the CrossFit JOURNAL ARTICLES

Variable Resistance

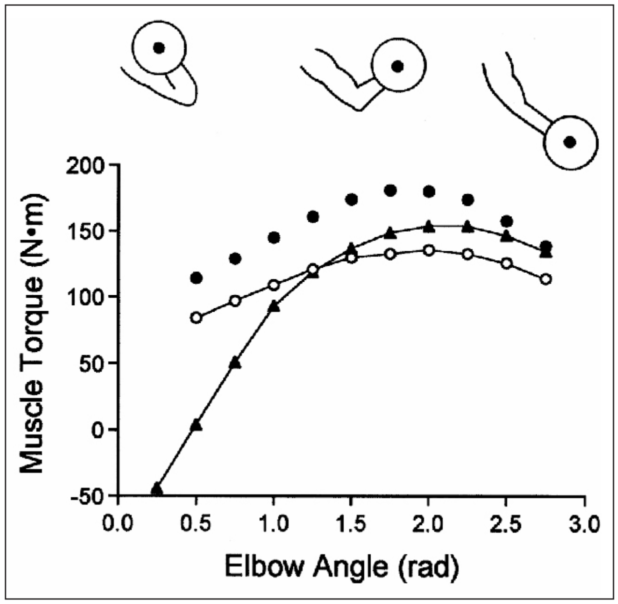
Nature or Design?

Tony Leyland

Continuing with my theme of muscle mechanics (following my article two months ago on the stretch-shortening cycle), this month I would like to explain the rationale behind the plethora of variable resistance machines and training concepts that are so common. It isn't that designers of exercise machines and fitness programs do not understand muscle mechanics (although some clearly don't), but that knowledge is often applied in ineffective and/or illogical ways.

Take the torque production from a muscle-joint complex for example. As your limbs rotate, the line of action of the muscle force changes, as does the force a muscle can exert at varying lengths, and this results in changes in torque production. Torque is a simple concept that everyone inherently understands. Nobody tries to get out of room by pushing close to the hinge of a door as we all realize that a smaller force applied farther from the axis of rotation will get the job done (over at the handle!). This is torque: mathematically it is force multiplied by the perpendicular distance to the axis of rotation. When working with free weights you learn this fast: keep the weight close to your body—i.e., as close as possible to both the joint's axis of rotation and to the body's center of gravity—and despite the obvious fact that the weight is the same, the torque will be lower and the load will feel more manageable.

We can easily measure the torque at various degrees of a flexion of a given joint. The diagram below shows graphs the torque produced throughout a biceps curl. The black dots (not connected) show the maximal torque output of this subject's elbow flexors at each position



From Enoka, R.M. Neuromechanics of Human Movement, 3rd ed. 2002 (redrawn from Smith, 1982). Note that the graph reads from right to left for tracing the actual movement in time of the biceps curl. (One Newton meter, the unit of measure for torque in this graph, is the equivalent to 0.75 pound-force feet, and one radian is equal to 57.3 degrees.)

(the position of the curl is shown above graph). The dark triangles show the torque produced when curling a barbell, and the open circles show the torque produced when curling on a Nautilus cable machine. Clearly, the Nautilus curl requires much more consistent application of force throughout the range motion, whereas the torque required for the barbell falls off dramatically once the elbow flexes past ninety degrees.

Variable resistance principles

Why the difference? Well, the Nautilus machine is a variable resistance machine. You will probably have seen many of these machines dotted around your local globo gyms. They are often cable machines and you can identify them by the odd-shaped pulleys (cams). The diagram below shows the principle by which these machines work. In the starting position on the left, it is relatively easy for the athlete to rotate the cam and lift the weight. This is because the 50-kg weight stack is close to the axis of rotation—the cable the weight hangs from is close to the center of the cam--and therefore requires less torque to rotate. However, as the cam rotates, it increases the perpendicular distance between the weight stack and the cam's axis of rotation, thus increasing the torque you have to exert to lift the weight and counteracting the natural decrease in torque you would experience with free weights. So in the diagram on the right you would require more muscular force to lift the same weight.

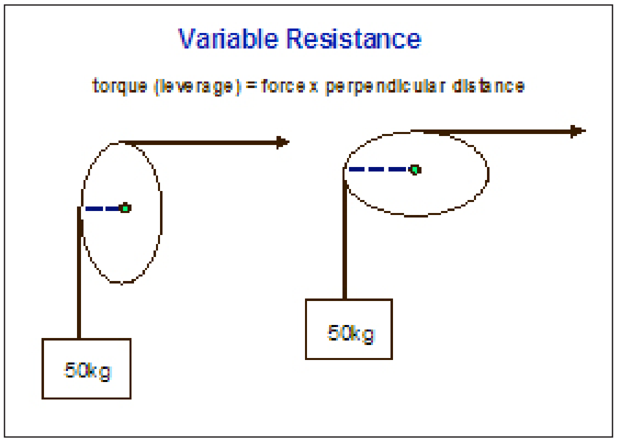
This wonderful piece of knowledge about muscle-joint mechanics means we can design a machine to force a muscle to work harder throughout the entire range of motion, doesn't it? That is the idea behind variable resistance machines. But that doesn't necessarily mean they're a good or particularly useful thing. For one thing, on a cable machine, the weight is somewhere else and you're working through a cam or pulley, so you can't stabilize the weight over a joint center. But before I go further into why I don't advocate variable resistance machines, let's look at some other common variable resistance systems.

The fitness industry doesn't stop at kidney and other odd-shaped cams to achieve variable resistance. Another common machine system is isokinetic variable resistance. The term isokinetic means "constant velocity." These machines are based on viscosity and they basically will resist as hard as you push or pull. (They are also expensive and some clubs will change a premium for you to use them.) These machines have fluids (oil, water, or air) that are forced though an aperture in a cylinder when you push or pull on the bar. You set the effort (velocity) you want to work at and then push as hard as you like throughout the range of motion. The narrower the aperture, the harder it is to force the fluid quickly through it and hence the resistance is greater and the slower you'll move the bar. Again, you will exert high forces throughout the entire range of motion. As with the variable resistance pulley machines, you haven't got a weight you can position directly above or below a joint (thus reducing the torque).

The best way for you to feel how isokinetic machines work is simply to put your hand in a bathtub or swimming pull and pull your hand slowly though the water. Now try to pull your hand through as fast as possible. The faster you try to move, the greater the resistance. Another example is to put your hand out a car window when going 30 miles per hour and do the same at 60 miles per hour. These examples show that the resistance fluids (gas and liquids) offer to your path through them is velocity dependent. Another example is to look at sports clothing. Marathon runners don't worry about smooth, tight-fitting clothing; at their speeds, wind resistance is minimal and no real advantage can be gained from having aerodynamic clothing. Downhill skiers, however, go much faster and do not want baggy clothing slowing them down.

Another less common (and less expensive) method of variable resistance is to attach heavy chains to a barbell that unfurl as the barbell is lifted farther from the floor, increasing the effective weight of the barbell as more chain is supported by it rather than resting on the floor. Admittedly this method does require you to control a free weight and therefore places demands on your coordination and additional stabilizing musculature, but I still wouldn't rush out to buy heavy chains if I were you.

People often ask about Bowflex and other spring resistance systems. They too are based on variable resistance but it works opposite to how we commonly experience resistance in the real world. When you pull against a spring, it gets harder and harder to pull the farther you stretch it. When working with barbells, kettlebells, dumbbells, rocks, jerry cans, and other real-world objects (i.e., when countering inertial resistance), the resistance will generally be reduced as you speed up the load. This also true in grappling, wrestling, tackling, etc. Once you have made a large effort to get an opponent slightly off balance they are easier to then drive completely to the ground. But working with springs is not going to effectively train you to coordinate muscle torques in a functional way. You get good at pushing springs (principle of specificity) on a machine that dictates for you the direction to push and pull. And though it is, like any form of resistance training, a lot better than just lifting the TV remote, it is not the most effective use of your time.



Do you need variable resistance?

So why am I not sold on the benefit of variable resistance machines? As I have said, the weight is somewhere else and you do not need to develop any skill to control the weight. In addition, because many of the machines work on isolated muscles you do not develop the skill to coordinate numerous muscle groups into functional patterns of contraction (including core stabilizers).

I think the fundamental problem is the conceptual separation of muscle mechanics from the neural control of the muscles (neuromechanics). While variable resistance machines do stress muscles throughout the range of motion, that is only part of what we need from strength training. As Coach Glassman puts it in "Foundations," our pursuit of optimal fitness must "strive to blur distinctions between 'cardio' and strength training. Nature has no regard for this distinction." Similarly, nature has scant regard for strength in isolation. By this I mean force production (strength) should not be separated from flexibility, coordination, accuracy and balance. Is the strongest athlete always able to lift the most? Clearly not, as is easily demonstrated when a strong athlete with poor shoulder and hip flexibility and or poor coordination attempts an overhead squat. At a fundamental level, the problem with all machines is the attempt to separate the physical skills. Variable resistance machines claim to be better because they supposedly mirror torque-angle relationships, but that doesn't solve the fundamental problem of attempting to separate muscle mechanics from neural control and the ability to use the body as a coordinated whole. The ten physical skills that we take to define fitness (cardiovascular/respiratory endurance, stamina, strength, power, flexibility, coordination, accuracy, agility, and balance) should never be viewed in isolation. And while some training will necessarily focus on one aspect more than another, there is no need to artificially separate these components (as occurs in machine-based strength/endurance work).

We must also realize that while some of the most common movements and lifts result in the resistance dropping as we complete the motion, as in the biceps curl example in the first figure. This is a natural mechanical response and not something that we should try to avoid or circumvent in training. Let me explain.

The laws of physics tell us that a body will continue in its state of rest or motion (constant velocity) in a straight line unless compelled to change that state by external forces exerted upon it. This is Newton's first law of motion, sometimes called the law of inertia. We inherently know that starting that heavy barbell moving is hard but that once we've got it moving it wants to keep going. So heavy lifts have what is called a sticking point where the amount of muscle force that can be exerted on the load (which is moving slowly and resisting changing that state) is only just able to get the weight moving. Once past that point, the weight starts to accelerate and, toward the end of the lift (even if less muscle force can be used), the lift is easier. Of course, that pesky thing called gravity is trying to slow the weight down but unless it is a really heavy weight we can get the load moving upward at a reasonable pace, and as stated, once we get it going it will be easier to keep it going. This is why you can lift more in a push press than a strict press: your much larger leg musculature gets the weight going up and you only have to use the smaller upper-body muscles to keep it moving to the finish. This pattern of resistance is one of nature's very common forms of variable resistance.

However, not all resistance motions we perform result in reduced torques as the load is accelerated. If the load moves farther from the joint center, the torque can increase even if the load is being accelerated. For example, in the middle part of kettlebell swing to overhead, the torque will be very high even though you already have the kettlebell moving fast (this because the load's is a full arm's length from your shoulder). So in nature if loads have to be moved from close to farther away from the body you will get, yes, variable resistance.

Working with free weights also teaches us when we really need to keep the torques as low as possible for a given weight. The gravitational line of action on a weight is always vertical, and the distance between this vertical

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line of action and a joint center is crucial. If, for example, you do not get a heavy press directly overhead (elbows into your ears, weight above feet) the resultant torque is going to demand much more effort from your shoulder muscles and may in fact cause you to lose balance and drop the weight. Similarly, if want to make that max deadlift, you better keep that bar on your shins, reducing the torque on your lower back. Training a multitude of movements in your workouts prepares you for a variety of real-life situations where loads can sometimes be kept close and sometimes not. The bottom line is that you don't need a machine to provide artificial variable resistance.

If you go back to the first diagram you'll see that the torque drops to zero toward the end of the curl. Well, if you take a light weight (say something around your 15-rep max) and do an explosive push press, you can get the barbell moving upward so fast that although gravity is pulling it back it'll carry on upward for a bit without much, if any, more effort from you. In fact, if you get enough momentum on it, you can let go of the barbell and the bar will continue up past your full extension height (as with wall ball, for example). In this scenario you will actually have to grip tight and stop the barbell from continuing upward. However, with much heavier weight (your one- to three-rep max, for example) you will have to push hard during the entire motion. That is why it is also beneficial to work with a wide range of loads. Varying the weight is essentially another way, along with every other natural movement, of creating variable resistance.

I will admit research has shown that variable resistance does improve strength throughout the full range of motion better than "non–variable resistance." This benefit, however, is only compared to strength training on non–variable resistance machines, and these studies tend to look at force production at the specific intensities trained (like 10-rep maximums, for example). But what about the effective application of strength? By this I mean the skill component—the development of the motor control required to effectively lift heavy weights. If we can keep the line of action of a heavy weight close to the joint center of rotation, lifting it requires less torque than lifting a lighter weight whose line of action is farther from the center of rotation. This is why, as discussed above, lifting heavy weights is not just about pure strength. Studies that suggest that variable resistance machines are a great way to train are looking at one narrow parameter—one very specific definition and isolated definition of strength—but not at the functional expression of athleticism or power in the real world.

In this article I have criticized machines in general and specifically the claim that variable resistance machines are better as they mirror the torque-angle relationship of a muscle/joint system. But the question remains: "Are they bad?" As an educator and trainer, I have to accept that someone who is doing any kind of resistance work is better off than the majority of the population. However, real-life movement and strength requirements will challenge all ten physical skills, and so should your training. If you are in the military, a first responder, or a martial artist, you don't need me to suggest machines are not an effective training tool. The bottom line on this question? If you put a CrossFitter on a variable resistance machine, they will do well. If you give a reasonably heavy barbell to someone who only trains on a machine and tell them to get it overhead, I suggest you stand clear!

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