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The Definition and Assessment of Muscular Power

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Considerable confusion still exists in the sports medicine literature concerning the measurement of muscular power and what it represents. Measures of muscular performance cannot be conveniently categorized as "strength" or "power" on the basis of the contractile velocity employed in the performance task. Given the proper physical definitions and formulations involved in muscular power measurement, it is concluded that although strength (force output) and power (work/time) are quantitatively related, they remain separate physical parameters that can be measured in all dynamic muscular contractions, whether fast or slow.

MUSCULAR POWER

By physical definition, power is equivalent to energy output per unit of time, or the rate of doing work.[9] The label of "power" has been applied too loosely in the sports medicine literature, creating what now amounts to an identity problem for the term. The confusion over muscular power has primarily concerned 1) the means of measuring the power output associated with a given muscular performance task, and 2) the kinetic characteristics of muscular performance tasks specific to power testing.

POWER MEASUREMENT

All proper tests of muscular power must employ a quantitative formulation or measurement that is consistent with the true physical definition of power. Any test that does not meet this criterion does *not* measure power. When attempting to determine whether a muscular performance test score constitutes a true power measurement, one should check the units. Power measurements must be expressed in units that are equivalent to work per unit of time. Joules per second (watts), horsepower, and foot-pounds per second are all common units used to express power. Force × velocity is equivalent to work/time as a formulation for power; the units of each are the same.

In a rotational work measurement system such as a Cybex isokinetic dynamometer, confusion often arises over units. Foot-pounds of torque (applied force × perpendicular distance between line of force application and axis of rotation) are not equivalent to foot-pounds of work (applied force × distance through which force has acted), and cannot be directly substituted for one another when calculating power. Foot-pounds of torque must be multiplied by angular displacement (in radians) to become equal to foot-pounds of work. One can also simply multiply torque (foot-pounds) × angular velocity (radians per second) to arrive at a proper work/time (foot-pounds per second) measurement of power.

In addition to being expressed in the proper units, power measurements should be qualified as being either *mean* or *instantaneous* values. Mean power values express the average rate of doing work over some period of time whereas instantaneous power values express the rate of doing work at some instant in time.

A review of the sports medicine and human performance literature reveals many different methods of measuring muscular "power," not all of which are consistent with its true physical definition. One group of investigators[13] has stated that the "peak power" in an isokinetic test movement could be calculated by dividing the peak muscular torque by the duration of the contraction. With respect to both physical formulation and teminology, this is incorrect. Power is calculated as work/time (i.e., torque × angular displacement/time), not simply torque/time. The authors acknowledged that their "peak power" quantity was only a correlated index of true power because of their substitution of peak

torque for work, but, in contradiction, they incorrectly expressed it in watts, a true power unit. The same investigators described "instantaneous power" as peak torque divided by the time required to reach peak torque. This numerical index may represent a *functional* muscular performance parameter, but it is not a measure of instantaneous power. Another investigator similarly arrived at erroneous isokinetic muscular power output values, in part because foot-pounds of torque was directly substituted for foot-pounds of work in a work/time power calculation.[2] As stated earlier, the two quantities are not equivalent even though the units read the same.

At least two groups of investigators[14, 16] have used the initial rate of force development in a dynamic isokinetic test movement as a measure of "power." This rate of force increase, given in units of pounds per second, was derived from the initial slope of maximal muscular force output curves recorded at a controlled movement velocity. Their measure of "power" (force/time) is not equivalent to force × velocity or work/time and thus is not equivalent to muscular power output. The fact that their variable represents a different physical quantity is illustrated by the observation that a high rate of force development can be produced in isometric tests, even though no external mechanical work or power is generated. We consider the maximum rate of muscular tension development to be an important *functional* parameter in human physical performance, but it is not a measurement of muscular power output.

"POWER MOVEMENTS"

There is no single "correct" muscular performance test for evaluating muscular power output. As long as a proper method of calculating muscular power output is applicable, the actual muscular performance task can be selected in accordance with the functional and/or experimental requirements of the testing situation.

In the physical education literature, the term "power" has been adapted to mean the ability to perform fast, forceful, propulsive movements, such as the sprints, jumps, and throws.[4, 6, 8, 11, 15] The use of the term "power" in relation to such fast, forceful performance tasks as the vertical jump may be descriptively attractive, but it has been shown that scores in the physical educator's best tests of "muscular power" do not measure or even correlate significantly with the true muscular power output associated with the test movements.[1, 3, 5, 7]

Investigators in the fields of sports medicine and human performance would be well advised to adopt a specific *functional* term for the ability to perform high velocity, "explosive" force-generating movements, and limit the term "power" to its correct usage as defined by Newtonian mechanics.

STRENGTH VERSUS POWER

The common misuse of the term "power" in the literature has apparently led to the misleading concept that "fast" speed muscular force output tests measure "power," while "slow" speed force output tests measure "strength."[10, 17] In actuality, power is generated and can be measured in *any* dynamic movement associated with an applied force, *regardless of speed*. Similarly, any maximally applied force is an external manifestation of a muscle's ability to develop tension (strength) regardless of contractile velocity. Muscular force output measurements at fast contractile velocities simply represent high-speed strength capabilities, while force outputs measured at lower velocities represent slower-speed strength. The same principle applies to muscular power: measurements at fast contractile velocities represent high-speed power output capabilities, while measurements at lower velocities represent slower-speed power output capabilities. When proper physical definitions are applied, measures of dynamic muscular performance cannot be separated into strength values and power values on the basis of movement speed or contractile velocity.

The choice of contractile velocity in strength and power testing should not be governed by which of the two variables one wishes to measure, but rather by the experimental, functional, or physiologic considerations attendant to the testing situation. For example: an experimental protocol may call for the measurement of maximum muscular power output capability at a particular movement speed; or functional specificity may dictate the particular contractile velocity necessary to relate laboratory strength measurements to an actual physical performance task.

An illustration of how physiological factors may play a role is in the determination of the *velocity of maximal power development*. External muscular power output will vary with contractile

velocity as a function of both physical movement speed and the physiological force-velocity relationship in skeletal muscle for concentric contractions. Up to a point, maximum muscular power output becomes greater with increasing contractile velocity, even though maximum muscular force development (strength) declines.[12] With further increases in contractile velocity, however, muscular power output capability decreases, and the measurable external power output will eventually drop below the levels produced at even relatively slow speeds.[12] The point just before power output begins to decline marks the specific velocity of maximal power development, a parameter that may prove to be very useful in clinical testing as well as in physical training and rehabilitation. It is the author's experience, using a Cybex dynamometer as a testing modality, that this velocity varies between different muscle groups in the same individual and from subject to subject for the same muscle group. Whether this represents an optimal testing and/or training velocity remains to be determined.

SUMMARY AND CONCLUSIONS

Improper use of the term "power" still occurs with regularity in the sports medicine literature. Inappropriate terminology and related misconceptions have been discussed, yielding the following conclusions.

1) Application of the term "power" to any muscular performance measurement that does not represent the correct physical formulation for power (work/time or force × velocity) is unwarranted.

2) The rate of muscular force development (force/time) is a functional parameter and is not a measurement of power in its proper physical sense.

3) None of the physical education tests long held to measure muscular power actually do so.

4) Strength (force output) and power (work/time) are related but separate physical quantities that can be independently measured in *all* dynamic, muscular contractions, whether fast or slow. For physiologic or functional reasons, it may be desirable to test strength and power output at different contractile velocities, but measures of muscular performance cannot be separated into "strength" values and "power" values on the basis of movement speed.

5) The specific velocity of maximum muscular power output may prove to be a valuable parameter with application to both training and testing in the field of human performance.

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