of the contraction depends on the resistance being handled. In a ballistic movement, when the muscle lengthens, the intensity of its contraction increases.

When the eccentric contraction is strong enough, it stops the movement. The eccentric contraction can generate up to 50% greater tension than the concentric. This is why the eccentric contraction is so powerful, not only in controlling and stopping movement, but in generating sufficient tension in the muscles for them to contract explosively.

3. Isometric Strength. In an isometric contraction you exhibit strength, but there is no movement of the limbs. The muscle develops tension and there is some shortening of the muscle fibers and tendon, but there is no limb or body movement.

This type of contraction is seen in stabilization of a joint or the body as when you hold a particular position to execute an exercise. You can generate approximately 20% greater strength in an isometric contraction than you can in a concentric.

When executing a strength exercise, all three muscle contraction regimes are involved. As you perform a movement, the main muscles (agonists) undergo a concentric contraction while the opposing antagonist muscles undergo an eccentric contraction. The adjacent joints and parts of the body that are not in use are stabilized via the isometric contraction. Thus, all three muscle contraction regimes are in operation at the same time, each with a very important purpose.

Types of Movements

A muscle can contract with different amounts of force and in different ways to produce different types of movement. This includes:

1. **A sustained force movement** in which there are continuous muscle contractions to keep moving a weight. In other words, force is applied by the prime muscles involved throughout the ROM. It is usually seen in moderate to slow lifting of a heavy weight and may involve co-contraction with the antagonists. Sustained force can also apply to holding a weight with no movement (isometric contraction), such as for example, when you hold a particular position or pose.

2. **Ballistic movement** in which there is inertial movement after an explosive or quick, maximum force contraction. Usually there is pre-tensing of the muscle in the eccentric contraction so that the muscle can contract concentrically with maximum speed and quickness. The weight is accelerated and continues movement on the momentum generated. No additional force has to be applied to keep the limb or weight moving.

To stop the movement there is deceleration due to gravity and/or to the eccentric contraction of the antagonist muscles. The tension the antagonists develop as the ROM increases becomes strong enough to stop the moving limb. If there is no stopping of the limb, the weight must be released before you can go into the follow-through phase to dissipate the forces and come to a complete stop.

3. **Guided movement** occurs when both the agonist and the antagonist contract to control the movement. Guided movement is seen most often in fine skills such as when you are writing or when you must move the limb through a specific movement pattern. Very important here is the eccentric contraction of the antagonist muscles since they are responsible for most of the guiding work. The prime movers are responsible for putting and keeping the limb or body part in motion.

4. **Dynamic balance movements** occur when there are constant agonist-antagonist muscle contractions to maintain a certain position or posture. For example, if you stand on one leg you will not be able to stand perfectly still. To remain as stable as possible, there are constant slight correctional movements of the body.

For example, as you begin to lose balance in one direction, the antagonists contract to pull you back into position. The pull will usually take you slightly beyond the beginning position, at which time the muscles on the opposite side then contract to bring you back into alignment. Thus, there are constant low level contractions to keep you in a certain position or in balance.

Part 3 – Biomechanical Components of Exercise

Biomechanical Components of Exercise

Knowledge of the joint, muscle structure, and the actions possible, leads to a better understanding of what occurs during execution of strength exercises. It is also necessary to understand the mechanical and physical factors involved in exercise and movement. These factors determine not only how effectively the exercise is executed, but also its safety.

On the following pages brief descriptions of some of the key concepts derived from biomechanics are brought out. Some of them may already be familiar to you mainly through practice. Examples of specific exercises are used where applicable.

Stability

Maintaining a stable (balanced) body is needed to ensure safety during execution as well as for getting the desired results. This is especially true when using free weights. With machine weights, when you assume the necessary position, there is little need to balance your body as you execute the exercise. (This is based on the premise that you are seated and the machines allow you to do the exercise correctly in this position).

For example, when doing an overhead press the muscles of the legs and trunk must contract to hold you in place. The trunk must be rigid to provide a stable base for effective contraction of the shoulder muscles. If not, any change in the balance of the weights overhead may make you lose your balance, which in turn could cause injury, especially if you cannot regain balance and lose control of the weights.

The basic principles of stability are simple: the larger the base of support, the greater your stability. This is why you should most often assume a position with the feet approximately shoulder width or wider. If you have your feet together you have a very small base of support, which will not give you the foundation needed for stability when doing heavy lifts and, especially, overhead lifts.

Another way of increasing stability is to bend your knees in order to lower your center of gravity (where your weight is concentrated). The lower your center of gravity, the more stable you become. You can see this when the athlete assumes a ready position or positions himself for execution of a specific skill.

For example, when doing shoulder (upper body) twisting, in order to prevent lower body movement and keep the spine vertical, it is important that you bend your knees to stabilize the lower body and hips so the spine does not fall out of alignment. This serves to limit the movement to the shoulders. The bent knee position also works to prevent knee injuries.

Foot placement also plays an important role. If your feet are parallel and shoulder width apart, the weight should be close to you or overhead. This is the preferred stance in most exercises because you have good stability in a left to right direction. In a stride position you get better balance in the anterior-posterior planes when the legs are in a forward-backward direction (one leg more forward than the other). This stance is best when doing exercises such as the cable overhead triceps press or overhead jerk. When lying on a bench always place the feet on the floor to increase sideward (lateral) stability. Keeping the feet on the bench is an unstable position especially when you use heavy weights and/or a barbell. It is even more important to keep the feet on the floor when doing explosive or throwing type actions.

Components of Force

Muscular force is exhibited in a push or pull, i.e., actions that cause motion. Only the muscles (or more accurately, muscle strength) can create the force needed to put an object into motion. When moving a weight in a strength exercise, there are four components of force that must be taken into consideration: magnitude, direction, point of application of force and line of force.

Magnitude relates to how much force is applied to the dumbbells, barbells, machine handles, etc. If you wish to lift a barbell weighing 100 pounds, you must apply more than 100 pounds of force to lift it. Keep in mind that additional force is needed to overcome the weight of the limbs or body part involved and to overcome resting inertia.

Direction refers to the way in which the force is applied. For example, is it applied horizontally, vertically or a combination of both? This information is especially important in sports such as running, swimming, and the throwing events where the direction of force application changes as the limb moves through the full ROM.

Point of application of force refers to where the force is applied to the body or implement being used. It plays a role in many exercises from the overhead press to the squat. The closer the force is to the weight of the object, the more the force can be applied to effectively move it.

For example, if you hold a barbell in the middle of the bar with your hands close to one another, the force applied is close to the center of mass of the bar and the exercise becomes more effective. But in this situation, greater balance is needed, especially if the barbell is long, such as with an Olympic bar. In this case, you must assume a wider grip, in which you apply force at two points to raise one barbell.

This positioning loses efficiency but enhances safety and enables you to do the exercise. In sports, the point of application of force is where the hand or fingers are in contact with a ball when shooting (basketball) or throwing (baseball). In hitting, it is where the ball and hitting implement make contact, as for example, golf ball on the club head, baseball on a bat, or tennis ball on a racquet.

Line of action or **line of force** refers more to the angle or direction in which the force is being applied. To depict line of action, a straight line is drawn from the point of application of force through the direction of force. The more directly the force is applied in exactly the same direction as the intended movement, the greater the amount of force that goes in this direction. It is important to understand that you can push in one direction to get motion in another direction, usually a side component.

For example, if you have a very wide stance in the squat, as is demonstrated with the sumo style, you have less distance to rise up when doing the squat but the force generated by each leg does not go straight upward; it is at an angle to the body. As a result, only a portion of the total force raises you. To have all of the applied forces go through the center of gravity of the body to raise yourself you must keep the feet under the hips.

In sports, the legs must drive the hips upwards, forwards, or a combination of both in various jumping and running actions. Thus it is important that the feet be directly under the hips when force is applied in the intended direction. Because of this if the purpose of doing an exercise is to improve a jumping a running action, the squat and other exercises should be done with the feet under the hips.

Angle of Muscle Pull

When you do a strength exercise, the strength exhibited at different points in the range of motion will vary because of the angle at which the muscle pulls. For example, if you do a biceps curl beginning with fully extended arms, it is more difficult to generate sufficient force to start moving the weight than when you start with the arms bent. But the reason for this is that when your arm is straight the biceps muscle inserts at approximately an angle of 10 degrees on the radius bone of the forearm. When the muscle shortens, most of its force pulls the forearm (radius) into the joint to stabilize the elbow rather than to raise the forearm with the weight.

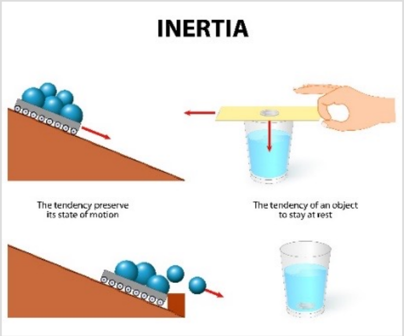
When the angle of insertion approaches 90 degrees, all the force of the muscle is used in raising the weight (all the strength generated is used to rotate the forearm). Because of this, you are much stronger when there is approximately a 90-degree angle in the elbows than when the arms are extended. This is known as having a mechanical advantage, i.e., you can do more work at this angle of muscle pull.

Because of this if you use a weight that is the most you can overcome in the early range of movement, it may appear light when you approach the 90-degree angle in the elbow. To overload the muscle in this range you must use more weight or go through a shorter ROM; you should not fully straighten the arms in the bottom position. Doing only this over a long period of time, however, results in loss of flexibility. As a result, it is necessary to vary execution.

The body is best suited for speed, not force. Thus, even though you are weak at the beginning of a straight arm elbow flexion movement, you possess the ability to develop great speed of the hand (if the resistance is not too great). Very little shortening of the muscles produces a large movement of the hand. This is known as having a physiological advantage, which is very important in speed and quick movements.

Newton's Laws of Motion

Inertia



Inertia is based on Newton's first law of motion. There are two types of inertia: resting and moving. Resting inertia indicates that when an object is at rest it tends to remain at rest unless acted upon by some outside force. A loaded barbell or a dumbbell lying on the ground has resting inertia. In order to lift it you must apply a force greater than the weight of the implement to move it.

Moving inertia simply means that when an object is in motion it will remain in motion unless acted upon by some outside force. Once you put a barbell or dumbbell into motion it will continue on its own accord without additional application of force to keep it moving. This can easily be seen with lighter weights.

For example, when doing lateral arm raises with straight arms and light weights you will experience the weights "flying" upward without effort if you apply a vigorous thrust in the bottom position. In all cases, gravity pulls to slow down movement. The weights also continue to move more freely in horizontal actions when gravity is not directly opposite the force being applied as it is in vertical lifts.

When you use heavy weights in a strength exercise, the movement is slow in an upward movement. This requires you to apply force through the entire ROM to keep the weights in motion. Although the heavy weights are moving, they will quickly stop because of the constant force of gravity pulling down. It is the force that creates the slow speed. However, if the weight gets moving too fast (for example, when you "throw" a heavy weight such as a medicine ball), it may require great force to stop it at the end of the range of motion. If your muscles are not capable of generating this stopping force, injuries can occur if you do not release the weight. The role of the eccentric contraction is especially important here.

When you are lifting a weight, the further away the mass of the weight (barbell, dumbbell etc.), the greater is the inertia, especially on the return. This means that when the weight is far from the body and moving, it is more difficult to control regardless if it is moving up or down. It is especially difficult on the down movement when gravity pulls.

Because of this you should always position yourself as close as possible to the weight you are lifting. The closer the weight, the easier it becomes to control because there is less lateral rotational inertia. The further away the mass, as in straight arm front or lateral arm raises, the more difficult it is to move the weights -- especially when heavy, will with control.

Note also that with straight arms you can use a lighter weight and it will feel the same as a heavy weight held at half the distance. It is because of this that most bodybuilders bend the elbows to bring the weights in closer to the body. It also allows them to use more weight.

However, it is important to understand that when you bend the elbows you may be putting the arms in a different position, which will change the muscular involvement. This can be seen in the front arm raise when you bend the arms so that the elbows may be out at approximately a 45-degree angle. As a result you will be doing a combination of front and lateral arm raises rather than pure front arm raises. This also changes muscular development.

The use of heavy weights is not always best for precise strength development. By using a long lever arm to create greater rotational inertia, you can create great resistance with light weights. Also very important to consider is that the stress on the spine is considerably less when lighter weights are used. This is especially important for beginners.

Relationships Between Force, Mass, Acceleration

Newton's second law of motion deals with force and its relationship to mass and acceleration. In essence, in order to create a force you must place a mass into motion with acceleration, i.e., a change in velocity. Note that mass multiplied by velocity is known as momentum. Thus, in the example above, when a weight (mass) is moving (has velocity) it has momentum.

Momentum is seen in many exercise machines that use weight stacks attached to a cable. When you do the exercise you must adjust the speed of your movement to how fast the weights move up and down. If you move the resistance levers at a very fast rate the weight stack will continue to move when you stop. Thus at times the weight may be going up when it should be going down or vice versa. When this happens the cables may bind or snap off the pulley. To do an exercise fast, you must use machines that allow for fast movements. If they are not available then you must use free weights, medicine balls or tubing such as the Active Cords set.

A key point to keep in mind is that when a force is generated by the muscle, there will be acceleration of the weight. In other words, the speed of the object must be increasing to be a true force. When first starting an exercise you must generate force. When the weight is stationary and you begin movement, you accelerate the weight; however, once the weight is in motion then it only has velocity. You are no longer creating force unless you are changing the speed of the object.

You must, in essence, place the weight into acceleration to get it moving. Once the weights are in motion, they have momentum. For some reason, acceleration and momentum of a weight have become unacceptable to many trainers. They consider that acceleration and momentum are dangerous and should be avoided at all costs. In such cases it appears that they have not analyzed the exercises that they and others typically do.

Rather than avoiding acceleration and momentum, you should understand what is taking place and prepare the body to handle the forces that are encountered. Force, acceleration, and momentum are your allies, not your enemy. The key is to learn how to make best use of them.

If a force is maximal or if a weight is accelerated at a maximal speed, then you must release it in a throwing or pushing action because it will be impossible for the muscles of the body to stop the weight or the limb from continuing its movement. The heavier the weight and/or the greater the acceleration of the weight, the more difficult it is to stop it. It is because of this that most strength exercises are done at a slow to moderate rate of speed.

Note that even light weights can generate tremendous force when they are accelerated as in some aerobic routines. A five pound weight on extended arms moving rapidly generates a tremendous amount of force that must be stopped by the eccentric contraction of the antagonist muscles. If they are not sufficiently strong to stop the movement, an injury may ensue.

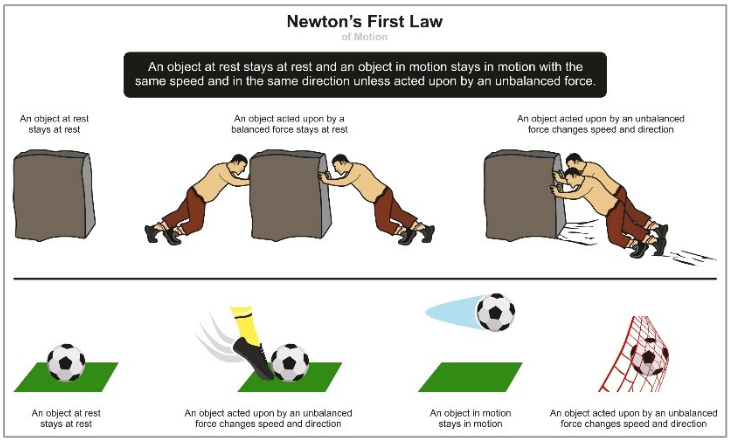
In general, you can increase speed of execution in some exercises, usually at the beginning of the movement, so that momentum will carry the weight through the remaining range before there is damage to the joints. But having a strong eccentric contraction of the antagonistic muscles is most often needed to stop the movement.

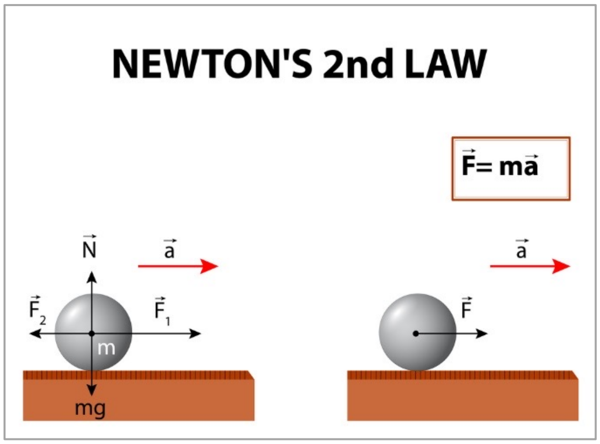
In addition to creating force to move a weight against the pull of gravity, it is also necessary to create a force to counteract gravity, the major force pulling the weight down. Your muscles contract eccentrically to generate the force needed to control the downward movement of the weight. Keep in mind that gravity causes a weight to go into motion at increasingly greater rates of speed; it pulls with a force of 32.2 feet per second *per second*! Thus for every second of downward fall, a weight gains much greater speed.

It is for this reason that care must be taken when handling weights, especially heavy weights. If they drop from a high height the amount of force upon landing can be extremely high. Even the height of a few feet can cause a weight to have a force of several times its actual weight. Because of the acceleration produced by gravity, you must always control the weights on the (negative) return with the eccentric contraction.

Equal and Opposite Reactions

Newton's third law of motion, known as the equal and opposite reaction principle, applies to weightlifting and bodybuilding exercises. When doing an exercise such as the push-up, you must push against the floor with your hands. The floor, in turn, pushes against you, and as a result, you raise the trunk. This is known as reactive force. The same concept applies when jumping. When you land on the ground you apply a force against the ground and it, in turn, applies an equal and opposite force against you to propel you into the air.





Work

The actual amount of work that you do is measured by the formula W = F x D, where W = work, F = force, and D = distance or displacement of the object being moved. The greater the force and the greater the distance over which the force is applied (the weight is moved), the more work you do.

When you hold a weight in the hands with an isometric contraction, even though the muscles are generating great tension and you may use a lot of energy to hold the position, you are not doing any work because you are not moving the weight. For work to be done, there must be movement. If not, you are only expending energy, which is not work. Energy is more physiological whereas work is more mechanical.

Power

Power is often a misused term in the fitness and sports literature. It is usually equated to the amount of force one generates, but this is only partially correct. In physics and in sports, power is defined as the work done in a unit of time. To calculate, you must take into consideration the time involved in executing the movement, i.e., how much work was done per unit of time.

For example, if you do a squat with a 300-pound barbell and you move the barbell three feet from the bottom position to the top position, you will have done 900 foot-pounds of work. (W= 300 lb. x 3 feet = 900 ft. lb.) In reality, you actually lifted more, but for simplicity, your body weight and external factors are not taken into consideration.

To calculate power, the same example can be used taking into consideration the amount of time it took to lift the weight three feet. Let's say it took 3 seconds to rise up out of the squat. Therefore 900 foot pounds of work divided by 3 seconds equals 300 foot-pounds of work per second. If you executed the squat in approximately two seconds, then the amount of power generated would be 450 foot pounds per second. Thus you can see how the amount of power generated depends very much on the amount of time it takes to accomplish the work. The faster you execute the movement (the work), the greater the amount of power. The slower the work is done, the less the power.

Much confusion has arisen in this area because of powerlifting. In this sport maximal weights are lifted slowly; because of this it should be considered a pure strength sport. The amount of power is not great in comparison to a weightlifter who lifts maximal weights but moves as quickly as possible. The weightlifter exhibits much greater power than a powerlifter. But the powerlifter exhibits greater strength than the weightlifter.

Levers

All exercises involve levers created by the body limbs or body itself. The potential force of the levers is created by the length of the limbs and/or body and where the resistance and muscular force is applied. There are three major classes of levers in the body: first, second and third.

First Class

The first class lever is similar to the see-saw in that it has its fulcrum or balance point between the force and the resistance. When you sit on one end you apply a downward resistance on one side of the fulcrum. To raise yourself, a downward force must be applied on the other side.

For example, if someone else sits on the opposite side another downward resistance is brought into play. If the weights are equal and the distance from the fulcrum is equal, you will be in balance with no movement occurring. In order to get movement, you will have to make your body “heavier” by creating more force or some momentum to place the see-saw into motion.

The most common exercise that uses the first class lever is the heel raise. The axis is in the middle of the ankle joint while the force is the pull of the Achilles tendon behind it and the resistance is against the ball of the foot in front. In this case the first class lever does not produce a great amount of force. It is best suited for a maximum range of motion and speed of movement.

Second Class

The second class lever is one in which the weight (resistance) is distributed between the axis of rotation and the application of force. It is most suited for a gain in force and is easily visualized by imagining a wheelbarrow. The axis is the wheel, the weight is in the bucket located in the middle and the force is your arms pulling the handles upward.

The best weight training exercise to describe this lever is the push-up. In this case the axis is the balls of the feet in contact with the floor, the weight is the center of gravity of your mass, and the force is in the arms, pushing you upward.

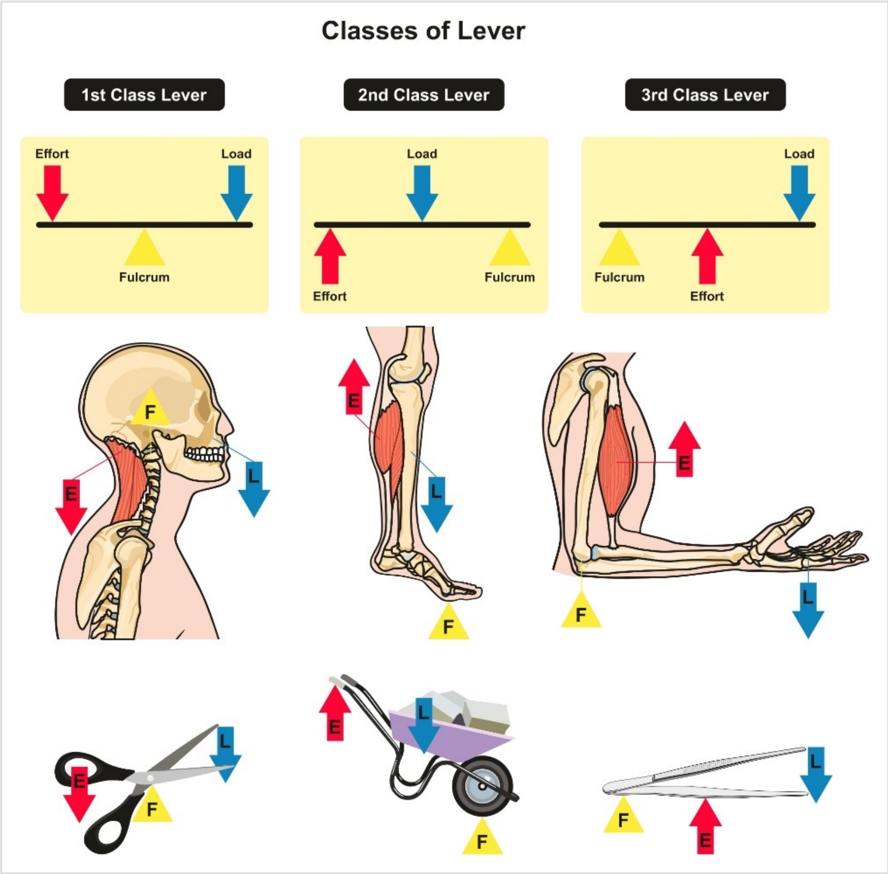
Third Class

In the third class lever the force is applied between the axis and the resistance. This is the most common type of lever found in the body. For example, in the biceps curl, the biceps inserts approximately one inch below the elbow joint. The point of attachment is known as the point of application of force. The elbow is the axis of rotation, the resistance is the forearm, and the weights held in the hand.

Thus the distance from the point of application of force to the axis is very short (the force arm) and mechanically inefficient. The key reason for this is that the resistance arm, the distance from the axis to where the weight is located, is quite long. This places the weight far from the application of force.

A short force arm and a long resistance arm is most advantageous for speed, not for the production of force. In the case of speed, a short contraction of the muscle can move the end of the limb (hand) a great distance even though there is very little movement at the actual insertion of the muscle on the bone. This relationship is also advantageous for ROM.

The speed advantage of the third class lever system is most important in sports, not when lifting weights. Individuals with short limbs have an advantage in lifting heavier weights because of their shorter resistance arms. There are, however, exceptions to this; in the deadlift for example, longer arms allow you to raise the weight less distance.



Wheel and Axle

Wheel and axle-like arrangements in the body are needed for the transmission of force. A good illustration of this is shoulder joint medial and lateral rotation. For example, hold the upper arms in line with the shoulders, elbows bent 90 degrees, and the forearms vertical and holding a weight in the hands. Lower the forearm downward behind the head, maintaining the 90-degree angle (or greater) in the elbow to execute lateral rotation with the axis along the long shaft of the humerus.

When you raise the hand in the opposite action you execute medial rotation in which the humerus rotates in the opposite direction (forward) on its long axis. In this case, there is a short radius of rotation of the humerus, but with the forearm bent at a 90-degree angle you generate considerable speed or force at the end of the forearm (the hand).

Many strength exercises involve some rotation of the arms (or legs). To prevent injury to the muscles involved especially when executing medial and lateral rotation, you should not execute other actions in the same joint at the same time. This is often difficult to see but it typically happens quite naturally.

Pulley Systems

Another muscular-structural arrangement in the body is the pulley. Pulleys are very common in exercise machines such as in the lat pull-down to create a greater mechanical advantage and to move the limbs freely. In the body we find a pulley type system in the knee joint, more specifically, with the patella. The quadriceps tendon (ligament) goes over the patella to insert on the tibia bone in the shin.

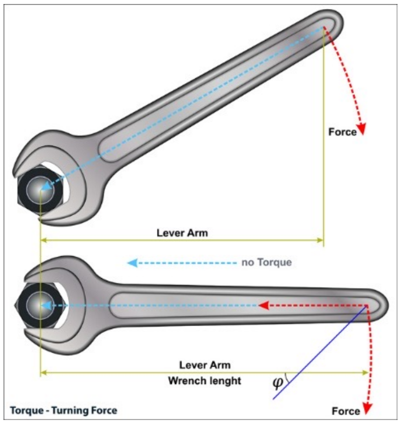
Because of the patella protrusion, the quadriceps tendon inserts at a greater angle to create more of a straight-line force when the knee is in the bent position. As a result, you generate greater force which goes around the patella to change the direction of pull. There are few such pulley type muscle arrangements in the body.

Most pulley (cable) systems (free weight machines) create the ability to guide and move the resistance handles in various directions, especially the free motion systems. Depending upon the configuration of the pulley or pulleys you can increase or decrease the amount of effective resistance. Some pulley machines even have an extremely strong negative component.

After you execute the lift in an exercise, the weight stack is raised. At this time the amount of force involved in lowering the weights can be extremely high. Thus care must be taken on different exercise machines. To prevent an injury you should become familiar with the exercise machine before using appreciable weight.

Torque

The concept of torque is important in understanding how force is produced in weight training exercises. Its definition is simple: it is the magnitude of twist around an axis of rotation. Thus torque (twist) is rotary (angular) movement in any plane about an axis. Torque is seen in almost all movements of the body as, for example, when you do single joint actions.



In isolated movements the axis of rotation is fixed so that the bony lever moves in an arc of a circle. For example, in knee joint extension the foot circumscribes an arc of a circle because it is moving on an angular pathway. When you twist the shoulders they rotate around a stationary vertical axis (for example, the spine), and you make an arc of a circle when viewed from above.

When torque is produced, the force is applied at some distance away from the axis of rotation. For example, picture driving a car and turning the steering wheel. The hand applies a force on the wheel (rim) with the axis in the center of the steering column. This is known as an off-center force or, more accurately, an eccentric force. But the rotating or turning force is called torque.

It should also be noted that the axis of rotation can also be in motion. This is sometimes needed for safety. For example, in the seated leg extension exercise in which your thigh is immobile, the forces generated in the knee joint are extremely high when you straighten the leg. Because of this, this exercise has been negatively criticized as being potentially dangerous.

To rectify this situation I developed an exercise with tubing, using the Active Cords set, in which you assume a standing position and hold the thigh up at approximately 45-60 degrees. You then straighten the leg against the resistance of the cords. In this action the thigh moves slightly as the leg is extended, and, as a result, the axis is in motion. The thigh acts a safety valve which helps to decrease the negative forces, making the movement more natural, especially for sports such as running.

Pushing

In some compound (multi-joint) exercises, rather than using only a rotary component to move the weight, you use a push pattern in which the hands or feet move in a straight line as a result of two or more rotary actions. This pushing action is seen in exercises such as the leg press, overhead press, dips and push-up. To move the extremity or body part in a straight line, you must involve more than one joint action. For example, in the leg press there are simultaneous rotary actions at the knee (extension) and hip (extension) joints to move the feet in a straight line. In the military overhead press the shoulder joints undergo flexion (elbows are in front) or abduction (elbows out to the side) as the elbow joints undergo extension. The hands then move in a straight line upward.

Pulling

Pulling is the opposite of pushing. The hands or feet move in a straight line while two or more joints are in rotary action. For example, in the seated row, the body is stable while the hands move in a straight line as you pull them in toward the body. Extension in the shoulder joint, along with flexion in the elbow joint, occurs simultaneously to allow the hands to move in a straight line.

The same occurs when doing a chin-up or pull-up. The body in this case moves in a straight line upward, the hands remain in place, and there is flexion in the elbow joint together with extension (supinated grip) or adduction (pronated grip) in the shoulder joint.

Gravity

Gravity is the downward pulling force that creates resistance. Because of this, when using free weights it is important that you adjust your body position so that the weight that you are handling is moving as much as possible directly against the pull of gravity for maximum resistance.

For example, in the triceps kickback, only when your arm is almost fully extended does the triceps work fully against gravity in the upward phase of movement. When the forearm is vertical there is very little resistance to overcome because the weight moves more horizontally as the forearm rotates upward. The resistance increases as the arm straightens because you are now working more against the pull of gravity.

To make the triceps kickback most effective, the body should be horizontal so that the ending ROM is against gravity. Since the triceps is also involved in shoulder extension, you should then raise the straight arm upward above the level of the back. This makes the movement much more difficult since you now have a long lever when raising the dumbbell against the pull of gravity. This action is totally against gravity and you will find that is more difficult than all the preceding movements.

Center of Gravity and Line of Gravity

Center of gravity is referred to as the point in the body around which your weight is equally distributed. It is considered to be the point where all your weight is concentrated (balanced). Usually this point is located in the hips but it can also fall outside the body, as for example, when your body is rotating in space in a pike position. When you drop a vertical line straight down from the center of gravity it is known as the line of gravity. It should fall within your base of support formed by an outline (circle) around your feet in order for you to be in balance. If it falls outside the base of support, you will be in motion, i.e., falling. When doing strength exercises, it is critical that the line of gravity fall within your base of support in order for you to remain in balance.

Kinesthesis

Kinesthesis is the ability to perceive your position and movement of the body and/or limbs in space. Kinesthesis relies on the use of various receptors in the joints, muscles and tendons. For example, the muscle spindle that lies in parallel with the muscle fibers is activated when the muscle is stretched during an eccentric contraction (This is known as the stretch reflex).

The Golgi tendon organs are other receptors located at the junction of the tendon and the muscle. They respond to the amount of stretch taking place in the tendon and the muscle. It is important to understand that when a muscle stretches, the tendon also undergoes stretching. It is very elastic tissue and can withstand great tension.

When activated, the Golgi tendon organs trigger the antagonistic muscle groups to stop the movement and to inhibit the agonist muscle contraction. This is done to avoid possible injury to the muscle-tendon complex. Because of their actions, it is much easier to fully stretch a muscle when the Golgi tendon organs are shut down. There are also receptors located in the joint capsules and in the ligaments that relay information to the brain. This includes a change in position, speed of movement, or the acceleration of the limbs that occur at the joints.

These receptors are very sensitive and fire when there is a small change (up to two degrees) in joint position. There are also many pressure receptors that are very active in posture. When there is any deviation in position, they are fired so that a correction can be made to bring you back into the normal position.

Vision

Related to kinesthesis is the use of visual reference points or visual cues when doing exercises. For example, focusing on a particular object during an exercise enables you to better balance your body and to keep yourself oriented to your surroundings. To verify this, merely try doing an exercise with your eyes shut and you will see how difficult it is to control your movements.

The visual cue must be such that it does not change the position of your head, which also relates to the balance mechanisms in your ears. For example, many weight trainees look up at the ceiling when doing a squat in order to maintain an arch in the lower back. In so doing they have difficulty orienting their body. More effective is to have stronger back muscles to maintain an arched position and to look directly ahead when doing the exercise. You can then maintain the arch more easily and yet have good balance. The same concept holds true for other exercises that require holding an arch in the lower back.

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