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Getting Some Leverage

Paying attention to simple mechanics can help great coaches improve technique and get better results in the CrossFit box.

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The human body is a complex system of levers that enables us to perform everything from very basic to extremely complex movements. Individually, levers are simple machines, and we can think of the body as a collection of machines. Bones are the rigid frame part of the lever machine through which force is transferred. The joints of the body provide

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the axes around which rotation occurs. The muscles generate the force (or tension) needed to cause overt movement. An intermediary and important structure here is the tendon. Because force produced by a muscle is transmitted to the bone via tendon, tendons are crucial to human movement.

Levers and Lifting Weights

In the human body, all three possible types of lever are represented anatomically (this is arguable, as one type requires special circumstances to be present; see *Gray's Anatomy* reference below). When classifying levers we need to consider the following entities to assess a lever system by type:

- The point of force application (F)—the site of muscle attachment and action.
- The point of resistance application (R)—the site of the load to be moved.
- The fulcrum or axis of rotation (A)—the joint to be flexed or extended.

When these three entities are laid out linearly, the space between the point of resistance application and the axis (fulcrum) is called the resistance arm. Similarly, the space between the point of force application and the axis is called the force arm.

If we introduce inappropriate lever configurations or inadvertently create extra lever arms, we create poor technique, poor force transference and poor fitness results.

It may not be immediately apparent why any of this really matters—but it does. The squat, for example, is accomplished by a collection of levers, and something as simple as placing the bar high on the traps or low across the scapular spines alters moment arms and joint angles. Subtle changes in the system alter the nature of the forces generated and experienced by the body and therefore affect, for good or bad, the nature of adaptation the exercise will produce. If we introduce inappropriate lever configurations or inadvertently create extra lever arms, we create poor technique, poor force transference and poor fitness results. We have to learn how to recognize levers in order to be able to reinforce good technique and eliminate bad.

First-Class Levers

First-class levers are the most efficient and probably the most identifiable: they look like a teeter-totter (Figure 1). In fact, the use of this type lever is extremely well documented throughout human history, and in 200 B.C. Archimedes famously said, "Give me a place to stand and a lever long enough and I will move the world."

With a first-class lever, the axis or fulcrum always lies between the force and resistance (F-A-R). A first-class lever can perform all four basic machine functions: (1) balance forces, (2) change direction of the force applied, (3) modify (increase/amplify) the force applied, and (4) modify the speed and/or range of motion.

This is a good point to introduce the concept of mechanical advantage. Think of a teeter-totter, exactly 10 feet long end-to-end, with the fulcrum at dead center and a 50-lb. kid on each end. What will happen if they just sit there? Right. Nothing. The forces are balanced, and without a little leg push from one of the kids no one goes up or down. Now think about when you were a kid and how hard you had to push to go up. Not very hard. That's the lever system giving you a little advantage. Putting this into an anatomical perspective, the same situation is present where the skull sits atop the cervical vertebrae. How hard do you have to work to tilt your head from side to side or from front to back?

What happens if you move the teeter-totter's fulcrum to a point where one arm is 4 feet long and the other is 6 feet long? Which side has an advantage? Well, if you draw the short arm, you are only along for the ride. The moment around the axis of rotation (fulcrum) is a product of the force applied and the distance from the force to the axis.

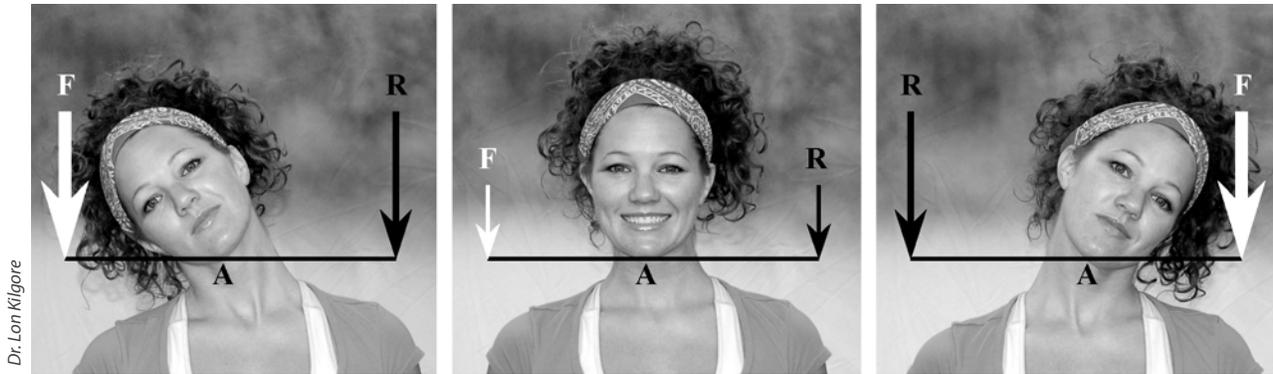


Figure 1: An example of a first-class lever causing a lateral tilt of the head (anterior view). Force = neck-muscle contraction, Axis = atlas vertebrae, and Resistance = weight of head. The size of the arrow indicates the relative magnitude of muscular force exerted.

Simple math tells us that the shorter arm is at a disadvantage. That means the kid on the long arm can keep the kid on the short arm up in the air as long as he wants. It also means that to balance the force to where the asymmetric teeter-totter works as desired, a heavier kid needs to be on the short arm.

Second-Class Levers

With a second-class lever, the resistance is in the middle, between the axis and fulcrum (F-R-A). The most easily identified example of this class of lever is the wheelbarrow. In this arrangement the force arm is always longer than the resistance arm, and this favors force production. Henry Gray, writing in the Myology Section of *Gray's Anatomy*, said there are no second-class levers occurring in the body. In an unweighted human producing unresisted joint movement in the lab, this is true. However, in sport and exercise we can find several examples of the body as a whole acting as a second-class lever. An easy example is the push-up (Figure 2).

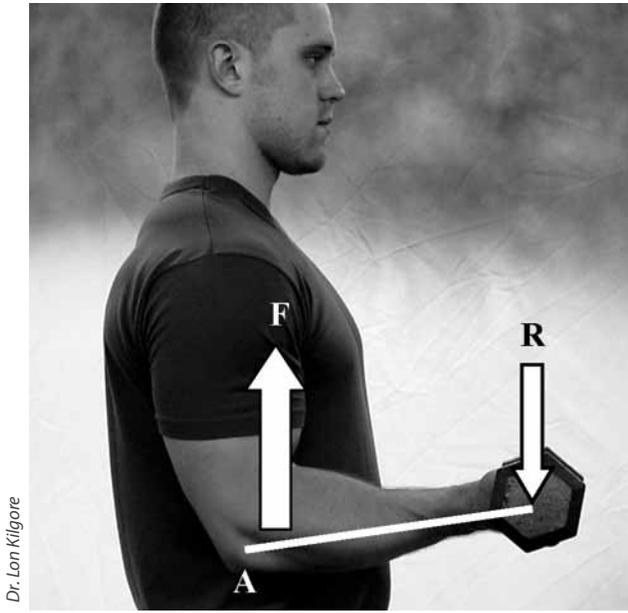
Third-Class Levers

The third-class lever is the most common type of lever in the human body. With this class of lever, the force applied is in the middle, between the resistance and the axis of rotation (R-F-A). In this lever arrangement, the resistance arm is always longer than the force arm. The easiest and most recognizable such lever in the human body may be the biceps and elbow (Figure 3). Think of the resistance being in the hand and the elbow as the axis. The force applied to flex the elbow, although produced in the upper arm, is applied to the system between the elbow and hand.



Figure 2: An example of a second-class lever in exercise is the push-up, where the body is pushed up by the upper-body musculature as it rotates around the ball of the foot on the floor. Force = arm-muscle contraction, Resistance = body weight, Axis = ball of the foot.

This system provides a good reason to know where muscles attach at both ends because that knowledge will aid in understanding physically how muscles work. Human-implement interactions also provide examples of third-class levers. A baseball bat is a good example of a third-class lever. The spatial arrangement of lever elements in this class results in a mechanical advantage biased towards increased range of motion and increased velocity of movement.



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Figure 3: *One of the exercises of modernity associated with the artificial cultural concept of masculinity is the biceps curl, an example of a third-class lever. Force = biceps contraction, Resistance = weight placed in hand, and Axis = elbow.*

Controlling Levers for Best Results

While we can classify individual muscles acting on a single joint as a specific lever type, things are rarely so cut and dried. The human body revels in compound movements, meaning that multiple joints and muscles are simultaneously in action. When considering functional anatomy, it is important to carefully consider contributing muscles and joints when doing an analysis of a movement.

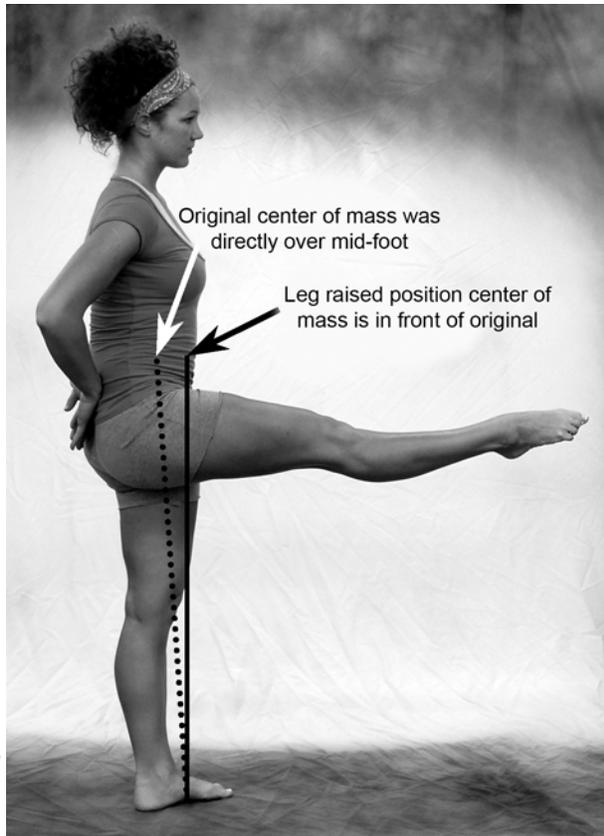
During exercises, we want to use the levers of the body to produce movement of body segments or the entire body while maintaining control of the body so it does not perform extra work.

An example is that many people think of the squat as a quadriceps exercise, and thus they consider only the action of the knee joint. It is much more relevant to also consider the hip joint because this joint contributes greatly to the movement. The musculature involved in the squat is not just the quadriceps; the hamstrings and gluteus muscles are also greatly involved. This means a simple movement, squatting, is composed of multiple lever systems, multiple muscles and multiple joints. Simple observation reveals this, and later we will find out how to easily approach such an analysis.

During exercises, we want to use the levers of the body to produce movement of body segments or the entire body while maintaining control of the body so it does not perform extra work. Essentially, we do not want to create any unnecessary lever arms that introduce movement inefficiency (bad technique).

How do we create unnecessary lever arms and how do we know if we have done so? In answering, let's first consider the concepts of center of balance and center of gravity. Center of balance can be described as the point where the body contacts the ground and above which the body's mass is balanced. The center of balance is quite plastic, constantly changing as we unconsciously exert muscular effort to keep our balance and not fall over—even when we are standing still. If we are standing on both feet, the center of balance will occur somewhere on the soles of the feet (both of them), usually between the calcaneus (heel bone) and the ball of the foot (metatarsals).

Center of gravity (sometimes referred to as center of mass) is the point within the body where there is equal mass above, below, in front and in back (the intersection of the cardinal planes). The center of gravity can change, too, depending on the conformation of the body. Normal standing posture usually places the center of gravity an inch or so above and a couple of inches behind the navel. If we flex the hip and hold the foot at or above waist level to the front, the change in body-weight distribution induces a change in the position of center of gravity. In this case, the center point will no longer be above and behind the navel, it will have moved forward on the body. The point in the body that was once the center of gravity will now be behind the new center of gravity (Figure 4).



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Figure 4: Placing the body in different positions alters the location of the center of mass/gravity on or within the body. Mass moved forward requires a movement of another mass to the rear in order to keep the center of mass/gravity over the mid-foot to maintain balance.

If we add an additional element, an external load for example, this will change the effective center of gravity of the body to include the mass of the load. A load supported above the head moves the center of gravity upward. A load held low moves it downward. The larger the load, the larger the deviation of the center of mass from its unloaded location.

When we do standing exercises, we need to control the center of mass and keep it within the boundaries of support identified by our footprints. What happens when you stand at attention then lean back? As you lean back your center of gravity moves back and thus moves the center of balance back toward the heel. If no balance corrections are made and the center of gravity moves behind the

most posterior aspect of your support structure, then you fall backwards. The opposite, a fall forward, occurs if the center of gravity is allowed to move forward beyond the most anterior support structures, the toes (Figure 5).

Luckily, falling over from such occurrences does not occur with any frequency in humans because we have wonderful little reflexes that prevent it. If our center of balance is sensed to be too far back, then a nuanced series of muscle contractions brings the skeletal system back in line. In the case of the backward lean, muscles try to bring the knee back over the ankle, the hip over the knee, the shoulders over the hips, and it all occurs in a fairly imperceptible manner. In more unbalanced situations the arms may get pulled forward and the head may get rolled forward over the toes for a larger correction. What has occurred here is that the lean backward (or forward or sideways) has induced a lever arm that has produced a moment against which we have to produce force in order to balance the system. The fewer and smaller corrections we have to make, the better and the more efficient we are.

Lever Arms and Bad Technique

When we are doing stationary standing exercises, the most efficient technique is one that keeps the center of gravity directly over mid-foot. If you can move loads in as close to a straight line as possible and as close to the line between the center of balance and the point of load application, you will be moving efficiently. You will not have induced any extraneous lever arms that require additional work—movement that does not contribute directly to the completion of the movement.

When we do dynamic movements, such as simple walking, things are a bit more complex. Walking has been described as a controlled loss of balance forward. When we want to walk forward, we recruit a set of muscles that propel our center of gravity forward beyond the anterior support capability of the trailing foot. But instead of falling over, the heel of the lead foot picks up the load. More muscular activity moves the center of gravity forward, and the center of balance moves from heel to toe then beyond, and the cycle repeats.

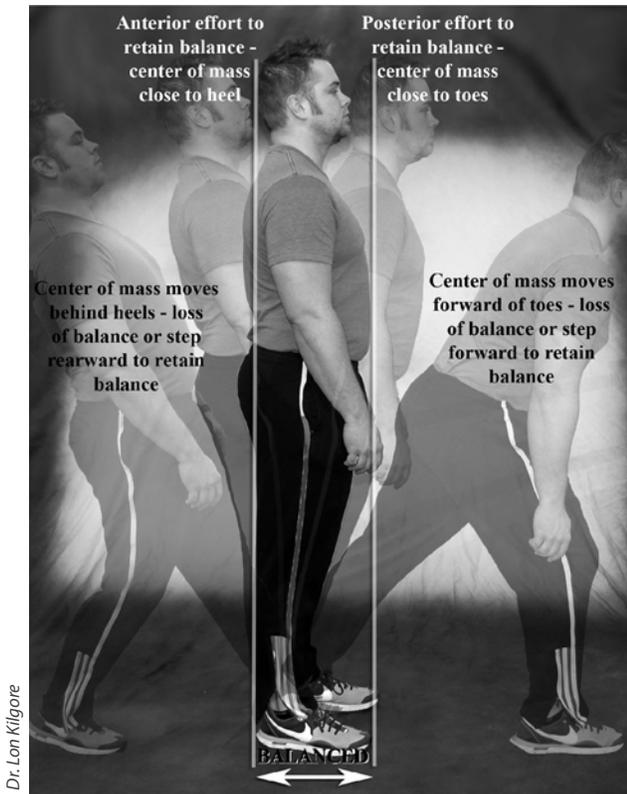


Figure 5: Deviations of the center of mass/gravity within the body's active support structures can be corrected with muscular activity. When the center of gravity cannot fall within an anatomically defined center of balance, large-scale corrective movements must occur (step forward or step back, for example). If the center of gravity moves backward, anterior muscles such as the tibialis anterior, rectus abdominis, and iliopsoas contract to pull the body and center of gravity forward into balance. If the center of gravity moves forward, posterior muscles like the gastrocnemius, gluteals and erector spinae contract to pull the body backward into balance.

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Anatomically we are dealt a fairly static hand when it comes to levers: we are built the way we are. We can't train to change the location where muscles attach to bones in order to improve mechanical advantage, but we can teach efficient technique. To do this, we must carefully observe our trainees routinely in order to identify lever arms that are erroneously introduced into the exercises we teach them. Once identified, we then need to practice the art of coaching to get rid of them. To do so accomplishes two purposes: (1) better performance leading to faster fitness gains and (2) safer exercise sessions. Accomplish these two things and we all win.



About the Author

Lon Kilgore is a professor at Midwestern State University, where he teaches applied physiology and anatomy. He has also held faculty appointments at Kansas State University and Warnborough University (IE). He graduated from Lincoln University with a bachelor of science in biology and earned a Ph.D. in anatomy and physiology from Kansas State University. He has competed in weightlifting to the national level since 1972 and coached his first athletes to national championship event medals in 1974.



He has worked in the trenches, as a coach or scientific consultant, with athletes from rank novices to professionals and the Olympic elite, and as a collegiate strength coach. He has been a certifying instructor for U.S.A. Weightlifting for more than a decade and a frequent lecturer at events at the U.S. Olympic Training Center. His illustration and authorship efforts include books, magazine columns and research journal publications.