The Study of Human Movement by the Application of Biomechanical Muscular Skeletal Leverage Physics: Understanding the Effective Lever Arm.

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Muscular skeletal leverage physics produces reliable and useful results concerning the reconstruction of the muscular skeletal system's performance in physical events. The definition of biomechanics as interpreted by Jim Hays, Iowa State, 1963 employs the study of muscular skeletal leverage physics. His abridged definition includes "The forces acting upon the muscular skeletal system, produced by the muscular skeletal system and then impacting within the muscular skeletal system".

From lifting a weight, to packing a 120 lb. sack of grain on your back, biomechanical leverage physics reveals the amount of muscle effort required at the joint and which joint tissue is used and to what degree to support the combined force of the weight and muscle. The 120 lb. study of the spine was first done by Giovanni Alfonso Borelli in 1660 (*De Motu Animalium*). He demonstrated there were over 25,000 lbs. of force produced by and stabilized by the muscles and joints of the spine in this event. Today, Borelli is known as the Father of Biomechanics. The American Society of Biomechanics recognizes the greatest achievement in biomechanics each year by giving an award named after him (http://www.asb-biomech.org/converence03/awards03.html).

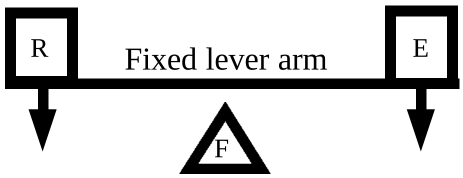
This mathematically based technology can potentially produce a broad spectrum of information for various specialties. In sports, it can be used as a predictor of athletic success. In forensic pathology, it can develop a roadmap of which tissues would be expected to be injured and to what degree. In physical anthropology, its application would lead investigators to know where to look for musculoskeletal stress markers when trying to determine evidence of human activity in physical tasks.

At the heart of studying the muscular skeletal leverage system is the necessity to understand the effective lever arm. The effective lever arm was first discovered and published by Benedetti in 1599 (De Mechanicis, Benedetti, G.B., Venetiis (Venice): Apud Baretium Baretium, & Socios, 1599.). For the first time in history, with this finding, this technology enabled man to truly

To fully appreciate Benedetti's discovery, we will begin by examining the muscular skeletal system functioning as a lever system in the act of producing leverage.

A simple lever system consists two opposing forces acting on a solid bar that would cause the solid bar to move about a fulcrum. "Solid" in this instance in the physics of leverage is known as fixed. The fixed (solid) portions of the lever system are known as the "fixed lever arms" of the lever system.

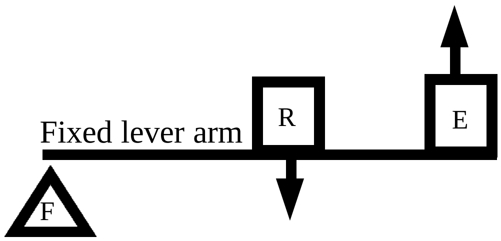
Example 1



Force R pulls down on the bar (fixed lever arm). This would cause the entire bar to rotate at F (the fulcrum) downward in the direction of the force.

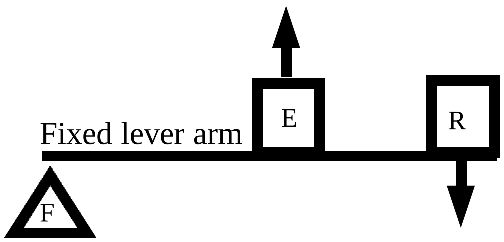
Force E opposes Force R and would cause the bar (fixed lever arm) to move downward on this side at the fulcrum.

Example 2



Force R would pull the bar (fixed lever arm) down causing it to rotate downward at the fulcrum (F). Force E would oppose Force R and would cause the bar (fixed lever arm) to move upward and rotate at the fulcrum upward.

Example 3



Force R would pull the bar (fixed lever arm) down causing it to rotate downward at the fulcrum (F). Force E would oppose Force R and would cause the bar (fixed lever arm) to move upward and rotate at the fulcrum upward.

In the human body the fixed lever arms (bars) are the bones. The fulcrum is formed by the joint. The two forces are created by weights that would move the bones around their mutual fulcrum. The weight can be supplied by an external mass (Force R) as in the weight of a barbell that would cause the fixed lever arm to rotate at the fulcrum. The weight (Force R) can also be supplied by an internal mass as in the weight of a body part as it would act on the fixed lever arm (bone) causing it to rotate at the fulcrum. Force E is the amount of weight a muscle produces on a fixed lever arm (bone) that would cause an opposing rotation to force R at the fulcrum.

Of these two opposing forces acting on the fixed lever system, one force is termed the force of resistance (Force R) and the other force is termed the force of effort (Force E). In the applied technology of leverage, Force R is typically identified as that force acting on the lever that does not possess variability. Force E that opposes Force R possesses variability, meaning its magnitude force can be manipulated by some intelligent means.

In the study of muscular skeletal leverage the external weight (barbell) or internal weight (body mass) would be termed the force of resistance (Force R). The force that the muscle can produce, because it can be intelligently and discriminately be increased or decreased and therefore possesses intelligent variability at the discretion of an intelligent source, is termed the force of effort (Force E).

The fixed lever arms will rotate around the fulcrum in the direction of the greater force.

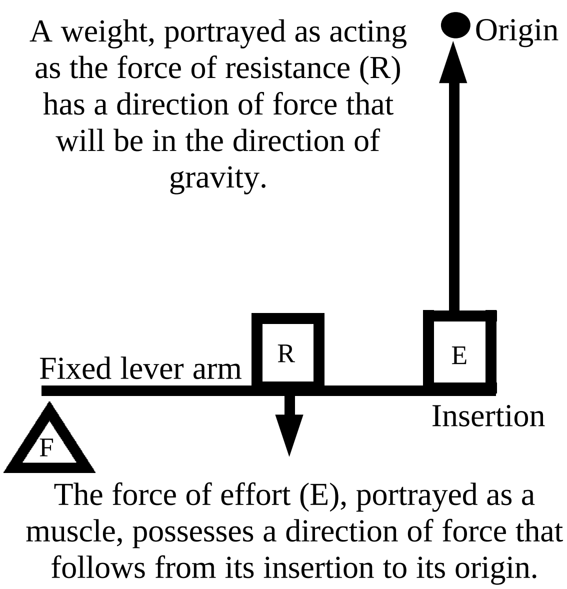
If the two forces are equal in their magnitude and there is no net movement by the fixed lever arms at the fulcrum, then the lever system is said to be stable or in equilibrium.
Equilibrium means that the two forces that would cause rotation of the fixed lever arm are equal and therefore there exists no rotation.

When studying lever physics, especially when applying the principles biomechanically, there are factors concerning the force of resistance and force of effort that one should be aware of. One of these factors concerns the typical consistency of direction of the direction of force by the resistance and the typical changing direction of force by the effort.

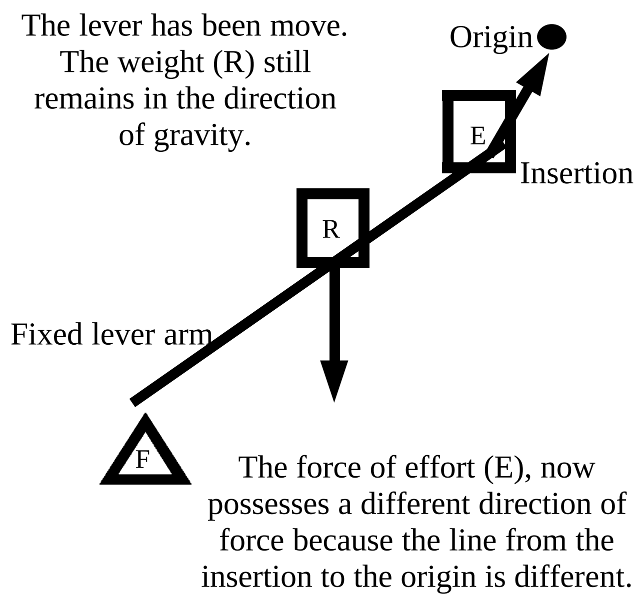
A force of resistance as it moves about the fulcrum will typically continually possess a direction of its force that is in the direction of gravity.

A muscle, producing a force of effort, as it moves about the fulcrum will possess a line of direction of its force that will follow from its insertion on the fixed lever arm back to its origin. Since the insertion and origin of a muscle is fixed, as the lever moves about the fulcrum (joint), the direction of force will typically be constantly changing.

Example



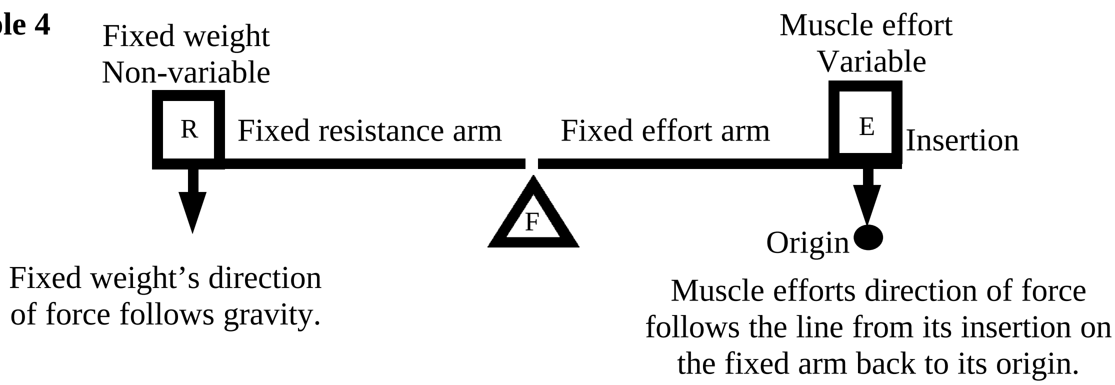
Example



The weight of the two forces is also only one of two factors that determines their ultimate magnitude in the lever system. The other factor is their relative distance from their point of application back to the fulcrum.

In a lever system, the point of application of Force E and Force R has historically been the actual physical point of contact of either force with their respective lever arms. These lever arms became known as the fixed effort arm and the fixed resistance arm respectively to Force E and Force R (see Example 4).

Example 4



Since Archimedes's time and into the present, academics continues to teach within the study of levers that the effective point of application of force (Force R and Force E) is determined to be the point at which the force of both the resistance and the effort lies on the fixed lever arms. The distance from the fulcrum to these points is length of the fixed effort arm and the fixed resistance arm.

In 200 BC, Archimedes went on to determine an equation to establish equilibrium within a lever system using the variables described above. His formula is known as the Equilibrium of Torque.

Equilibrium of Torque means when the effective force of the resistance and the effective force of the effort acting on the fixed lever arms are equal then there is no movement or torque, causing the fixed arms to rotate at the fulcrum.

The formula for equilibrium of torque is:

Weight of the resistance (Force R) x the length of the fixed resistance arm =
Weight of the effort (Force E) x the length of the fixed effort arm.

This equation is used to this day in modern lever analysis when determining lever Equilibrium of Torque.

In 1599, however, Giovanni Alfonso Benedetti, an Italian mathematician published his work wherein he proved that the distance at which the force of effort or resistance was applied to the fixed lever arm was not the distance that effectively determined the total magnitude of either forces impact on the lever system. He more precisely defined the resistance arm as the perpendicular distance from the line of pull (direction of force) of the resistance back to the fulcrum. He similarly defined the effort arm as the perpendicular distance from the line of pull (direction of force) of effort back to the fulcrum. These more elaborate explanations by Benedetti, have been overlooked and/or grossly misunderstood through the ages. What Benedetti discovered and defined were the *effective* lever arms.

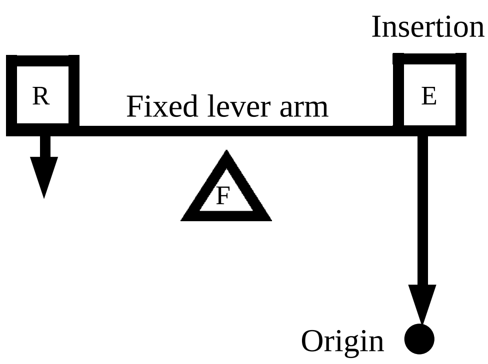
In the current teaching, Benedetti's effective effort arm or effective resistance arm occupies the same space as the fixed effort arm or fixed resistance arm respectively within the Equilibrium of Torque equation derived by Archimedes:

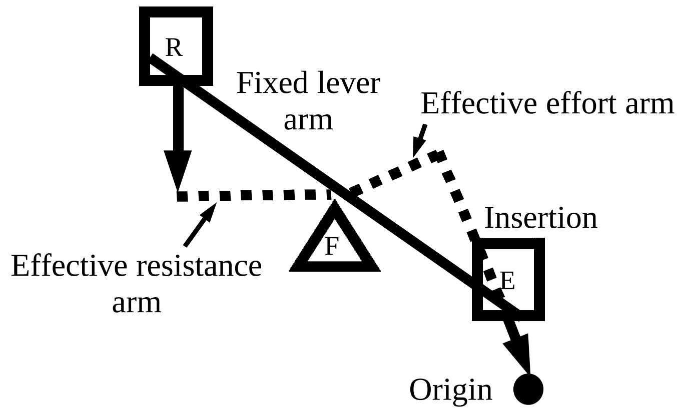
The weight of the resistance (Force R) x The length of the EFFECTIVE resistance arm = The weight of the effort (Force E) x The length of the EFFECTIVE effort arm.

Even though the lengths of each arm occupy the same place in the above equation. They do not always occupy the same space as the fixed resistance arm and fixed effort arm. Benedetti demonstrated that as the lever moves through a range of motion the fixed arms and effective arms do not occupy the same space.

Example shows a classic 1st class lever system with the fixed resistance arm and the fixed effort arm superimposed with the effective resistance arm and the effective effort arm.

Example



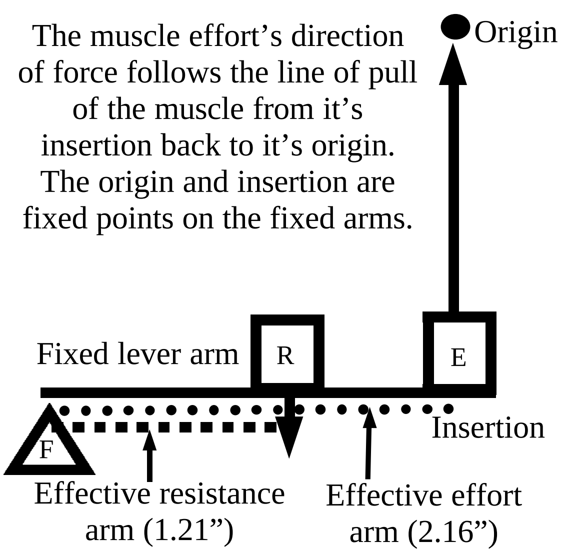


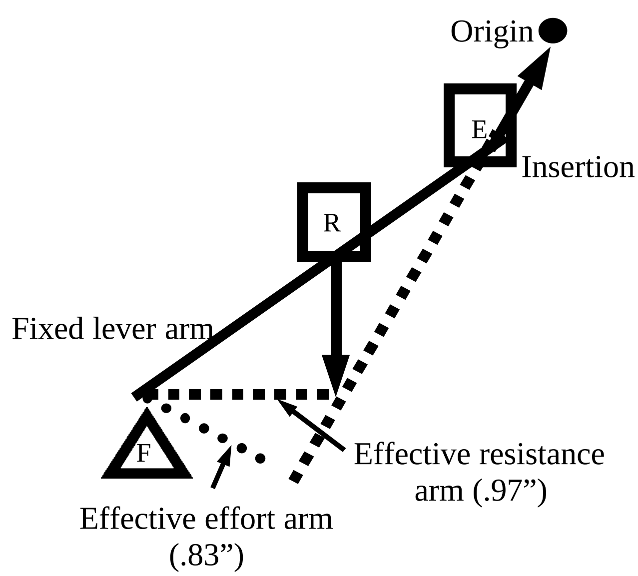
In the first example, the effective arms and the fixed arms are superimposed.

As the lever is moved through a range of motion, the fixed arms and effective arms become different entities.

Now we will demonstrate with 2nd and 3rd class lever as they move though a range of motion how the effective lever arms differentiate from the fixed lever arms.

2nd Class Lever



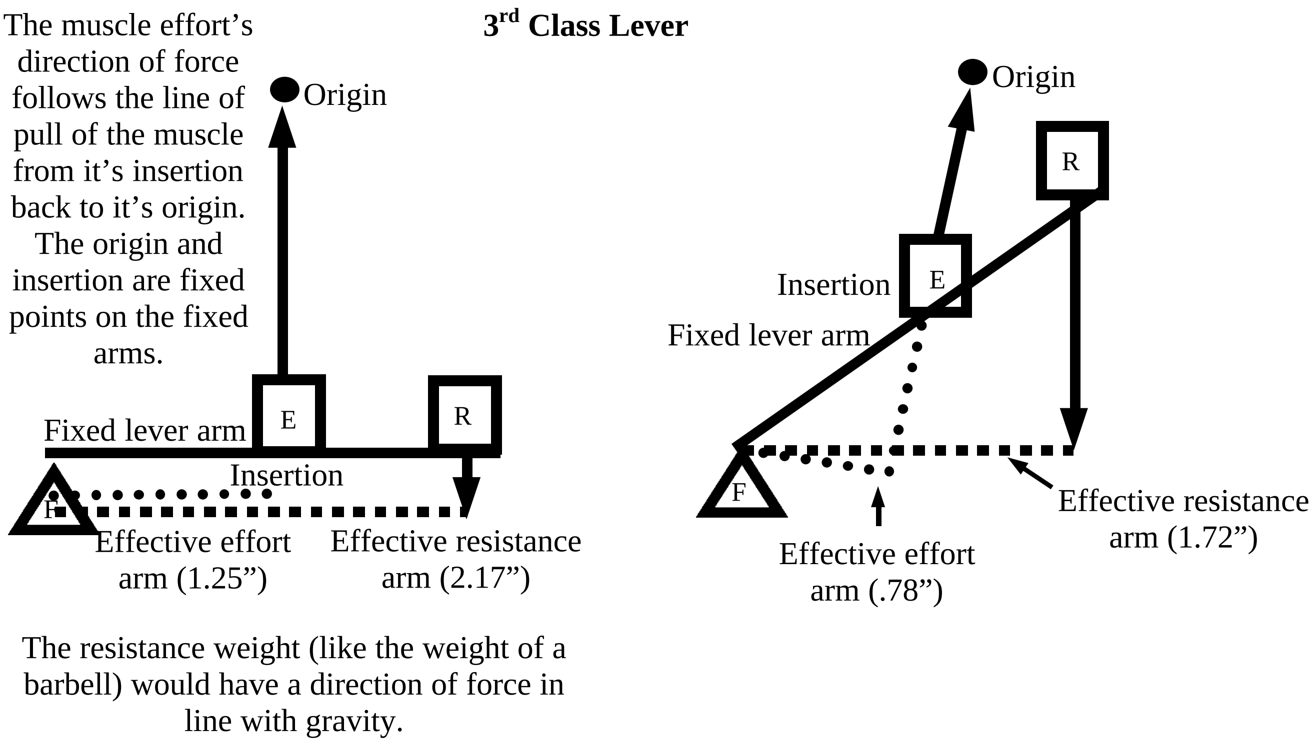


The resistance weight (like the weight of a wheelbarrow) would have a direction of force in line with gravity.

As the lever system moves through a range of motion, the effective lever arms become discernable as different from the fixed lever arms.

In the first example using the classic 2nd class lever system, the effective effort arm (2.16”) was longer that the effective resistance arm (1.21”). In the second example having moved the lever through a range of motion, the effective effort arm actually became shorter than the effective resistance arm. The length of the effective resistance arm is .97” long whereas the length of the effective effort arm is .83” long. Since the effective effort arm is shorter than the effective resistance arm, this 2nd class lever at this point in its movement, possesses poor mechanical advantage. Poor mechanical advantage means it takes more force of muscle effort than force of resistance to hold the lever system in equilibrium.

3rd Class Lever



As the lever system moves through a range of motion, the effective lever arms become discernable as different from the fixed lever arms.

In the first example using the classic 3rd class lever system, the effective effort arm (1.25”) was longer that the effective resistance arm (2.17”). In the second example having moved the lever through a range of motion, the effective effort arm remained shorter (.78”) than the effective resistance arm (1.72”).

When examining the classical (current) teaching of levers and their concurrent mechanical leverage properties once can see as the lever system translates through a range of motion that the fixed lever arms and effective lever arms break out and demonstrate their own very different structural and functional impacts on the lever system.

Benedetti’s discovery revealed when determining mechanical advantage, especially in biomechanical leverage studies involving muscles with their fixed origins and insertions, that the current teaching of lever systems employs erroneous tools. Understanding that the force of resistance and force of effort work on the lever system effectively relative to the perpendicular distance from the direction of their respective forces is important. This understanding truly leads to demonstrating the mechanical advantage of a lever system.

In the study of leverage, understanding how the forces of effort and resistance effectively work through a distance on the lever system is important because it demonstrates the true mechanical advantage of the lever system. When it takes less force of effort to than the force of resistance to put a lever system in equilibrium then the system is said to have good mechanical advantage. When it takes more force of effort then the force of resistance to put a lever system in equilibrium then the system it is said to have poor mechanical advantage.

Currently, 1st class levers can have either good or poor mechanical advantage depending on the distance at which the force of resistance or force of effort is applied to the fixed lever arms which measured at their point of attachment or point of influence.

2nd class levers are taught to possess good mechanical advantage because the distance at which the force of effort is effecting the fixed lever arms is longer than the distance at which the force of resistance is effecting the lever arm.

3rd class levers are taught to possess poor mechanical advantage because the distance at which the force of effort is effecting the fixed lever arm is longer then the distance at which force of resistance is effecting the fixed lever arm.

Currently in academics, the impact of the resistance and the effort is calculated as being the physical distance from each respective point back to the fulcrum. After incorporating Benedetti's concepts, it becomes necessary to study the effective impact on the lever system by looking at the perpendicular distance from the pull of the resistance and the pull of effort relative to the fulcrum.

From MSN Encarta encyclopedia defining Lever: http://encarta.msn.com/encnet/refpages/RefArticle.aspx?refid=761567646

> "The mechanical advantage (MA) of a lever tells how much the lever magnifies effort. In practical terms, the MA is the distance of the force of effort to the fulcrum divided by the distance of the load (force of resistance) to the fulcrum. Depending on the class of lever and the location of the fulcrum, the MA may be less than or greater than 1."

> "The 2nd class has the fulcrum at one end, the force at the other end, and the load in the middle. A common example is the wheelbarrow, where the wheel is the fulcrum, the load rests within the box, and the force is the lift supplied by the user. A CLASS 2 LEVER "ALWAYS" HAS MECHANICAL ADVANTAGE GREATER THAN 1. This because the distance of the force of effort as it is applied to the lever arm is "ALWAYS" greater then distance at which the force of resistance is effectively applied back to the fulcrum."

The above excerpts from Encarta illustrate how current lever teaching applies the distance of either effort or resistance on their fixed points on the fixed arms and not the effort or resistance effective arms. As can be plainly seen in our example of the 2^{nd} class lever moved through a range of motion contrary to Encarta and contemporary teaching, a 2^{nd} class lever does not "always" have a mechanical advantage greater than 1.

CONCLUSION

Whenever studying levers or biomechanics of muscular skeletal leverage, the distinction must be made between the distance of the fixed and effective arms. The fixed arms are the distance from point of application of either resistance or effort force back to the fulcrum. The effective arms are the perpendicular distance from the line of force back to the fulcrum.

The distinction must be made in academics that when determining the mechanical advantage of a lever system, it is the effective lever arm distances that must be discovered and used in the equilibrium of torque formulae and not the fixed distances that contemporary academics teaches.