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Explosive is not a Term Defined in the International System of Units and Should not be Used to Describe Neuromuscular Performance

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ABSTRACT

Despite not being recognized by the International System of Units, explosive is a term often applied in sports science and professional practice. While associated with force, strength, power, performance, exercise, movements, contraction, action, and training, readers may be misled to believe that there are further analyses beyond power output, peak force, contractile rate of force development, and impulse. This critical review discusses the misuse of the term 'explosive' in sports science literature, proposes alternatives, and encourages correct definitions of terms, units, and nomenclature to describe exercise performance. The suggestions provided in this review can help to reduce the confusion and perpetuation of an erroneous understanding of mechanical work, energy, and power in sports science.

Keywords: Strength and power training; Neuromuscular performance; Plyometrics; Weightlifting.

INTRODUCTION

The study of Newton's laws of motion enables us to analyze a wide range of mechanical phenomena and refine our understanding of forces (45). For all physical activities, Newton's second law is the fundamental mechanical relationship used to document the changes in performance and, together with work and power, represent the basic concepts to describe the muscular activity (23, 54).

In exercise physiology, muscle strength, power, flexibility, and endurance are often connoted as functional aspects of the neuromuscular system. According to Newton's second law of motion, the acceleration of an object is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to its mass. Therefore, muscular strength refers to the force that can be developed by the muscles performing a particular joint movement (e.g., elbow flexion, knee extension) (24), which ultimately contributes to the production of torque (i.e., the rotational force or moment of force that tends to cause an object to rotate around an axis) around that joint. Work is expressed when the force moves an object through a displacement in the direction of the force, and power is the derivative of work concerning time (i.e., 1 joule per second = 1 W) (24). In the context of exercise physiology, muscular strength and work are related concepts, but they represent different aspects.

Muscular strength may be influenced by factors as muscle fibre area and motor unit firing rate (1). On the other hand, work is a measure of the energy expended to move an object against a resistance. Muscular strength contributes to the amount of work that can be performed, but work depends on the distance moved. In addition, skeletal muscles can maintain either a specific isometric force or power level, involving combinations of concentric and eccentric muscular actions, a functional property connoted as endurance (54). Flexibility is also an intrinsic property of body tissues, determining the range of motion achievable without injury (22).

The assessment and quantification of human physical performance must adhere to principles of science and be accomplished by using the International System of Units (SI) for force (newtons), torque (newton-meter), work (joules), and power (watts). Considering these basic concepts, physical demand in sports may be broadly classified into events that require great neuromuscular strength and power (e.g., weightlifting, powerlifting, and throwing events in track and field), endurance (e.g., marathon run and triathlon), and the intermittent modalities (e.g., soccer, basketball, combat sports, etc.). Nevertheless, despite these well-consolidated mechanical concepts in the description of human performance, sports science literature often fails to use correct definitions of scientific exercise terms, nomenclature, and units (53, 54).

A peculiar, but incorrect term often used in scientific literature is *explosive* (53). Due to not being a recognized term of SI, it has already been recommended to be no longer used to describe human movement (53). Nevertheless, consulting recent articles available on Pubmed/Medline (4, 6, 28), we found that it continues to be used. We agreed that the use of the term (i.e. explosive) as colloquial jargon in practice might be useful for coaching cues (21) and informal communication between athletes and coaches. Although, in scientific literature, readers may be misunderstood to believe that explosive performance represents a distinct parameter to be evaluated and developed beyond force, power, impulse, torque, and rate of force development. The dissemination of this inconsistent mechanical concept (i.e., *explosive* performance) may induce nonsensical and redundant physical evaluations and exercise prescriptions (e.g., strength, power, and *explosive* force performance).

Following the recommendations stated by Winter et al. (53), if sport and exercise science research wants to be recognized as an established and credible area of application of science and so advance, terms and vocabulary to describe the performance of exercise must abide by principles of mechanics laid down by Newton and in turn, use the SI. The presented article was conceived to improve the quality of the studies and contribute to proper communication among sports science areas, students, coaches, nutritionists, and athletes. For this purpose, we aim to discuss the use of the term *explosive* in sports science literature, propose possible solutions, and encourage the use of correct definitions of terms, nomenclature, measurements, and units to describe exercise performance.

APPROPRIATE TERMINOLOGIES, MEASUREMENTS, AND UNITS

Consulting the most recent articles available on Pubmed/Medline (search performed in June 2021), the term *explosive* is associated with *force* (48), *strength* (38), *power* (29), *performance* (46), *exercise* (41), *movements* (5), *contraction* (28), and *training* (25). It is employed in the description of high-intensity brief tasks (e.g., jumps, kicks, sprints, strikes, throws, and weightlifting) (21, 53), performance on neuromuscular evaluations (4, 28, 32), and in the description of strength and power training exercises as the plyometrics (36).

The following sections will discuss the rationality in the associations of the term *explosive* with *force*, *power*, *training*, and possible solutions. For this purpose, we will present force-time data Figures obtained in our laboratories during a maximal voluntary contraction (MVC) test and a vertical countermovement jump recorded on a force plate. The MVC test was conducted in a 45° leg press machine (Tonus fitness equipment®, model RT 009). The equipment was adjusted so that the knee and hip relative angles during the isometric action were ~70° and ~130°, respectively (0° for full extension). Force was acquired at a rate of 1000 Hz and measured by a load cell (Reaccion® model CZCB-500) attached to the equipment. A pre-conditioner signal (DataHominis Ltda, C500 model) of 5 to 1000 kg capacity was employed for load cell data acquisition. During the late off-line analysis, the load cell signal was converted to newtons and smoothed by a low-pass digital fourth-order Butterworth filter by using a cut-off frequency of 15 Hz (3). The testing protocol consisted of instructing individuals to exert force as fast as possible for ~3 seconds and then soon relax.

A young female (23 years old) handball player performed the vertical countermovement jump on a force plate (Advanced Mechanical Technology, INC, USA, AMTI®, Model OR6-7-1000). The individual was instructed to jump as high as possible while keeping their hands-on-hips. Knee and hip flexion magnitude during the countermovement was self-selected. The frequency sample was set at 1000 Hz, and during the late off-line analysis, the ground reaction force signal was smoothed by a low-pass digital two-order low-pass Butterworth filter by using a cut-off frequency of 200 Hz. All Figures and parameters were obtained through specific routines created in MatLab 2020b software (The MathWorks Inc, Natick, Massachusetts, USA).

EXPLOSIVE FORCE/STRENGTH

In general, some studies consider explosive force/strength as to the increase force as quickly as possible during a rapid voluntary muscle action (4, 6, 28). The most common neuromuscular performance test used to evaluate this ability in laboratories is the maximal isometric voluntary action test or simple MVC or one-repetition maximum (1-RM) test. The test may be conducted using commercial isokinetic or custom-built dynamometers incorporating a linear strain gauge load cell (28). The resultant force-time curve analysis may provide three main parameters: 1) peak force; 2) contractile rate of force development (RFD), and 3) contractile impulse. Figure 1 presents a force-time curve obtained during an MVC test performed by a young (25 years old) resistance-trained individual in a 45° leg press machine.

The peak force is considered the highest force value achieved on the test. Contractile RFD may be defined as the slope of the force-time curve over time intervals of 0-30, 0-50, 0-100, and 0-200 ms relative to the onset of muscle action (4), or by the maximum value of the first derivative of the force-time curve (dF/dt) (32) - see Figure 2.

Impulse ($\overrightarrow{I}$) is a vector quantity that can be determined by integrating force to time (see Eq. 1), which will essentially yield the area under the force-time curve (35). Readers interested in detailed methodological considerations about the RFD evaluation are invited to access the excellent review provided by Maffiuletti et al. (28).

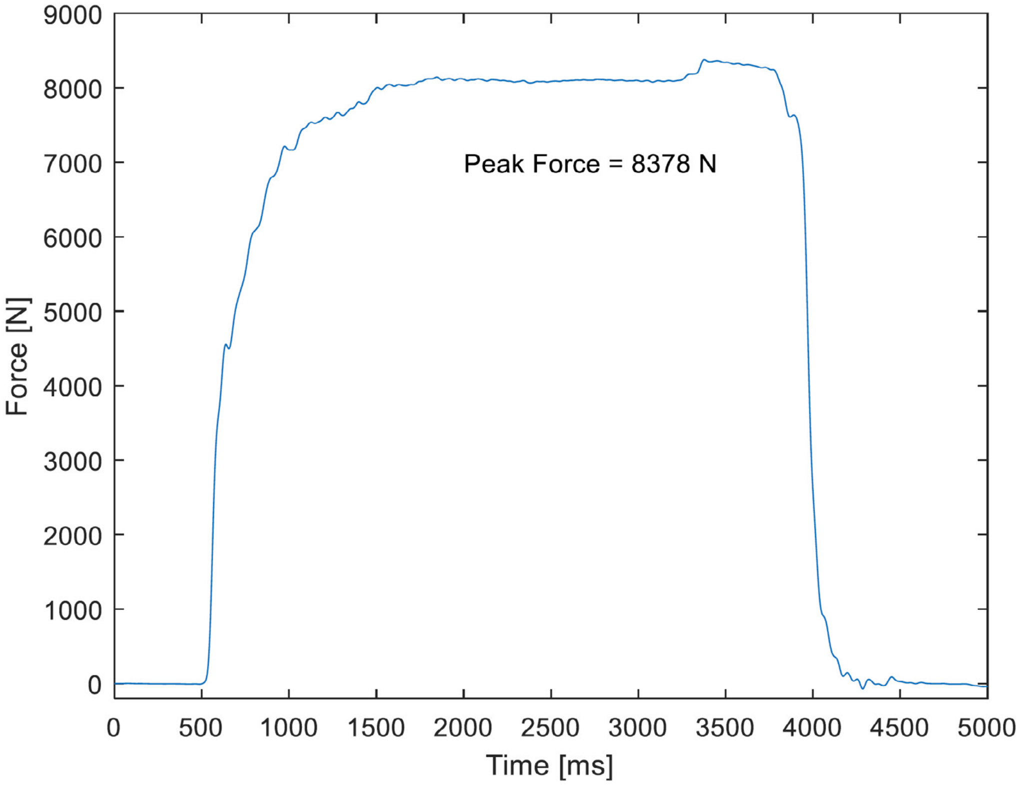

Figure 1. Force-time curve obtained during a maximum voluntary action test performed in a 45° leg press machine. The result is from a young male (25 years old) resistance-trained individual, and the peak force achieved was 8378 N.

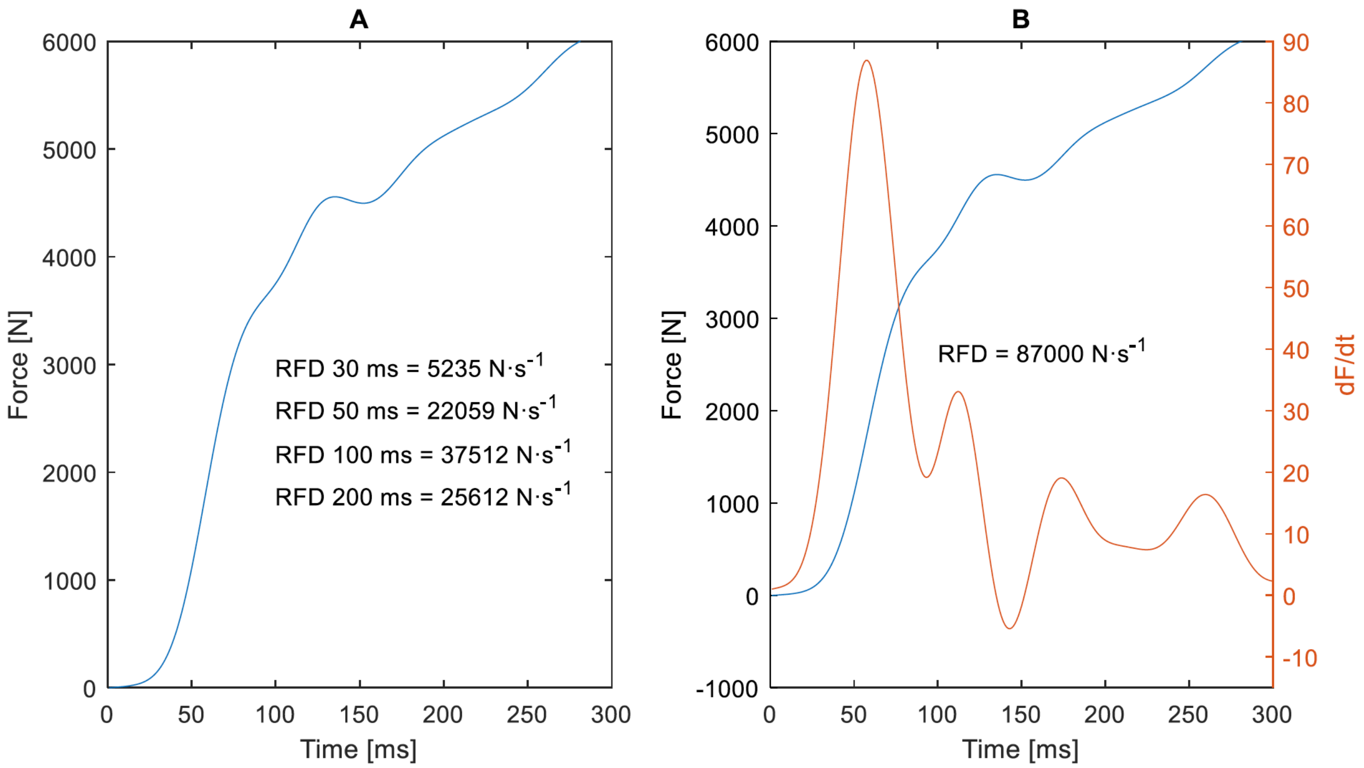

Figure 2. Analysis of the contractile rate of force development (RFD) as the slope of the force-time curve over time intervals of 0-30, 0-50, 0-100, and 0-200 ms relative to the onset of muscle action (A), and by the maximum value of the first derivative of the force-time curve (B).

$$\vec{I} = \int_{t_1}^{t_2} \vec{F}_x \, dt$$

Equation 1.

Where, ($\vec{F_x}$) is the magnitude of the force.

Previous research has indicated that RFD differs between different levels of athletes (28). Therefore, the ability to properly quantify and interpret the parameter is important for researchers in exercise science. Contractile RFD, rather than peak force, becomes of paramount importance for performance because in a range of strength and power sports (e.g., sprint running, karate, jumping), the time allowed to exert force is typically minimal (~30-250 ms) (3). Thus, a high contractile RFD exerted during the initial phase of muscular action may be more relevant for successful performance than peak muscle force because this last parameter is only reached more than 300 ms of the force-time curve (1, 2).

In summary, when a MVC accesses neuromuscular performance, the parameters obtained from the force-time curve analysis (i.e., peak force, RFD, and impulse) must be expressed according to respective SI units; newtons (N), newtons per second ($N{\cdot}s^{-1}$), and newton-seconds (N·s), for peak force, RFD, and impulse, respectively. Once these specific parameters (i.e., peak force, RFD, and impulse) can be reported according to respective physical quantities and SI units, the association of the term explosive is incorrect and unnecessary. Unfortunately, several studies have made the error of referring to these biomechanical concepts as 'explosive force' (11, 37, 40, 48) or 'explosive strength' (4, 9, 12, 15, 30, 38, 42). The use of these superfluous terms may cause confusion and misunderstanding as readers may believe that these constructs represent different parameters beyond those which were measured. Additionally, the use of the term explosive strength training has been used to refer to plyometric exercises (36). Nevertheless, plyometrics represents only one of the exercises that can be employed in strength and power training programs, which often involve traditional resistance training, ballistic exercises, and weightlifting (14). Since readers may be misunderstood to believe that explosive force or explosive strength are different parameters beyond those cited above, we recommend that the term explosive should not be associated with these physical quantities.

EXPLOSIVE POWER/TRAINING

The use of the term explosive power has been often used when referring to the assessment of vertical jumps (i.e., squat and countermovement jump) performance (7, 10, 19, 29, 31, 49). Nevertheless, consulting the studies (7, 10, 19, 29, 31, 49), the explosive power analysis was basically the jump high, expressed in m or cm, making the term explosive power inappropriate.

Mechanical power is expressed as the first derivative of work in function of time (dW/dt). Considering a particle moving with instantaneous velocity, the particle undergoes the displacement in a short time interval (45) (see Eq. 2). Thus, power can also be expressed as the product of force and velocity (see Eq. 3).

$$dW = \vec{F} \cdot dx = \vec{F} \cdot \vec{V} dx$$

Equation 2.

$$P = \frac{dW}{dt} = \vec{F} \cdot \vec{V}$$

Equation 3.

Work is a scalar quantity expressed when the force moves an object through a displacement in the direction of the force. It represents the transfer of energy by a force that can be positive, negative, or zero. The work done by a constant force is represented graphically as the area under the force versus displacement curve (see Eq. 4) (45). Although force is not constant during sports and daily activities, so work equals the integral of force concerning displacement (see Eq. 5) (45).

$$W = \overrightarrow{F_x} \Delta x = \overrightarrow{F_x} \, |\Delta x| cos\theta$$

Equation 4.

$$W = \int_{x_1}^{x_2} \overrightarrow{F_x} \, dx$$

Equation 5.

Where, $(\overrightarrow{F_x})$ is the magnitude of the constant force, and the magnitude of the displacement (x) of the point of application of the force, and θ is the angle between the directions of the force and displacement vectors. Δx is the change in displacement.

Work is the measure of energy transferred by force, and power is the rate at which a force does work. The SI-derived unit of work is the joule (J), which results from a newton and a meter (N·m). Power is a scalar quantity, with the SI-derived unit of the joule per second, connoted as the watt (W). Neuromuscular power is often connoted as a determinant mechanical aspect in the description and performance of high-force and high-velocity brief tasks (e.g., jumps, kicks, sprints, strikes, throws, and weightlifting). In this context, a concern must be addressed because external force and mechanical power are not direct muscle strength and power (47). Mechanical power may be estimated via joint power directly or via the sum of kinetic, frictional, gravitational, and environmental power (47). Nevertheless, it is complicated to consider short-duration, high-intensity activities as *power* events and hence incorrectly extend the assessments of power in the description of performance in activities (39).

A particular concern already highlighted in the literature is the association of *power* with jump performance (39, 52). The attempts to justify the use of *power* in this movement are based on the strong relationship between this measure and jump height (27, 39). Although the ability to jump either horizontally or vertically is mainly dependent on the velocity at take-off (see Eqs. 6 and 7), so the correlation between jump height and take-off velocity is perfect (i.e., precisely 1) (27, 39).

$$\frac{1}{2} m \cdot V_{to}^2 + m \cdot g \cdot h_{to} = \frac{1}{2} m \cdot V_{to}^2 + + m \cdot g \cdot h_{peak}$$

Equation 6.

$$h_{peak} = \frac{V_{to}^2}{2g}$$

Equation 7.

Where m is the individual's body mass; h_{to} is the height at the beginning of the jump; h_{peak} is the peak height achieved during the jump; V_{to} is the take-off velocity, and g is the acceleration due to gravity.

According to Eq. 7, the calculus of peak height achieved during the jump depends on the take-off velocity. When available, standard equipment used to determine take-off velocity and jump high is a force platform. According to Newton's third law of motion, the force platform measures the force exerted on it by the individuals, giving the force

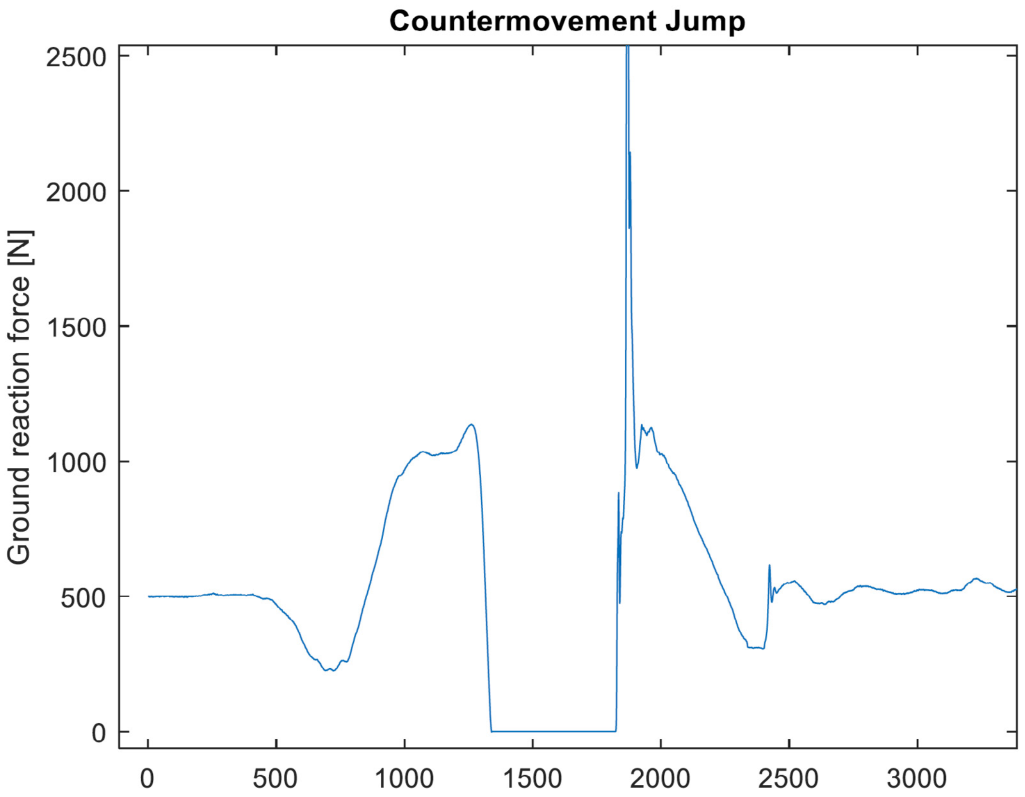

Figure 3. Ground reaction force data of a countermovement jump performed by a young female handball player on a force plate.

exerted by the platform on the individual. In human movements, the force exerted by the platform on the body is commonly called the *ground reaction force* (26). Figure 3 presents the ground reaction forces recorded during a vertical countermovement jump recorded on a force plate.

Once this data is available, take-off velocity can be calculated by three distinct methods: 1) the flight time of the jump; 2) the impulse-momentum theorem to the force-time curve; 3) the work-energy theorem to the force-displacement curve (see Eqs. 8, 9 and 10, respectively) (26). Readers interested in a detailed analysis of standing vertical jumps using a force platform are invited to access the excellent paper provided by Professor Nicholas P. Linthorne (26).

$$V_{to} = \frac{g \cdot t_{flight}}{2}$$

Equation 8.

Where t_{flight} is the flight time.

$$\int_{ti}^{to} F_{GRF}\, dt - \int_{ti}^{to} m \cdot g\, dt = J_{GRF} - J_{BW} = m \cdot V_{to}$$

Equation 9.

Where J_{GRF} and J_{BW} are the impulses due to the ground reaction force and individual's body weight, respectively.

$$\int_{yi}^{yo} F_{GRF}\, dy - \int_{ti}^{to} m \cdot g\, dy = W_{GRF} - W_{BW} = \frac{1}{2} m \cdot V_{to}^2$$

Equation 10.

Where W_{GRF} and W_{BW} are the work done on the individuals by the ground reaction force and the work done on the individuals by gravity, respectively.

From Newton's second law of motion, the take-off velocity is attributable to the initial impulse (see Eq. 1). It is enshrined in the impulse-momentum relationship, not its ability to generate power (39, 52). Therefore, research into jumping that seeks meaningful explanations of performance should focus on factors such as jump height, impulse and RFD (39), making the term *explosive power* inconsistent when discussing jump performance.

Additionally, ground reaction force and net impulse appear to determine the resultant performance not just in jumping but also during sprint running (34, 50, 51). Measures, such as running speed, acceleration, and horizontal external power, may represent sprinting performance (34). At the start of a sprint (i.e., in accelerated running from a standstill), the generation of forward (horizontal) acceleration is likely the most important performance-determining factor (17, 34). An increase in sprinting velocity can only be achieved by upsetting the balance between propulsive and braking impulses so that the runner gains a surplus of propulsive impulses (17, 34).

Nagahara et al. (34) study aimed to clarify the mechanical determinants of performance during a single sprint. Eighteen male athletes performed a 60-m sprint over fifty-four force platforms connected to a single computer. Ground reaction force was measured at every step over a 50-m distance from the start. During the maximal speed phase, accelerations at 55%, 65%, 75%, 85%, and 95% of maximal speed and running speed were determined as sprinting performance variables. Stepwise multiple regression analysis selected propulsive and braking impulses as contributors to acceleration at 55%-95% and 75%-95% of maximal speed, respectively. The study results demonstrate that a large propulsive force during the acceleration phase while suppressing braking force when approaching maximal speed and producing a large vertical force during the maximal speed phase, are essential for achieving greater acceleration and maintaining higher maximal speed (34).

The ability to generate maximal power is influenced by the type of muscle action, the time available to develop force (see force-time curves on Fig. 1 and 2), the storage and utilization of elastic energy, interactions of contractile and elastic elements, and the stretch reflexes (13, 14, 16). Maximal muscular power output may be defined and limited by the force-velocity relationship (13, 14, 16), which can be classically explained by Hill´s hyperbolic equation (18) (see Eq. 11). Since isolated muscle fibres, whole muscles, and living organisms, various levels of organization have been used to study the relationship.

$$(F + a) \cdot (V + b) = b \cdot (F_0 + a) = a \cdot (V_0 + b) = k$$

Equation 11.

Where F is force; a is the parameter corresponding to force; V is velocity; b is the parameter corresponding to velocity; F_0 is the maximum isometric force at null velocity; V_0 is the maximal velocity at null force; k is a constant.

The functional importance of the Hill equation is that it allowed scientists to distinguish between slow-twitch and fast-twitch muscle fibres clearly and, using this relationship, develop force-power curves and determine peak power (8). In this context, the search for optimal loads for maximizing mechanical power output in different exercises is particularly interesting

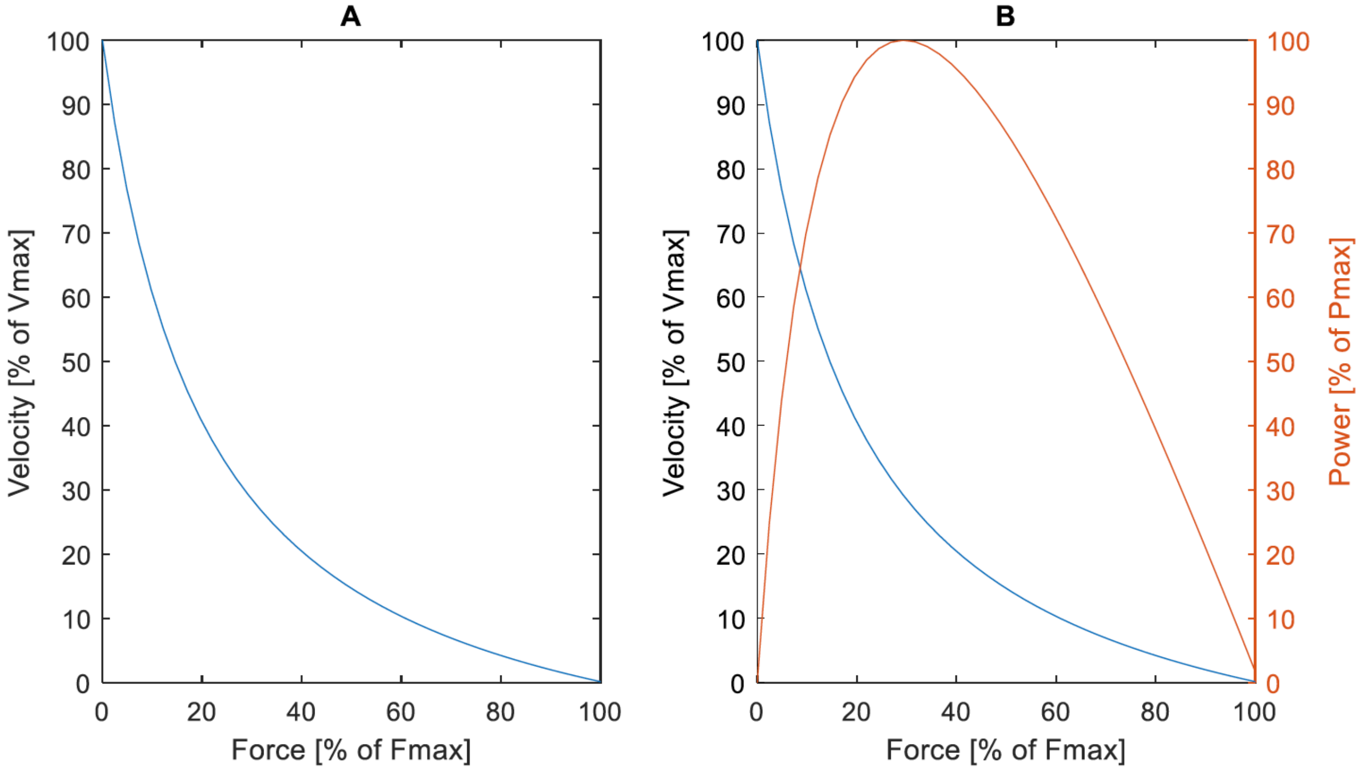

Figure 4. Force-velocity (A) and force-velocity-power curves (B). Data generated were based on the parameters of Hill´s hyperbolic equation (18). Force, velocity, and power were normalized to maximum force (Fmax) velocity (Vmax), and power (Pmax), respectively.

for strength and conditioning coaches (43, 44). The studies conducted by Soriano and coworkers (43, 44) showed other optimal loads for each exercise. Moderate loads (from >30 to <70 % of 1-RM) appear to provide the optimal load for power production in the squat exercise. Lighter loads (≤30 % of 1RM) showed the highest peak power production in the jump squat, and heavier loads (≥70 % of 1RM) resulted in greater peak power production in the power clean and hang power clean (43). Regarding upper body exercises, moderate loads (from >30% to <70% of 1RM) appear to provide the optimal load for peak power and mean power in the bench press exercise, and lighter loads (<30 % of 1RM) appear to provide the highest mean and highest peak power production in the bench press throw exercise (44). Figure 4 presents the force-velocity and force-velocity-power curves obtained based on Hill´s hyperbolic equation (18).

In short, strength and power training encompass short-duration activities performed at high- or near maximal intensities, increasing the capacity to perform high-force, and high-velocity efforts (13, 33). Theoretically, the use of both low-load high-velocity, or high-load low-velocity may impact the area of the force-velocity relationship differently (13, 14, 16). Heavy resistance training can increase the ability to generate peak force and RFD (20). Conversely, ballistic exercises can increase the overall RFD that is greater than what can occur with heavy resistance training. However, ballistic training cannot increase the overall maximal strength levels to the same extent as heavy resistance training. Therefore, a mixed training approach is often recommended to maximize the RFD and power output (20).

In summary, since mechanical power is the rate of energy transfer, it is easy to understand why explosive becomes a nonsensical term to be associated with. Therefore, during brief high-intensity tasks, such as jumps and sprints, neuromuscular performance should be described via the ground reaction force and net impulse. Thus, we also recommend that the term *explosive* should not be associated with high-intensity brief tasks like jumps, sprints, kicks, strikes, throws, and weightlifting.

Regarding training stimulus, the term explosive training can be easily replaced by the specific exercises employed in strength and power training programs (e.g., traditional resistance training, ballistic exercises, plyometrics, and weightlifting). Strength and power exercises can be classified using high-force, and high-velocity efforts, impacting the force-velocity relationship differently. Thus, force, work, and power are the basic mechanical concepts to describe the muscular activity, function, and the classification of training stimuli, making the term *explosive* training incorrect and unnecessary.

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FINAL CONSIDERATIONS

The inappropriate use of standardized mechanics terms may create numerous problems for students, coaches, athletes, and scientists in sports and exercise science. We recognize that the term *explosive* is used as colloquial jargon in practice, which may be useful for coaching cues (21) and informal communication between athletes and coaches. However, it has no rationale to be used in scientific literature with this purpose. Considering the importance of quantifying exercise performance, we recommend abolishing the term explosive according to the classical mechanics' concepts. The basic mechanical proprieties of the neuromuscular system (e.g., force, work, and power) must always be used to describe the muscular activity and classify training stimuli. Our suggestions would help reduce the confusion and perpetuation of an erroneous understanding of mechanical work, energy, and power in sports, providing consistent and clear communication between students, coaches, athletes, and sports scientists, as well as scientists of other areas.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest relevant to the content of this article.

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