THE SCIENCE OF RESISTANCE

A COMPARISON OF IRON AND AIR

KEISER®

THE POWER IN HUMAN PERFORMANCE

THE SCIENCE OF RESISTANCE

A POUND IS NOT ALWAYS A POUND

Thanks to some basic laws of physics, a pound is not always a pound. When looking at an iron weight, whether in the form of a barbell or a weight stack, one assumes it represents a particular resistance. It does, but only when it is at rest or moving at a constant speed. Once in motion, the changes in speed of movement cause the weight to change.

These changes in force can be illustrated by the sensation felt by people riding an elevator. As the elevator starts to move upward, one begins to feel heavier. When it achieves a constant speed, a feeling of a return to normal weight is experienced. As it slows to a stop, one feels lighter. A person standing on a scale would have seen that exact change. Even though actual body weight did not change, the force exerted on the scale did. The same thing happens when a barbell or weight stack is lifted. The force exerted by a barbell or weight stack on the body during an exercise will vary in the same way. This occurs because the barbell is accelerated just as the elevator accelerates the people riding in it.

The foundation for this phenomenon may have been encountered in a high school or college classroom. Long before man thought of exercise machines, Sir Isaac Newton showed that this changing force is proportional to the mass or weight one is lifting multiplied by the acceleration (rate of change of speed). $F = ma$, "F" being the force, "m" mass, and "a" acceleration.

Acceleration changes as the speed of movement changes. To attain greater speeds of movement, higher accelerations are necessary. Because of this simple formula, it can be seen that if the mass is high (as it is when using iron weight as a resistance), the forces can change greatly depending upon the speed of movement. It is not unusual when a person is moving a weight to have acceleration forces equal to or greater than the actual weight being lifted. For example, a shot-putter may exert a force in excess of ten times the weight of the shot-put, because of the tremendous acceleration necessary to get the distance.

Newton's Law has challenged every designer of a variable resistance machine since its invention in 1898 by Max Herz. When Arthur Jones introduced his Nautilus machines in 1970, he too was plagued by this phenomenon. To reduce the acceleration forces to near zero, Jones had two choices: reduce either the mass or acceleration to near zero. Since iron was his source of resistance, Jones couldn't lower the mass, so his only option was to keep the acceleration near zero. Therefore, he required everyone training on Nautilus machines to train at a speed of out on two seconds and back on four seconds, thus keeping the speed slow enough to make the acceleration forces insignificant.

Keiser, on the other hand, chose to do the opposite. Knowing that speed is essential in athletic performance, Keiser chose not to control the acceleration but to reduce the mass. This meant the weight stack had to go, and another form of resistance would have to take its place.

Keiser chose the force of Air, one of the most powerful forces on Earth. A small 2½ inch diameter cylinder can produce over 500 lbs. of force, but with only 3lbs. of actual moving weight. This is the secret to the very pure, very consistent, and very controllable resistance of Keiser's Pneumatic Technology. The operation is simple. The heart of the system is the compressor, which provides a source of compressed air that is distributed to each machine. When you depress the right thumb button (+), air flows from the compressor to the cylinder.

The longer you hold the button down, the more air flows into the cylinder, thus increasing the force it produces. Once the desired force (resistance) is reached, you release the thumb button and the air is trapped in the cylinder. As you begin to move through the concentric phase (positive stroke) of the exercise, the cylinder moves against the air pressure further compressing the air in the cylinder. This is very important, because it does two things. First, the increase in air pressure increases the force produced by the cylinder, which when combined with the mechanical linkage in the system, creates the variable resistance force curve. This is the exact method by which the human body varies its forces. The contractile effort of the muscle changes as it shortens, and the muscular leverage changes as the joint passes through its range of movement. Second, the increase in pressure stores the energy that you expend on your positive stroke to deliver it back to you on a negative or eccentric contraction (unlike a hydraulic machine, which cannot produce a negative or eccentric contraction).

Keiser provides a positive and negative resistance just like a weight stack, but without the high impact loads experienced while starting and stopping the weight. To decrease the resistance any time while you're exercising, you simply depress the left thumb button (-) and the air releases, thus reducing the resistance as long as the thumb button is depressed.

To illustrate the difference between these two approaches to muscular-skeletal performance, a special Leg Extension machine was built with two independent exercise arms contacting the user's lower legs. One is connected to a weight stack and the other to Keiser's pneumatic cylinder. The cams are made so that the two systems provide the same variable resistance curve at a speed of out on four seconds and back on four seconds. Force sensors are attached to each pad that contacts the user's legs, and wired to a computer that graphs the exact force being applied to the legs by each system as the user extends his or her legs through the range of motion.

Unfortunately, these high spikes in resistance most often come at a point in the range of motion that can result in the greatest harm to joints and connective tissue. That's why we've been told for years that high-speed training was dangerous.

BREAKING THE BARRIERS OF POWER

We know today that speed wasn't the problem. The injuries were caused by the impact loads from the weight equipment being used; the wrong element was blamed. It's just like saying that jumping from an airplane will kill you. It's not the jump from the plane that kills you, but the fact that you hit the ground going too fast. Once the proper equipment was designed to slow the descent, jumping from a plane was made much safer.

You can see the resistance provided by Keiser's Pneumatic Technology remains consistent throughout the various training speeds. This opens up a whole array of training options not possible with free weights and weight stack machines.

The ability to incorporate different speeds of training into a workout allows for speed and power (the combination of strength and speed) training. It also provides a much safer resistance for older adults and rehabilitation patients by decreasing the risk of injury and shortening recovery time. In short, Keiser is very hard on muscle (because you can't cheat) and very easy on joints and connective tissue (because of the low impact loads).

Strength has been the accepted measurement of athletic performance, primarily because it has been the easiest to measure. Yet, in actual performance, the athlete will probably never use maximum strength. In most cases, speed or a combination of strength and speed (power) will produce greater results than strength alone. Not only has this been proven in athletic competition, but there are also several research studies that prove that power is a better predictor than strength of an older adult's ability to perform the activities of daily living. Power is the key to performance, whether you're young or old. Keiser's Pneumatic Technology is one of the most significant contributions to resistance training in the 20th century.

For the very first time since Herz received his patent on variable resistance over a century ago, the true benefits of variable resistance can be realized thanks to Keiser's revolutionary machines.

KEISER®

The following graphs depict data from an actual demonstration

Figure 1

Shown here is a graph of a user doing several repetitions at a speed of out on four seconds and back on four seconds. The RED line shows the force the weight stack is producing and the BLUE line shows the force the pneumatic cylinder is producing. The upper portion of each tracing is the extension of the leg and the bottom half is the returning of the leg. As you can see, the two systems are producing almost exactly the same forces at this speed.

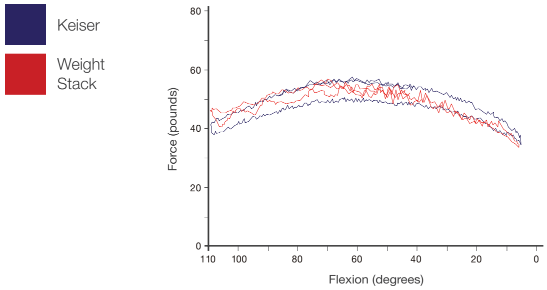


Figure 2

Shown here is a graph depicting what begins to happen as the training speed is increased to two seconds out and two seconds back. There is a slight increase in force at the beginning to get the weight moving, and a slight drop off towards full extension as the momentum tends to carry the weight. The Keiser forces don't appear to change. All in all, the systems are very close. However, the weight stack has already increased its force so much at the beginning that the maximum resistance is no longer occurring at the optimum range of 60 to 70 degrees of flexion, but rather at the beginning, where the knee is more prone to injury.

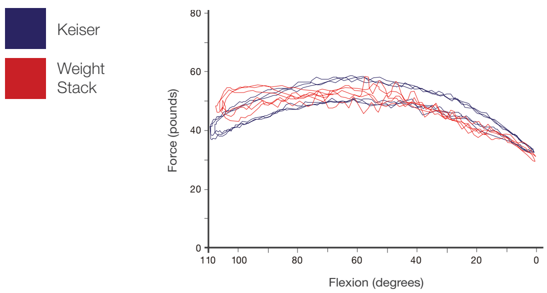


Figure 3

This graph shows a more dramatic change in the weight stack side when the training speeds are increased to out on one second and back on one second. Note the 70% increase in resistance in the weight stack at the beginning of the exercise, by just going out on one second instead of two seconds. As you can see in Figure 4, the weight stack shifts significantly when the speed is doubled to out in one-half second and back in one-half second resulting in a near doubling of resistance at the beginning and near zero resistance at full extension.

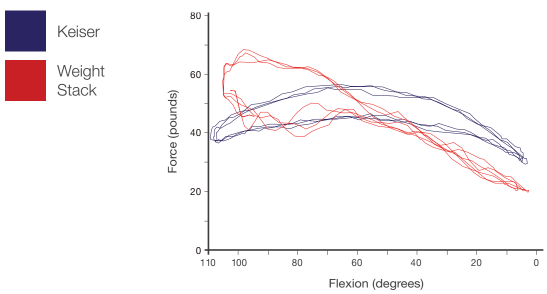
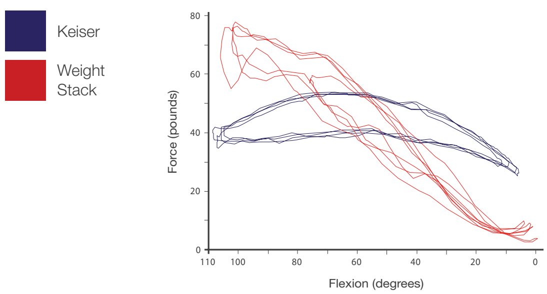


Figure 4

Figures 3 & 4 very clearly show Newton's Law in action. As the weight stack leg begins to extend in the first part of the stroke, additional force is required to accelerate the weight to the desired speed. Once up to speed, momentum takes over and in the last half of the positive stroke the resistance drops as the weight slows to a stop. The negative portion of the stroke is the mirror image of the positive stroke. The resistance drops as the weight accelerates downward to a constant speed. As the leg nears the starting position, a greater force must be exerted to slow or decelerate the weight to a stop. The faster the speed of movement, the greater the acceleration force, hence the difference between Figures 3 and 4.



KEISER®

THE POWER IN HUMAN PERFORMANCE

Keiser Corporation
Tel 559.256.8000 Fax 559.256.8100 Email info@keiser.com