EXERCISE PHYSIOLOGY

Strength and Power: A Definition of Terms

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The terms strength and power are used by virtually every physical conditioning professional seeking to improve performance through resistance training. However, fundamental these terms may be in the strength and conditioning profession, their definitions are not universally agreed upon. While it is difficult to please everyone when defining terms, a discussion of the underlying concepts may lead to a consensus, thereby facilitating communication between professionals.

Strength Defined
It is widely accepted that strength is the ability to exert force. However, because force application can be measured by a variety of conditions and techniques, there is considerable disagreement as to how strength should be measured. Maximum weight lifted is probably the oldest and most commonly used quantitative measure of strength. Technological developments popularized isometric (no movement) and isokinetic (fixed movement speed) strength testing. More recently, biomechanical analysis techniques have been used to measure the force exerted during body movements involving acceleration, which encompass virtually all sport and daily life activities (1, 13).

The most precise definition of strength is the ability to exert force under a given set of conditions defined by body position, the body movement by which force is applied, movement type (concentric, eccentric, isometric, plyometric) and movement speed. A similar definition was suggested by Knutgen and Kraemer who defined strength as "the maximal force a muscle or muscle group can generate at a specified velocity" (8). According to these definitions, someone who is strong under one set of conditions is not necessarily strong under another set of conditions; different sports activities may require different types of strength.

The amount of weight lifted is not a direct measure of the force exerted because acceleration (increase in velocity per unit of time) is involved in lifting. According to Sir Isaac Newton's law (11):

\[
\text{Sum of Forces} = \text{Mass} \times \text{Acceleration}.
\]

If a barbell is the mass under consideration, the sum of forces equals the upward force on the bar exerted by the lifter, minus the barbell's weight, which pulls downward. To allow upward acceleration of the bar from the floor, the lifting force must be greater than the weight of the bar. When a weight is lifted, the lifter is capable of exerting a vertical force at least equal to the weight of the barbell; however the actual force exerted may be considerably greater if the acceleration is high. The patterns of acceleration and force mirror each other and can vary infinitely.

All sports involve acceleration of the body and sports implements. Due to individual differences in the ability to exert force at different speeds (7), strength scores obtained from isometric and slow speed lifting tests may have limited value in predicting performance in sports which involve acceleration at high speed. Although more advanced tests that control or monitor movement velocity require sophisticated and sometimes expensive equipment, the resulting strength scores may be more related to sports ability.

Power Defined
The limited applicability of isometric or slow speed strength scores has led to a heightened interest in power as a measurement of the ability to exert force at higher speeds. Yet there is less agreement on the meaning of the term power than strength. Among nonscientists, power is loosely defined as "force, energy, strength and might" (12). This definition probably led to the term "powerlifting" to describe a competition in which the winner lifts the highest total in the bench press, squat and deadlift. However, the commonly used definition of power conflicts with the precise scientific definition, which is "the time rate of doing work" (11).

According to the scientific definition, work is the product of the force exerted on an object and the distance the object moves and is expressed as:

\[
\text{Work} = \text{Force} \times \text{Distance}
\]

When a person lifts a weight, the amount of work performed on the bar per repetition is equal to the weight times the vertical distance the weight is lifted. However, people often quantify a workout according to tons lifted; they multiply weight lifted per repetition by the number of repetitions and divide by the number of sets. This does not describe actual work performed and...
fails to take into account that the vertical distance a weight is moved differs among exercises and individuals.

It is more accurate to quantify a workout according to total work performed on the bar by multiplying weight times the vertical travel of the barbell per repetition times the number of repetitions. Dividing that number by all sets in the workout gives the total work in foot/pounds or newton/meters, depending on the measurement system used. This procedure requires a tape to measure the vertical travel of the weight for a given exercise and individual. On a weight stack machine, the vertical travel of the stack should be measured, rather than the handles or pedals.

Even greater accuracy in calculating total work can be obtained by accounting for the work performed by lifting the bar and body parts that rise during each repetition (6, 9). This is particularly important when the part of the body lifted represents a significant portion of the weight lifted (e.g., squats, sit-ups). Such an approach is most applicable in a scientific setting and requires tables that express the masses of individual body segments as percentages of total body mass (14).

Power is the rate of doing work, quantitatively defined as:

\[
\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}
\]

The above equation can be rewritten as:

\[
\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}
\]

Power can also be defined as:

\[
\text{Power} = \text{Force} \times \text{Velocity}
\]

More precisely, power can be defined as the product of the force exerted on an object and the velocity of the object in the direction in which the force is exerted.

Power output changes constantly during any lift. The measurement of instantaneous power requires sophisticated equipment. However, average power can be estimated by dividing the work performed by the time it takes to do the work. A stopwatch or other timing device may be used for such measurements. For example, a test set-up may be designed to start a timer when a weight is lifted off a contact pad; the timer stops when a light beam is broken at the top of the movement. The average power for the lift is the weight, times the vertical distance traveled, divided by the time. Therefore, raising a weight in half the time requires twice the average power output.

Consistent units of measurement must be used to ensure that the equations above are correct. In the Systeme International d’Unites (SI) (10), the worldwide standard, force is measured in newtons, distance in meters, work in joules (newton/meters), time in seconds and power in watts (joules per second). The appropriate input units for the equations can be obtained from other common units using the factors listed in Table 1.

High power output is achieved when both force and velocity are high. The term powerlifting is inaccurate because such lifting involves high forces but relatively low movement speeds; thus, less mechanical power is produced than in several other sports, including Olympic lifting (2). Since the term is well established and is not likely to change soon, the inaccuracy of the term must be tolerated. Because the discrepancy between the common and scientific definitions of power has led to a misunderstanding, strength professionals can avoid confusion by using the scientific definition.

### Rotation Work and Power

The work and power equations apply to an object moving through space. Work and power are also required to start an object rotating or to change the velocity at which it rotates, even if the object doesn’t move through space at all. The angle through which an object rotates is called angular displacement (and is measured by SI unit radian); one radian equals 57.3 degrees. Angular velocity is the object’s rotational speed, measured in radians per second.

Torque is expressed in newton/meters. Just as for movement through space, the work done in rotating an object is in joules, and power in watts (10). The equations for rotational work and rotational power are:

\[
\text{Work} = \text{Torque} \times \text{Angular Displacement}
\]

\[
\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Torque} \times \text{Angular Displacement}}{\text{Time}}
\]

Because the above equation can be rewritten as:

\[
\text{Power} = \frac{\text{Torque} \times \text{Angular Displacement}}{\text{Time}}
\]

power can also be defined as the product of torque and angular velocity.

\[
\text{Power} = \text{Torque} \times \text{Angular Velocity}
\]

The fact that torque and power are required for rotational work is the reason that weightlifting bars are designed so the bar can rotate freely without the weight plates rotating. Because the lifter’s grip is fixed, and the forearm pivots about the elbow, rotating the bar during a lift from floor to shoulders cannot be avoided. Independent rotation of the bar and weight plates free the lifter of the work required to initiate and halt rotation of the plates, which would make the lift more difficult.

### Strength at Slow and Fast Speeds

While strength is often associated with slow speeds, and power with high speeds of movement, both are evident in all body movements, no matter what the speed. Both reflect the ability to exert force at the speed tested. Force and power are both evident during acceleration of the body or an implement at any speed. Thus, force and power are closely related factors and

| Table 1. Factors for conversion of common measures to SI units. |
|-------------------|----------------------|-------------------|
| To get            | Multiply            | By                |
| newtons           | pounds              | 4.448             |
| newtons           | kilograms           | 9.8*              |
| meters            | feet                | 0.3048            |
| meters            | inches              | 0.02540           |
| radians           | degrees             | 0.01745           |

*This conversion factor is given to only two digits of precision because the pull of gravity on the earth’s surface varies.
not at all independent. Power is a direct mathematical function of force and velocity. Therefore, if at any instant, any two of force, velocity and power variables are known the third can be calculated. If an individual can generate high force or high power at a particular velocity of movement, the same ability is used to accelerate a mass at that particular speed. It is incorrect to associate strength with low speed and power with high speed. Strength is the capability to exert force at any given speed. Power is the product of force and velocity at any speed. What is critical, however, is the ability to exert force at speeds characteristic of the sport to overcome gravity and accelerate the body or an implement. Low-speed strength is most critical in sports that are relatively slow due to high resistance. High-speed strength is most important in sports requiring fast movements due to low resistance.

Because of the close association of strength and power it is misleading to imply that they are independent entities. When coaches speak of an individual's strength and power, they are usually referring to the individual's low- and high-speed strengths, respectively. An example of their proper use of the terms strength and power is provided in an experiment on the performance correlates of isokinetic strength test results. It was observed that low-speed isokinetic strength scores were similar for slower and faster sprinters (5). However, the faster sprinters were better at generating torque during high-speed isokinetic tests. Thus, while all subjects exerted less torque at higher speeds, the strength of the faster sprinters did not degrade as much when movement speed increased. In other words, low-speed strength was similar among the slower and faster sprinters, while the faster sprinters exhibited greater high-speed strength. It is not necessary to refer to power in this context.

Power output, because it reflects both force and velocity, is a convenient quantity for comparing different sports activities or individuals. For example, two football players might have equal vertical jump ability, however, the heavier player must produce greater power to reach the same height. When power output during the jump is calculated (3, 4), it reveals something that the vertical jump distance alone cannot reveal — the ability to move an opposing player.

An improved understanding of strength and power can reduce confusion and improve communication between strength and conditioning professionals seeking to improve performance through resistance training.

References