Quantification and Description of Physical Exercise

Cuantificación y descripción del ejercicio físico

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Physical exercise is a core therapeutic modality in the practice of sports medicine, physical medicine, and rehabilitation that can be described as muscular activity that is planned, structured, repetitive, and purposeful for the improvement of functional movement capability. It has been shown to benefit patients with a wide variety of conditions such as neurologic injuries, musculoskeletal conditions, cardiorespiratory diseases, cancer, and many others. Further, it is practiced by persons with a wide variety of disabilities and Paralympic athletes. It encompasses combinations of concentric, eccentric, and isometric skeletal muscle actions[1]. In keeping with the standardization of procedures in the reporting of various types of research and the increased requirements for scientific manuscript preparation, it is vitally important that investigators conform to standard terminology. Failure to use appropriate terminology and the use of inappropriate measurements can adversely affect meaningful communication. The need for standard terminology is also evident in clinical settings where different health professionals must communicate and discuss rehabilitation interventions.

The International System of Units

First presented in 1960, an international system (SI)[2] has been universally accepted as the system of quantification for exercise performance. The units employed for quantifying exercise are mass (grams, kilograms), force (Newtons), energy (Joules), work (Joules), heat (Joules), distance (meters), torque (newton-meters) volume (liters), time (hours, minutes, seconds) and power (Watts) (Table 1). The Newton is the basic unit of force, but it is rarely presented in the research literature because "free weights" and weight stack machine plates are manufactured and labeled in terms of their kilograms of mass. The force for lifting 1 kg of mass against gravity is equal to 9.81 N on most of the earth's surface.

Energy, work, and heat are interrelated and, therefore, have the same unit of quantification, the Joule. As related to exercise, they conform to the equation:

Energy (J) = Work (J) + Heat (J). The energy released in the active skeletal muscle cells to produce body movement may result in mechanical work being performed. If no work is performed as a result of the muscular activity, all of the energy will evidence as heat. For dynamic human performance, the typical mechanical efficiency of 20% would result in 5 J of energy producing 1 J of work and 4 J of body heat.

Table 1. Certain base and derived units of the SI.

Quantities	Units	Symbols
Length	centimeter, meter, kilometer	cm, m, km
Time	second, minute, hour	s, min, h
Mass	gram, kilogram	g, kg
Volume	liter	l
Force	Newton	N
Torque	Newton-meter	N-m
Work	Joule	J
Energy	Joule	J
Heat	Joule	J
Power	Watt	W

Human Performance

Strength (maximal force or torque) can be measured for every movement of the human body and is, in part, dependent on the speed of movement. A system of strength assessment and exercise program design was presented in 1945 as the Repetition Maximum system by DeLorme[3]. Assessing a person's ability to exert force or torque via free weights or an exercise machine is determined as the resistive force or torque that can barely be performed for a given number of repetitions (R) and is termed a "repetition maximum" (RM). The highest resistance that can be performed for only one movement thru the full range of motion of a joint is identified as the 1RM for the particular movement and is defined as an individual's strength for the movement. Muscular endurance for a movement is often quantified as the weight with which an individual can barely perform a given number of repetitions (e.g. 10RM).

Aerobic exercise involving large muscle activity, such as in walking, running, bicycling, cross country skiing, exercise on treadmills, elliptical machines, rowing machines, exercise cycles, and other endurance exercise machines depends in great part on the delivery of oxygen from the lungs to the active muscles.

Utilizing a special ergometer for the performance of leg "cycling" exercise[4], it was possible to evaluate subjects through the entire range of power production from long term (e.g., 20 minutes or longer) to the

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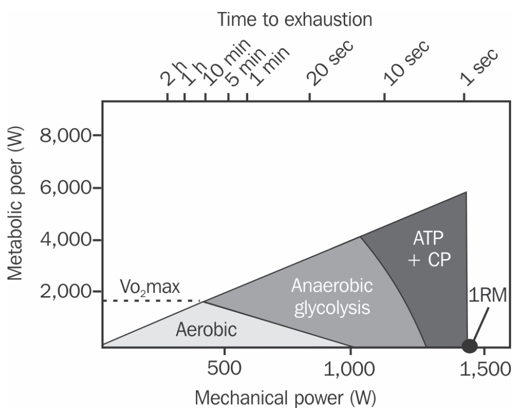
Figure 1. Relationship of sources of metabolic power vs. mechanical power for the leg exercise of a 80 kg male subject on a cycle ergometer at an rpm of 60/min. The upper horizontal coordinate presents the time to exhaustion at the various levels of mechanical power.



highest force and torque development (as in the RM system). In Figure 1, metabolic power is plotted *vs.* the mechanical power that the subject transfers to the exercise ergometer. The metabolic power is provided in the muscle cells via aerobic metabolism of carbohydrate and fat, via anaerobic metabolism (with production of lactic acid), or directly from the high-energy phosphates (ATP and CP) as dependent on the intensity of the exercise.

At the lower intensities of exercise, the muscles provide energy exclusively through the aerobic metabolism of carbohydrates and fats (e.g., in this example, for as high as 450 W of mechanical power). The aerobic metabolism is measured via spirometry and identified as the rate of oxygen uptake in the lungs and referred to VO_2 (l/min). As the subject approaches maximal oxygen uptake (VO_2max), the muscles turn increasingly to the anaerobic metabolism of carbohydrate with the production and appearance of lactic acid in the muscles and into the circulating blood. Between 450 W and 1,300 W, power for the exercise relies predominantly on anaerobic glycolysis and, above 1,000 W and exercise to exhaustion in less than 20 s, increasingly on the energy from the high-energy phosphates, ATP and CP, that are stored in the muscle cells.

Exercise prescription

Most exercise programs for conditioning and rehabilitation are oriented either to strength development, to aerobic (cardiovascular) fitness, or to a combination of the two[5]. Because strength performance and aerobic performance are located at the opposite extremes of the muscular power continuum (Figure 1), the design of a program must be highly specific as regards the exercise to be undertaken. This includes the intensity, duration, frequency (daily and weekly), and type of exercise in order to attain optimal results. Strength exercise programs involve free weight training or the use of high-resistance machines, in both cases with exercise that is limited to a few repetitions in a set (generally less than 20) before exhaustion. Aerobic exercise involves exercise performed for extended periods (e.g., 10-40 minutes) with large muscle activity involving hundreds to thousands of consecutive repetitions that challenge the delivery of oxygen to the active muscles. The chronic physiological adaptations and the variables in program design are highly specific to the type of exercise performed.

Strength exercise performance is mainly related to the recruitment of Type 2 (fast-twitch) skeletal muscle cells that will respond to systematic training by increasing in cross-sectional area, anaerobic metabolic capacity, and force development. Aerobic exercise relies on Type 1 (slow-twitch) muscle cells and appropriate training programs can be expected to improve both the oxidative processes in the cells and the ability of the cardiorespiratory system to deliver oxygen.

Utilizing the performance of the subject in Figure 1, exercise for the improvement of aerobic performance and cardiovascular capacity would involve the range of power output from 300 to 450 W which this subject could sustain resulting for many hours to a few minutes. Strength exercise prescription would involve performance exercise in the range of 1,000 – 1,400 W (e.g., 20RM – 1RM). Testing of various other movements and the related muscles would yield a wide variety of power values and must be determined by methodical testing.

The term, “work”, should never be employed as an alternative to “exercise” because it is specifically defined in the SI as the product of force and a displacement and not of continuing muscle activity. The term, “workload”, should not be employed when the unit of measurement presented is for “power” (W). Strict adherence to the definitions of the SI will insure standardization of terminology and make scientific communication more readily understandable to the worldwide scientific community.

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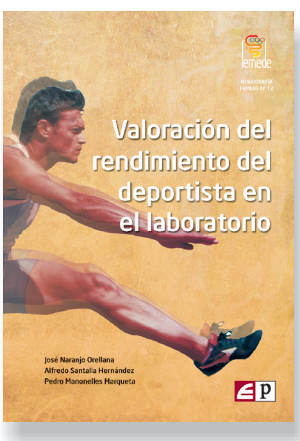

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Índice

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Índice