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Review Article

ASSESSING STRENGTH AND POWER IN RESISTANCE TRAINING

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ABSTRACT

Maximal Dynamic Strength is usually assessed either by the one repetition maximum test (1-RM) or by a repetition maximum test with submaximal loads, which requires the application of a formula to estimate the value of 1-RM. This value is needed to establish the objective of resistance training: such as maximum strength, endurance strength, and/or explosive strength. However, both 1-RM and submaximal tests are unable to highlight the changes produced on power and velocity. This manuscript summarizes and reviews several common strength testing protocols and proposes a novel approach that may offer greater insight to hierarchical muscle functionality.

Key words: *1-RM test, progressive load, velocity, power*

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INTRODUCTION

Strength is an essential function of the human body, which can manifest itself in various ways, depending on individual conditions and objectives used to perform different actions or exercises (Siff, 2004). The term strength can be employed to identify the force or torque developed be a muscle during a particular joint movement (Knuttgen et al., 2003). However an infinite number of strength values may be obtained depending of the type of action (isometric or dynamic), the velocity of the action, and the load mobilized when the measurement is accomplished (Knuttgen & Kraemer, 1987). Therefore, the main goal of this paper is to review the most frequently used protocols to evaluate muscular strength and to propose a progressive testing protocol, which can be applied to estimate the maximal value of force and power produced with light and heavy load in each assessed resistance training exercise.

Estimation of maximum strength from 1-rm and maximum repetition test

The value of maximum dynamic strength (MDS) is generally associated with the maximum weight that can be moved throughout an exercise for a single repetition (Brown & Weir, 2001; Fleck & Kraemer, 1997). This value of maximum weight is commonly determined by 1 repetition maximum test (1-RM), and is applied to obtain a reliable measurement of the maximum force production that a subject can generate with a correct technique (Sale, 1991). However, the 1-RM test does not measure maximum strength but a mass value or resistance (kg) that a lifter can perform in a single full movement during a designated exercise (Simpson, Rozenek, Garhammer, Lacourse, & Storer, 1997). As this definition implies, the 1-RM test goal is to mobilize the greatest possible resistance through a specified range of movement, without additional feedback on the rate of force development (RFD), or time spent producing the movement.

Despite the numerous purported concerns regarding the high risks associated with 1-RM testing, no conclusive studies directly relate the application of this test to the incidence of injuries (Faigembaum, Milliken, & Westcott, 2003; Ware, Clemens, Mayehew, & Johnston, 1995). With regard to training for sport, the value of the 1-RM test is an essential parameter, which may be used to determine the percentage of load to be used during strength training (Sale, 1991; Siff, 2004). This value provides a quantified starting point from which relative training intensities may be prescribed to elicit specific training objectives, including: maximum strength, strength speed, hypertrophy or muscle endurance (Fleck & Kraemer, 1997; Morales & Sobonya, 1996b). Usually, tests to evaluate muscular strength are applied to the most important exercises performed, in order to establish an index of the general and specific strength of the individuals throughout a training period (Brown & Weir, 2001; Rodríguez & Chagas Gomes, 2003).

Repetition Maximum tests to reach the value of 1 RM

Despite the fact that the 1-RM test is the most accepted method to determine the maximum weight in a specific exercise, it nevertheless constitutes a method that requires significant familiarization and mental preparedness, which is often not feasible (Ware et al., 1995). For this reason, many researchers have tried to develop alternative methods to estimate the value of the 1-RM in an indirect manner, by carrying out sets until exhaustion with sub maximal loads (Lesuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997). At present, numerous regression models have been proposed to allow the prediction of the 1-RM value without having to produce maximal force production through dynamic actions. Most of these equations have been scientifically validated and can be readily applied to estimate the 1-RM value in several exercise and subject with different levels of performance (Kravitz, Akalan, Nowicki, & Kinzey, 2003; Lesuer et al., 1997; Wood, Maddalozzo, & Harte, 2002).

Further, it has been theorized that sub maximal testing has a reduced tendency to produce injuries in comparison with the 1-RM test but no studies have demonstrated this assertion. Also the maximal repetition tests with submaximal loads are susceptible to error, as test outcomes, (i.e. number of performed repetitions) may be affected by the onset and accumulation of fatigue. As such, this system does not represent a direct index of maximum force production, but rather, is utilized to predict 1 RM values (Brown & Weir, 2001; Reynolds, Gordon, & Robergs, 2006).

Several researches have been investigated the validity, precision or the accuracy of the most important equations developed in previous resistance training works.

Lessuer et al. (1997) carried out a study with 67 students of low training status (*n*= 40 men and 27 women), with the intention to evaluate the validity of 7 distinct equations to predict true values of 1 RM for three different exercises, including bench press, squat and deadlift. Subjects were required to perform one set with sub maximal loads until exhaustion on each of the exercises. It was noted that the predictions of the maximum weight (i.e. true 1RM values) were more accurate whenever 10 repetitions or fewer were performed, per set. The seven equations demonstrated high correlation coefficients (>0.95) with the value of the 1-RM, determined by the traditional maximal strength test. However, the exponential formula developed by Mayhew et al. (1992) as well as the one by Wathen & Roll (1994) showed a lower margin of error in the prediction of the maximum load, especially when the intensities used allowed for only 3 to 10 repetitions to be performed. Within that range, the relationship between the repetitions and the magnitude of the weight lifted was practically linear whereas, with very heavy weights (i.e. permitting only 2 repetitions) or with very lightweights (i.e. that allow more than 10 repetitions), the relationship become exponential and showed a curvilinear relationship between 1 RM and repetition to fatigue. Figure 1 shows the relationship between percentage of 1 RM and maximum repetitions achieved until failure in the bench press exercise by a group of physical education students from the European University of Madrid (*n*=11). After determining the 1 RM value and allowing 72 hours of rest, the maximum repetitions to failure for 8 different sub maximal percentages was assessed (30%, 40%, 50%, 60%, 70%, 80%, 90% and 95% of 1 RM) (non published data) . These data show an exponential relationship where $\%1RM = 0.951^{(-0,021*rep)}$ ($p<0.001$) with a correlation coefficient of = 0.95 and standard error of estimate of ±4.2%. Therefore the percent 1 RM could be estimated reasonably well from this exponential relationship. However, as can be observed in figure 1, there is an intermediate zone between 3 and 10 RM where the equation is shown to be more accurate.

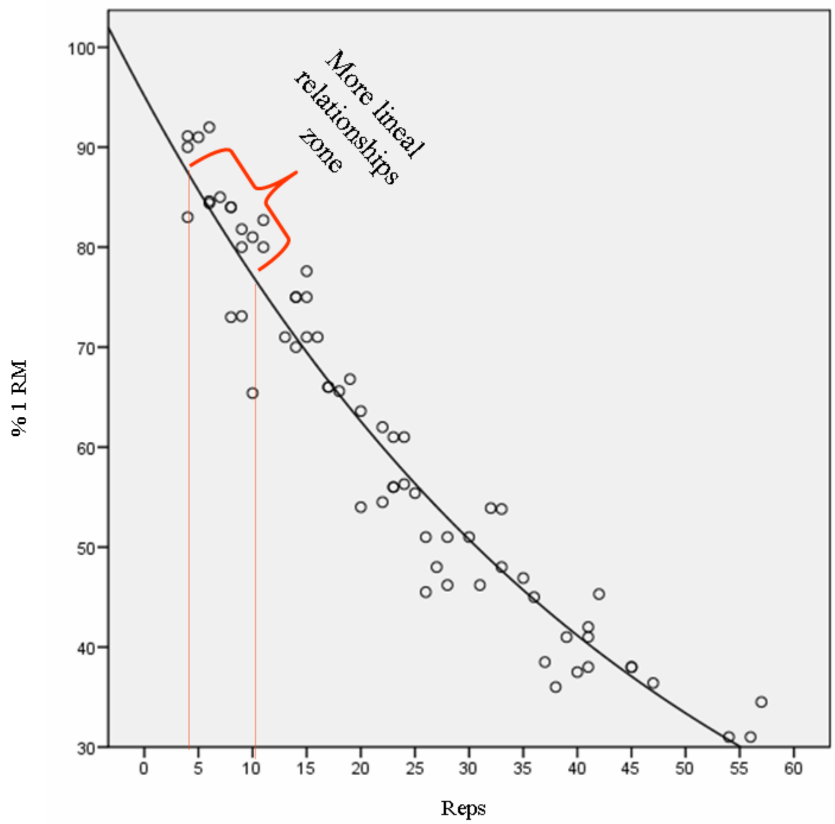

Figure 1. *Relationship between percent 1 RM and repetitions to failure in the bench press. The arrows indicate the point where the relationship became exponential with heavy and light load, but it remains more linear between the 3 and 10 repetition maximum (intermediate zone).*

Among the linear formulas, the most accurate for the lower body was the Eppley formula. For the upper body the Mayhew et al. (1992) formula was shown to be the most accurate (see table 1).

Table 1 shows the summary of the equations analysed by Lessuer et al. (1997), the degree of correlation found and the recommended range of repetitions to predict the level of 1-RM with the highest precision.

Table 1. *Seven validated Prediction Equation for 1-MR*

Author	Formula	Strength of Correlation	Type of correlation	Repetition
BRZYCKI	% 1RM = 102.78-2.78 Rep 1RM = kg*100/ (102.78-2.78*rep)	High in upper body Moderate in Lower body	Linear	< 10
EPPLEY	1RM= (1 + O,033 * rep) * Kg	High in upper body High in Lower body	Linear, Overestimate the 1-RM	<15
LANDER	% 1RM = 101.3 – 2.67123 Rep	High in upper body Moderate in Lower body	Linear, underestimate the 1-RM	<15
MAYHEW et al.	**% 1RM =** 52.2 + $41.9^{(e\ (-0.055*\ rep))}$ 1MR= 100*kg/**%1RM**	High in upper body High in Lower body	Exponential, underestimate in upper body and Overestimate in lower body	6 to 20
WATHEN	**% 1RM**=48.8 + $53.8^{(e\ (-0.075*rep))}$ 1MR= 100*Kg/**%1RM**	High in upper body High in Lower body	Exponential, underestimate the 1RM	< 10
O`CONNER et al.	1MR = load*(1+0.025 *rep)	High in upper body High in Lower body	Linear underestimate the 1RM	< 10
LOMBARDI	1 RM = rep + Kgr $(Rep)^{0.1}$	High upper and lower body	Exponential	< 10

Rep: maximum repetition doing in the test, kg: load utilized during the test. Adapted from Lessuer et al. (1997)

In another more recent study, Wood et al. (2002), compared the reliability of the same 7 equation analyzed by Lessuer et al. (1997) but they utilized a sample of 49 sedentary people (26 men and 23 women of 53.55±3.34 years that were evaluated in 10 upper and lower machine resistance exercise with percentage compresses between 50% to 90% of the predetermined 1 RM. The findings were the same as Lessuer et al. (1997), and showed that the equations of Mayhew et al. (1992), Eppley (1985) and Wathen and Roll (1994) are the most accurate, specially when the range of repetitions is less or equal to 10. However, all the equation underestimated the 1 RM values showing variable differences for each exercise.

In another study, Morales and Sobonya (1996a) analyzed the variables that have a major impact on the prediction of the maximum strength on 23 athletes (*n*= 16 American football players and *n*= 7 track and field throwers) who performed 1 RM test the bench press, squat and power clean exercises and then performed a series to failure over 6 percentages (70%, 75%, 80%,85%, 90% and 95%) and calculated a linear regression equation to estimate the 1 RM value for each percentage and exercise. The results of this study show that the estimation was more precise with heavier weights closer to 95% (2-3 RM) in bench press, whereas loads near 80% were more precise for the squat (8-9 RM). For the power clean, however, the best results were obtained with weights closer to 90% (4-5 RM) (Morales & Sobonya, 1996b). The authors also pointed out that the there are two principal factors effecting the accurate of the equation.

(1) The size of muscle cross sectional area.
(2) The specific muscle involved in each exercise.

According to the current literature, the accuracy of the submaximal tests to volitional fatigue, the use of light weights (e.g. lower than 75% of the 1RM), may influence the number of maximal repetitions, and thus, the predictability of the true 1RM. Furthermore, level of fitness and training experience has also been shown to impact performance on these tests, however, with submaximal loads that approach a true 1 RM (e.g. 95% of 1RM) one can also underestimate the 1-RM. This error may occur for lesser trained populations who are not accustomed to heavier loads, as neural factors (e.g. inhibitory processes by proprioceptive mechanoreceptors) could prematurely inhibit the production of strength (Enoka, 2002).

According to Rodriguez et al. (2003), the estimation of the 1-RM value among highly trained individuals using a submaximal strength test with many repetitions does not constitute a very reliable approach because the specific adaptations produced by training with heavier weights induces physiological changes that are not utilized when overcoming resistances with weights that are lower than 75%. Although the traditional 1-RM test still remains the most applicable method to determine the value of maximal strength, it is accepted that maximum repetition tests with sub maximal weights are a valid way to safely estimate the value of the 1-RM, if applied with correct technique (Siff, 2004). To further improve the efficacy of this approach, the following recommendations should be taken into consideration:

1) Linear equations are less precise with both heavier weights (i.e. more than 95%of 1RM) and with lighter weights (i.e. lower than 70% of 1RM) as the relationship between the maximum possible repetition is influenced by metabolic factors besides the levels of strength (Reynolds et al., 2006; Ware et al., 1995).

2) The use of light weights that allow for more than 10 repetitions is not recommended, especially among individuals who train for maximal strength adaptations. It is advisable to use weights allowing less than 10 RM, with 6 and 10 RM being ideal (i.e. 78-90% of the theoretical 1-RM) (Lesuer et al., 1997; Mayhew, Mayhew, Ware, & Bowen, 2000).

3) Sub maximal tests are more precise with single joint assistance exercises (Knutzen, Brilla, & Caine, 1999). The most applicable formulas are the Mayhew formula, (upper body) and the Wathen formula (lower body). However the Eppley formula can also be accurately used especially for the lower body as well as for Olympic lifts (Knutzen et al., 1999; Lesuer et al., 1997).

4) When using traditional machines, the Brzycki formula has shown a good correlation with the 1-RM (Knutzen et al., 1999).

5) Testing with sub maximal weights can be very useful for young or older people who do not consistently train with maximum loads. For these populations, tests with sub maximal weights may be more appropriated instead of 1 RM maximal load assessment (Reynolds et al., 2006).

Applicability of the 1-RM Test and Sub Maximal Tests

Strength applied from the neuromuscular system cannot be completely assessed by simply considering the magnitude of the resistance lifted in a maximum effort, or by the number of repetitions carried out with a submaximal resistance. For that matter, testing strength should also not be limited to a simple evaluation of absolute or relative training loads (kg), as muscular strength is the product of two very well defined variables (Nigg, 2000):

a) The **mass** or **resistance**, which is measured in kilogram (kg)
b) The **acceleration reached by the resistance**, which is measured in $m \cdot s^2$.

As such, strength is expressed in Newton (N). When combined with a unit of distance, work may be effectively calculated (expressed in Joules (J)). One Joule is the work done by the force of 1 Newton when it's the point of application moves a distance of one meter, in the direction of the force. Therefore 1 J equals 1 Newton-meter (1 N x m) (Watkins, 1999).

Additionally, the velocity reached during each movement, can also be measured and be expressed as the time spent for displacement through a range of motion. This is measured in meters per second (m/s) and influences the time spent to perform the work or power that was defined as the rate of doing work, and is measured in Watts (1 W = 1 N x s) (Armtrong, 1993; Nigg, 2000).

By denoting strength in this regard, the force applied to an external body may increase, altering either one or the two factors determining it: the mass or the acceleration (Watkins, 1999). Regarding to the resistance exercise, the level of force applied, will basically depend of the magnitude of the opposite resistance (Baker, Nance, & Moore, 2001; Cronin & Sleivert, 2005).

The changes experienced by the external objects are directly proportional to the magnitude of the applied strength, as well as the time and the space during which the strength acts. Hence, when the neuromuscular system applies force on an external body ("non-fixed" body with a constant mass) it will achieve an acceleration which is directly proportional to the applied strength, and elicits a movement in the same direction. Similarly, the velocity reached throughout the displacement, or range of motion, is proportional to the magnitude of the strength transmitted. When performing exercise against gravitational resistance, with the intent to produce maximum acceleration, any increase in external load will result in a corresponding increase, in applied strength (N) and a decrease in acceleration. However the proportion by which the acceleration diminishes is greater than the degree to which the load of the mobilized resistance increases, and thus the generated strength increases in a similar manner as the mass of the resistance increases. In fact, the relationship between these two factors, (i.e. applied strength (N) and resistance (kg)), is very high especially when the resistances are over the 40% of the 1-RM (Siff, 2004).

Considering that velocity of movement is a consequence of the acceleration transmitted to an object, and is inversely related to muscular strength, lighter resistances will yield greater acceleration, and the greater velocity will be reached during the performance of a given exercise. However, it is necessary to point out that the potential to increase the acceleration of an external resistance diminishes with the increase of the load, so it is not possible to maintain the production of strength up to the theoretical maximum level when the resistance progressively decreases below their maximum. Accordingly, when the isometric maximum force (FMI) is produced the velocity reaches 0, and the resistance is at maximum. The value of the strength produced in Newtons is also maximum, but when the resistance decreases below the maximum and, in spite of the subject attempts to apply the maximum possible force to the submaximal load, the value of the strength produced in N will be less (Siff, 2004).

Exercise prescription for sports performance enhancement, should not only account for the strength level produced against maximal resistances, but also the capacity to apply the maximal strength against sub maximal resistance (less than 100%). This is a particularly important variable among strength-speed sports, such as soccer, volleyball and wrestling (Baker, 2001; Branderburg, 2005; DeRenne et al., 2001; Siff, 2004).

Clearly, not all athletes that have very high levels of maximal strength are able to apply greater force against lighter loads. Therefore the evaluation of the capacity to produce strength (N) against submaximal weights is a very important component of muscular functionality that must be analyzed and offers a better picture of the athlete's neuromuscular capacities (Baker, Nance, & Moore, 2001; Cronin & Sleivert, 2005).

While the 1-RM test is a valid tool to determine the maximum resistance that can be moved, this test does not elucidate the actual values of applied strength, nor does it demonstrate how the velocity and power parameters relate to each other in which sub maximal resistances are mobilized. These factors are important to control the various directions of strength that occur throughout a training process and to properly assess the functional adaptations of each athlete (Cronin & Sleivert, 2005; Chandler, 2001).

Baker et al. (2001), contend that the level of the 1-RM may remain stable and that variations may be produced in the abilities to apply strength, achieve velocity and produce power against sub maximal resistances. This variation may greatly influence the performance of numerous sports activities, establishing a control index of training which is even more valid that the 1-RM test.

In summary, both the 1-RM and maximum repetitions with submaximal load are applicable methods to assess the strength levels throughout a training period in athletes or recreational physically active subjects (Fleck & Kraemer, 1997; Kraemer & Fleck, 2007). The performance of the 1-RM test requires a very important preparation on the execution of one or more maximum efforts for which not everybody is predisposed (adolescents, older adults, etc.). In such cases it is recommended to apply repetition maximum tests with sub maximal weights. Although a sub maximal test constitutes an alternative solution to avoid maximal efforts with very high resistances, it is necessary to use moderate to heavy loads that permit a range between 7 to a maximum of 10 repetitions (Lesuer et al., 1997; Reynolds et al., 2006; Rodríguez & Chagas Gomes, 2003).

Both the 1-RM test and the repetition maximum tests offer only one reference data point. The amount of weight lifted in a single maximum effort, which in some cases can be very important to assess the changes elicited by a training program, but it is not always completely accurate. Other factors exist such as the velocity and the power produced with various levels of weights, which may be greatly influenced by other adaptations caused by training, and is not preferentially taken into consideration in these tests.

Finally, in order to assess performance, it is necessary not only to know the lifted weight, but also the force applied, the speed, and the power achieved in each movement (Hori, Newton, Nosaka, & McGuigan, 2006).

A new proposal to evaluate the strength and power in resistance training

In the past several years, various devices that permit precise calculation of applied strength in Newtons, velocity and mechanical power produced during resistance exercise, such as, the squat, the bench press, or power clean have been developed (Hori, Newton, & Nosaka, 2005). These technological advancements have shown that the relationship between the level of weight lifted and velocity, or between the weight and the power, may vary due to the influence of specific factors such as the muscular groups utilized (upper or lower body), types of exercise (multiarticular or monoarticular), anthropometric characteristics of the subjects, or the performance of a specific type of training (Izquierdo, Häkkinen, González-Badillo, Ibáñez, & Gorostiaga, 2002). These parameters, relate not only to the level of the applied strength, but also to the velocity and power reached with different weights, and have proven to be factors that are related to specific neuromuscular characteristics of each person (Kawamori & Haff, 2004; Kawamori & Newton, 2006).

Experimental protocol description

To assess the neuromuscular characteristics of each individual performing resistance training a progressive resistance test (PRT) has been developed. The PRT permits simultaneous direct calculations of strength (N), velocity ($m \cdot s^{-1}$) and power (w), produced with different loads, and at the same time, determining the value of 1-RM or maximum load. To perform this test a special device is necessary. According to Hori et al. (2006) a rotational encoder constitutes a valid device to detect the position of the resistance during linear movements like those doing during resistance exercise. This data permits an estimate of the range of movement, acceleration, velocity, strength and the power produced during each action (Hori et al., 2006). The encoder sends data to an interface connected to a computer where a software program automatically calculates the averages and the peak values of strength (Newtons), speed (meters per second) and power (watt) produced during the concentric and eccentric phases of each exercise, see figure 2 (Baker & Newton, 2005).

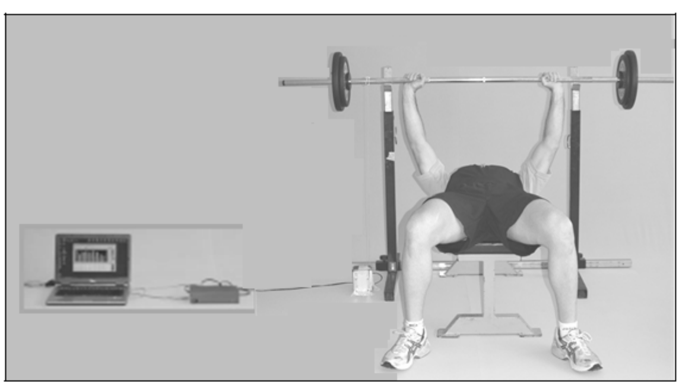

Figure 2. *Subject doing a bench-press with free weight, where the displacement of bar is controlled by a rotational encoder that measure the bar position during all range of motion. The encoder is connected with an interface that transfers the data to a personal computer where the software calculates the value of velocity, force and power show in table 2.*

The PRT consists the execution of 6 to 8 series of 2 to 3 repetitions, applying the maximum possible acceleration alternated with rest intervals of 2 to 5 minutes. The rest period is proportional to the intensity and duration of the effort, in order to avoid the prediction errors caused by the accumulated fatigue. The maximum power is usually produced in the course of the first three repetitions of a continuous series, especially with individuals of low bodyweight. Therefore, the recommendation is to perform three repetitions during the initial series, while two repetitions can be performed when the weights become heavier or approach maximum (Baker et al., 2001).

This system allows the tester to determine the value of the 1-RM and at the same time, to obtain the levels of strength, velocity, and power across a broad spectrum of loads ranging from the light (30 to 40%), to moderate (41 to 60%) heavy (61 to 80%) near maximum (81 to 90%) and the maximum (exceeding 90%). This categorization will provide a better description of how the neuromuscular system applies the strength against various magnitudes of load. For each magnitude of weight lifted, it is necessary to select the repetition with which the highest value of average power is reached, as this factor expresses the highest mechanical efficiency of the exercise (Morales & Sobonya, 1996b).

Determination of the Initial Weight (IW). Since the main objective is to evaluate the maximum strength across the widest spectrum of possible resistance's, the lightest load must be of adequate magnitude in which the expression of strength is significant to performance of the actions, and below the level where the factors related to the neural stimulation and the rapidity of the movement predominate. It is for this reason, that prior to testing, it is necessary to establish a load equivalent to approximately 30% of the predicted value of the 1-RM (Siff, 2004).

Estimation of the total sets to be performed. Once the initial load is established, it is necessary to avoid a very high number of sets which could elicit fatigue and negatively affects performance during the final stages of the test. Therefore it is recommended that the test do not take more than 8 series (Morales & Sobonya, 1996b). The 1st and 2nd series would be performed with lightweights (30 to 45%), the 3rd and the 4th with moderate weights (50 to 65%), the 5th and 6th with moderate-heavy weights (70 to 80%), and the 7th and the 8th with almost maximum and maximum weights (85 to 95% or 100%). By following this protocol, it is possible to cover the largest continuum of possible percentages, and theoretically target different strength outcomes (Morales & Sobonya, 1996b).

Estimation of the weight to be increased in each set. Once the initial weight (IW) and the final weight (estimated 1RM) have been determined, and the number of series is established, it is necessary to calculate the weight increase between series in order to be able to evaluate the relative load to prescribe. This increase is calculated according to the following formula:

(Estimated 1-RM (kg) – IW (kg)) / (Total series –1) = KIES (kg to be increase in each series)

Estimate 1-RM: predicted maximum load that the subject would lift at 1 RM.
IW: Initial load determined to begin the test
KIES: kg to be increase in each series

For example, if a level of 1-RM of 100 kg is estimated, the IW and

The kg to be increased in each series would be:

*100 * 30% = 30 kg*

kies = (100-30)/(8-1) = 10 kg

In this case the test would start with 30 kg, and there would be an increase of 10 kg in each series.

Test completion and estimation of the 1-RM. According to the estimated of 1-RM, the analysis of the strength parameters in real time, of velocity and power as well as the subjective perception of the effort expressed for each person at the end of each series, it is possible to check the load evolution throughout the test. Whenever the person approaches the value of a true 1-RM, the rest intervals will be increased to 5 minutes before the last series. During which, if the performance of the greatest number of possible repetitions is more than one, we can estimate the level of 1-RM applying one of the equations of table 1 (Lesuer et al., 1997).

Table 2 shows an example of the parameters that can be obtained when performing the tests in the bench press according to the above-mentioned example.

Table 2. *Variable that can be analyzed by a subject during a progressive test*

Subject	Body weight	67,5	Height	163	Edge	29	date	08/03/2004

Series	1º	2º	3º	4º	5º	6º	7º	8º
kg	30	40	50	60	70	80	90	100
reps	3	3	3	3	3	2	2	1MR
%RM	30%	40%	50%	60%	70%	80%	90%	100%
Time	0.38	0.42	0.5	0.58	0.69	0.82	1.2	1.86
ROM	0.43	0.42	0.41	0.43	0.4	0.4	0.39	0.37
VM	1.12	0.98	0.82	0.72	0.57	0.48	0.33	0.2
Vp	1.84	1.51	1.4	1.16	0.87	0.74	0.46	0.32
T Pv	0.57	0.6	0.66	0.75	0.87	1.04	1.41	2.15
WM	434.07	479.04	474.34	481.23*	419.55	400.93	295.2	199.75
Wp	924.52	899.68	1048.49	948.12	732.37	628.39	420.02	322.72
T Wp	0.25	0.3	0.36	0.43	0.51	0.58	0.78	1.72
N M	401.47	519.61	586.92	680.95	759.35	848.74	912.72	999.79
Np	617.53	790.04	765.33	895.07	1013.61	1122.79	1210.1	1336.22
Tpf	0.06	0.05	0.34	0.06	0.06	0.05	0.06	0.05

*Kg= Load of resistance in kg. reps= repetition for series. %MR= Percentage of 1RM. ROM= Range of motion in meters. VM= Average velocity (m/sec). Vp= Pick velocity (m/sec). Tpv= Time to reach the pick velocity (sec). WM= Average Power (Watt). Wp: Pick Power (Watt). Twp= Time to pick power (sec). NM= Average force applied (Newton). Np= pick force (Newton). Tpf= time to reach the pick force (sec). The shadowed part indicates the loads or percentages with which the maximal efficiency of movement can be achieved. *In the WM line the shadowed part indicates the loads or percentages with which efficiency of movement can be achieved. While the maximum power is reached with 60 kg (60%) the power produced with 40 kg and 50 kg are very similar. The range of loads with which the greatest power may be achieved where defined as the zone to train specifically to increase the power of the movement (Baker et al., 2001; Cronin & Sleivert, 2005).*

CONCLUSIONS AND FINAL RECOMMENDATIONS

The system of evaluation proposed has already been applied in various studies with different athletes (Izquierdo et al., 2002; Naclerio, Forte, Colado JC, Benavent, & Chulvi, 2007). These studies have demonstrated that this protocol not only permits the evaluation of the 1-RM but the manner in which each person applies force according to the various magnitudes of weight. It also enables the calculation of an integral profile of the performance, by taking into consideration the strength, the velocity, and the power produced. This valuable assessment enables the distinction of a range of loads wherein force is most efficiently applied and the maximum power are produced. The establishment of this range is vital to infer the effects of training, as well as to realize the transfer to performance (Baker, 2001; Dugan, Doyle, Humphries, Hasson, & Newton, 2004).

Although performing this test requires a specific testing device, the availability of these technologies should not constitute a large limitation for strength and conditioning coaches, or sport-conditioning facilities. The incorporation of this type of device allows the efficient monitoring of the evolution of the real results obtained by the athlete or recreational lifter, whatever their objectives are, ranging from performance to health.

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