The Influence of Strength and Power on Muscle Endurance Test Performance

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Abstract

Naclerio, FJ, Colado, JC, Rhea, MR, Bunker, D, and Triplett, NT. The influence of strength and power on muscle endurance test performance. *J Strength Cond Res* 23(5): 1482–1488, 2009—The aim of this study was to determine the importance of muscular strength and power on a muscular endurance performance test. Fourteen firefighter recruits performed a progressive resistance test (PRT) followed by a specific maximum repetition test (MRT40) on the bench press exercise with measurements of power, strength, and muscular endurance. Comparisons were then made to examine relationships between the 3 muscular fitness variables. The results, expressed in absolute form and related to body weight, indicate that the performance in the MRT40 is significantly related ($p \leq 0.05$) to body weight ($r = 0.78$), 1 repetition maximum (1RM) ($r = 0.83$), maximal power (Pmax) during the PRT ($r = 0.71$), Pmax produced with 40 kg in the PRT ($r = 0.64$), and the average power and force applied during all repetitions in the MRT40 ($r = 0.78$ and $r = -0.64$, respectively). The load that expressed the maximal average power during the PRT was 47.6 ± 9.0% of the 1RM and did not show any significant relationship with 1RM nor performance in MRT40. It was concluded that performance in this specific upper body endurance test depends on several variables, among which maximum strength, body weight, and maximum absolute power are the most important. As the ability to repeatedly apply submaximal force is a requirement of firefighters, and other occupations/sports, the current research suggests that the initial goal of a training program to enhance muscular endurance should be to increase maximum strength to a point that the specific load being lifted during repeated actions is less than 40% of the individuals' 1RM. Subsequent training should then focus on maintaining maximal strength levels and improving local muscular endurance in the specific task.

Key Words bench press, maximal force, repetition test

Introduction

Performance in many sports, some occupations, and some special tests of work selection depends on the capacity to apply strength at the highest possible speed (power) and to perform repeated submaximal muscular actions. Several studies (3–5,7,9,10,13,29) have analyzed the power produced during different resistance exercises as a fundamental variable to determine performance and also the effect induced by training. However, as Dugan et al. (15) and Cronin and Sleivert (13) indicated, there are still no uniform criteria with regard to the best way of measuring power levels or the degree to which power can influence performance in different physical activities.

It has been shown that the individuals who can produce a greater amount of maximal force are able to generate greater power at the same load compared with weaker individuals. In addition, they tended to produce maximal power (Pmax) at a lower percentage of the 1 repetition maximum (1RM) (5). Based on the close relationship between maximum strength and the level of power achieved when performing resistance exercise (5,13,22), many studies have used this relationship as the fundamental criteria to assess performance in different sport training activities (4,25). However, it is interesting to note that besides the levels of maximum strength, local muscular endurance and power achieved with a specific load may also limit the performance in some endurance activities (19,23). To date, there are numerous studies concerning maximum strength; local muscular endurance; or power exerted during various resistance exercises, jumps, or throws (5,13,20,21,27); however, no scientific studies were found that determine if there are some strength or power variables that have a greater influence over upper body endurance performance. Also, it seems that maximal strength is related to the ability to perform well on a submaximal muscular

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endurance test and additionally maximal strength may also be related to the ability to generate power during maximal and submaximal actions. Thus, further identifying these relationships would prove helpful in preparing exercise programs designed to enhance performance on muscular endurance tests and in occupational or sport activities, such as preparing aspiring firefighters in Madrid (Spain) for the required test of maximal repetitions on the bench press with 40 kg in 40 seconds.

According to the studies cited, we hypothesize that the performance in a maximum repetition test (MRT) with a submaximal load is related primarily to the 1RM and in a secondarily to the capacity to maintain a high level of applied force and power over a large number of repetitions. Also, we hypothesize that the percentage of the maximal load where the Pmax is obtained (optimal load) will decrease as the maximal force capability is higher. Therefore, the principal aim of this study was to determine the amount of influence that the maximal force and power measured in a progressive resistance test (PRT) and during a specific test with 40 kg in 40 seconds (MRT40) have over upper body endurance performance. An additional objective was to identify the load that expressed the best average power in the flat bench press exercise (during the PRT) and determine its association to maximal strength and maximum muscular endurance.

Methods

Experimental Approach to the Problem

Evaluations were performed 72 hours after the last training session of the subjects to minimize the effects of fatigue from the training. The tests themselves were performed in 2 sessions separated by a 48-hour period during which time the subjects could not perform any type of physical activity. The PRT test was performed in the first session, and the MRT40 test was performed in the second session. On day 1, the subjects arrived between 8 and 10 AM, without having breakfast, to assess their body composition. They ate breakfast as usual and 2 hours later, they performed the PRT. The MRT40 was performed 2 hours after breakfast on the second testing day, similar to the PRT. The intraclass correlation coefficient was previously determined in a pilot study conducted in our laboratory and the value was ≥0.90. Table 1 shows all the test data obtained for this investigation.

Subjects

Fourteen healthy male firefighter recruits aged 29.3 ± 4.2 years, with a body weight of 77.9 ± 8.3 kg, a height of 176.1 ± 10.4 cm, and a body fat of 12.6 ± 5.6% were evaluated. All the subjects were preparing for the physical tests of admission to the Firefighting Service of the Community of Madrid (Spain), with the same coach prescribing and individualizing a similar training plan. All subjects were experienced with resistance training, having trained for at least 5 years, and had utilized the bench press exercise during their training program for at least 1 year before beginning the study. The study was conducted at the end of the preparatory period, 3 weeks before the firefighter selection competition. In addition, all subjects declared not to have consumed, for at least 6 months, any banned or doping substance according to the International Olympic Committee criteria. At the time when the study took place, none of the subjects were suffering from

Table 1. Summary of variables analyzed.*

Variable	Description
1RM	Maximum load (kg) completed in the progressive test (PRT)
1RM rel	1RM normalized by body weight
Nmax40	Maximum force (newton) at 40 kg produced during the PRT
Nmax40 rel	Nmax40 normalized by body weight
Pmax40	Maximum average power (watts) at 40 kg produced during the PRT
Pmax40 rel	Pmax40 PRT normalized by body weight
Pmax	Maximum average power (watts) produced during the PRT
Pmax rel	Pmax normalized by body weight
Load Pmax	Load that expressed the maximum average power produced during the PRT
%RM Pmax	1RM percentage at which the maximum average power is produced during the PRT
R40s	Maximum number of repetitions performed in the 40 kg in 40 s test (MRT40)
Nmean40s	Mean strength (newton) produced during all repetitions in the MRT40
Pmean40s	Mean power (watts) produced during all repetitions in the MRT40
Pmax40s	Maximum average power (watts) produced during the MRT40
%N	Percentage decrease of force (newton) during the MRT40
%P	Percentage decrease of power (watts) during the MRT40

*1RM = 1 repetition maximum.

any cardiovascular, general, or local musculoskeletal contraindications in the scapular-humeral or scapular-thoracic articulations. All subjects were informed of the study's procedures before volunteering and signed an informed consent. The Ethics Board at the European University of Madrid gave its approval for the study.

Procedures

Body Composition Assessment. Body weight was measured on a standard scale, and the percentage of body fat was determined by the method described by Ross and Marfel-Jones (1991). Skinfolds were obtained by the same researcher using a Harpenden skinfold caliper (10 g·mm^{-1} constant pressure; Country Technology, Gays Mills, WI). The Jackson and Pollock equation for 7 skinfolds was used to estimate body density, and the Siri equation was subsequently utilized to express this value as a fat percentage (28).

Instrumentation. An optical rotary encoder (Real Power; Globus, Codogne, Italy) with a minimum lower position register of 1 mm was used for measuring the position and calculating the velocity, force, and power applied during each repetition of the bench press exercise in both tests. The cable of the encoder was connected to the bar in such a way that the exercise could be performed freely. The encoder's method of functioning enabled the cable to move in either vertical direction of the movement, sending the position of the bar every millisecond (1,000 Hz) to an interface that was connected to a computer. Proprietary software for the encoder (Real Power J110) was used to calculate the peak and average force in newton (N), velocity in m·s^{-1} (v), and power in watts (W) produced during the concentric phase of the exercise.

Progressive Resistance Test. The flat bench press exercise was performed using Olympic bars and discs according to the technique described by Baechle et al. (2). However, in line with the regulations governing the entry test for the Community of Madrid's Firefighting Service, the subjects were permitted to lift their pelvis while performing the exercise. The test was performed according to the protocol utilized by Naclerio et al. (26) and was utilized in a similar manner to other studies (5,9,10,24,25). Eight sets of 2 to 3 repetitions were performed. The sets, completed with the greatest force possible, had interset rest periods of between 2 and 5 minutes, depending on the magnitude of the resistance to be overcome. The first and second sets were performed with low resistance (25–45% of 1RM), the third and fourth sets with light-moderate resistance (50–65% of 1RM), the fifth and sixth sets with medium-high resistance (70–80% of 1RM), and the seventh and eighth sets with maximum or near maximum load (85–100% of 1RM). The repetition that produced the greatest average power in each set (26) was selected for analysis. To determine the initial load of the test, the first set was performed with approximately 30% of the estimated maximal load or from a 1RM that was previously performed by the subject (26). Because the test also involved performing repetitions with 40 kg (to compare with the MRT40), the first set of the PRT was always performed with a lower weight and the second set was performed with the specific weight (40 kg). The increment of

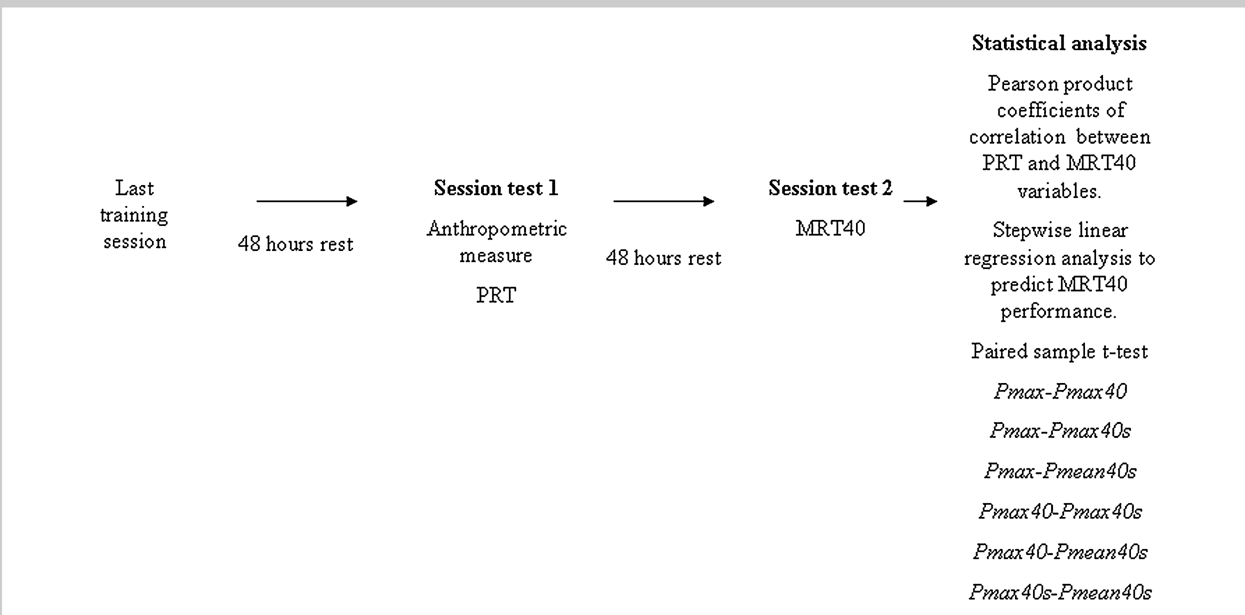

Figure 1. Schematic representation of the study design.

TABLE 2. Mean (±*SD*) values for strength- and power-related variables measured in both the PRT and the MRT40 tests.*

	Variables	Test	Mean	±*SD*
Strength	1RM	PRT	107.4	12.2
	1RM rel	PRT	1.4	0.1
	Nmax40	PRT	522.8	42.1
	Nmax40 rel	PRT	6.7	0.4
	%N	MRT40	−23.4	6.3
	R40s	MRT40	47.5	6.0
Power	Pmax40	PRT	507.2	125.8
	Pmax40 rel	PRT	6.5	1.0
	Pmax	PRT	557.4	140.7
	Pmax rel	PRT	7.1	1.3
	Load Pmax	PRT	51.4	9.5
	%RM Pmax	PRT	47.6	9.0
	Pmean40s	MRT40	465.9	113.8
	Pmax40s	MRT40	512.4	35.0

*1RM = 1 repetition maximum; MRT = maximum repetition test.

increase in the load for subsequent sets (after the 40 kg second set) was determined from the formula:

$$kg\ increase = (Estimated\ 1RM\,[kg] - initial\ load\,[kg])/(Total\ sets - 1)$$

The initial load was defined as the load used in the first set and "kilogram increase" represented the amount of weight to be added for each subsequent set. When the subject approached the estimated 1RM value, the rest periods between sets were prolonged to 5 minutes, and before beginning the last set, the subject was asked to perform as many repetitions as possible so that if he performed more than 1, the 1RM value was calculated by the formula of Mayhew et al. (23).

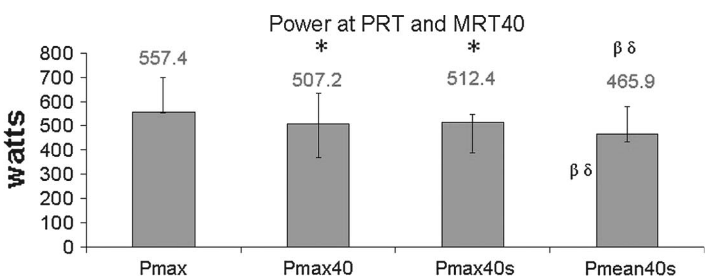

Figure 2. Comparison between the power variables measured in PRT and MRT40 *Significantly different ($p \leq 0.05$) from Pmax. βSignificantly different ($p \leq 0.01$) from Pmax and Pmax40. δSignificantly different ($p \leq 0.05$) from Pmax40. MRT = maximum repetition test; Pmax = maximal power.

Specific Test (Maximum Repetition Test 40). This is a competitive test involving the performance of the greatest number of repetitions possible in the bench press exercise with 40 kg in a period of 40 seconds (R40s). The same experienced researcher counted the number of correctly performed repetitions by all the subjects and the value was recorded. In addition, the encoder was used to obtain the average power produced in each repetition, as in the PRT test. Thus, several variables were computed from this test: (a) the mean force (N) and power (W) produced over all repetitions of the MRT40 (Nmean40s and Pmean40s, respectively), (b) the Pmax of the test using the repetition that gives the highest value in watts (Pmax40s), and (c) The percentage change in force (%N) and power (%P) was also determined over the course of the MRT40 test. Percent N was determined by the equation (Nmin/Nmax × 100), where Nmin was the minimum value of applied force and Nmax was the highest applied force value obtained during the test. Similarly, %P was determined by the equation (Pmin/Pmax × 100) where Pmin was the lowest and Pmax the highest value of the average power obtained during the test.

Statistical Analyses

The data collected were processed using the SPSS v.12.0 program for Windows. A descriptive analysis of the study variables was performed and subsequently the Kolmogorov-Smirnov and Shapiro-Wilk tests were applied to determine the degree of normality of the data. A Pearson correlation analysis was performed to examine the relationship between the variables analyzed. A stepwise linear regression analysis was undertaken to obtain the predictive variables of performance. Finally, a paired samples *t*-test was performed to determine the difference between the maximal average power measured across the entire load mobilized in the PRT (Pmax), the 40 kg load in the PRT (Pmax40), the maximal average power measured in 1 repetition in the MRT40

TABLE 3. Pearson correlation of PRT and MRT40 variables with the score in the MRT40 test (R40s).

	Variables	*r* (sig)	r^2
PRT	Body weight	0.78 ($p \leq 0.01$)	60.8
	1RM	0.81 ($p \leq 0.01$)	65.6
	Pmax	0.70 ($p \leq 0.01$)	49.0
	Pmax40	0.61 ($p \leq 0.05$)	37.2
	Nmax40	0.77 ($p \leq 0.01$)	59.3
MRT40	Nmean40s	0.76 ($p \leq 0.01$)	57.8
	Pmean40s	0.78 ($p \leq 0.05$)	61.1
	%N	−0.64 ($p \leq 0.05$)	40.9

1RM = 1 repetition maximum; MRT = maximum repetition test.

(Pmax40s), and the mean power determined during all repetitions in the MRT40 (Pmean40s). The level of significance was set at $p \leq 0.05$. Statistical power for the evaluations ranged from 0.85 to 0.91. Figure 1 depicts the schematic design of the study and the statistical analyses applied.

RESULTS

Table 2 depicts the mean and *SD* values for the variables measured in both the PRT and the MRT40. The data from Table 2 show significant differences between the Pmax produced in the PRT with the Pmax achieved with 40 kg during PRT (Pmax40) and the Pmax reached on the best repetition during the MRT40 (Pmax40s). Also, the Pmean40s measured during MRT40 showed a significantly lower value compared with the Pmax and Pmax40 ($p \leq 0.01$) and to the Pmax40s ($p \leq 0.05$). As expected, no significant difference between the Pmax40 and the Pmax40s was found (Figure 2).

Table 3 depicts the Pearson moment correlation (r) and the coefficient of determination (r^2) found between the anthropometric, force, and power variables measured in PRT and MRT40 with respect to the maximum number of repetitions achieved in the MRT40 (R40s). Although the correlations were significant, only body weight, 1RM, and Pmean40s demonstrated high correlations.

The stepwise regression analysis produced the following predictive equation:

$$PRT40 = -0.017 + 0.229 \times body\ weight + 0.278 \times 1RM$$

This equation had an $r = 0.84$ and $r^2 = 0.719$; thus, 71.9% of the shared variance of the MRT40 results can be explained by body weight and 1RM, which were 2 of the variables measured with the highest correlations. The maximal average power achieved during the PRT was obtained at 47.6 ± 9.0% of the 1RM determined by the PRT test (Table 2). This variable did not show a significant correlation to 1RM value nor the R40s achieved in MRT40.

DISCUSSION

In the present study, 1RM and body weight demonstrated the greatest degree of influence on the performance achieved in the upper body–specific endurance exercise (MRT40). Yet, the power produced in a progressive test at the same load used in the endurance test failed to correlate well with the power produced in the endurance test, highlighting the importance of absolute maximum strength.

It is interesting to note that when these variables are related to body weight, their correlation coefficient ceases to be significant. This may be due to the fact that the MRT40 test involves moving an absolute load and thus the performance will be limited by the absolute strength or power and not by the relationship of these variables to each individual subject's body weight. This fact supports the importance of being able to produce high levels of absolute strength and power to achieve good performances in a local muscular endurance test, as is the case of the specific test that our subjects have to do in their competition for a place in the Firefighting Service.

One of the limitations of the present study may be the lack of certain anthropometric measures, such as the length of the upper extremity that can influence performance in the bench press exercise (i.e., the subjects with longer extremities must lift over a longer distance and thus perform more work than those who have shorter extremities). However, to date, no similar works where such variables were taken into consideration in either upper- or lower-body exercises have been found. We therefore agree with Cronin and Sleivert (13) and Dugan et al. (15) who recommended that to obtain definitive conclusions, there is a need to examine in greater depth the variables that determine performance in strength exercises against resistances, like the length of the upper and lower extremity.

Also noteworthy is the correlation coefficient ($p \leq 0.05$, $r = 0.69$) between the 1RM and the Pmax in the PRT. It was slightly lower than that found by Naclerio et al. (25), which was produced in a similar test with powerlifters ($p \leq 0.05$, $r = 0.92$). Such differences are possibly due to the different types of training performed by each of the 2 groups (5,6,25). In the case of the firefighter recruits, training is generally aimed at improving the local muscular endurance with a light relative load, whereas powerlifters seek to achieve maximum strength by training with moderate to heavy weights.

In other studies with rugby players, Baker (4,5) found that the correlations between the 1RM and the Pmax obtained in an incremental bench press test were also high, varying as a function of the type of training undertaken by the subject. Thus, when the subjects trained with high load to improve their maximum strength at the beginning of the season, the correlation was $r = 0.89$; however, when training shifted to lighter load and increased velocity in the specific preparatory period, the correlation decreased to $r = 0.66$. This relationship dropped even further in the competition period ($r = 0.58$) when resistance training was reduced with respect to a more specific mode of rugby training. These results, which are in agreement with others (5,7,8,13,29), highlight the importance of strength in the performance of all types of physical activities, even those with a power or local muscular endurance emphasis.

In the current study, the maximum average power was localized at 47.6 ± 9.0% of the 1RM, which is near or slightly greater than the results reported by Izquierdo et al. (20) who evaluated a group of 70 sportsmen of 5 different specialties (weightlifters, handball players, amateur road cyclists, middle-distance runners, and age-matched control university students who performed recreational physical activities) and found that the maximum average power in a Smith machine bench press was between 30 and 45% of the 1RM. However, Aşçi and Açikada (1) evaluated the 1RM and the power with different loads in a free weight bench press in 56 sportsmen (track and field sprinters, basketball, handball and volleyball players, and bodybuilders) and found that the optimal load that expressed the Pmax value was between 50 and 63% of the 1RM. In both these investigations, the bench press repetitions for power determination were performed as explosively as possible, albeit without bar release. The power values obtained in the current investigation were during controlled repetitions of the bench press exercise, which may have had an effect on the location of the Pmax value on the load-power curve relative to the other investigations. Also, other methodological differences like the exercise being performed in a Smith machine (20) or the utilization of a 3-dimensional analysis with 3 linear transducers to measure the displacement of the bar in 3 planes (1) can account for the differences with respect to the results in the current investigation. As mentioned, the percentage of the 1RM at which the maximal average power is achieved did not show any degree of influence over the performance variables measured in this study (1RM or R40s). These results may be considered in opposition to the conclusions made by Baker (5) who demonstrated that the strongest subjects tended to obtain Pmax at a lower place on the load-power curve, or at a lower percentage of the 1RM. Given the high coefficient of correlation found in our study between the 1RM and the R40s, we can expect a negative and significant correlation between %RM Pmax with both 1RM and R40s. However, in the work of Baker (5), subjects (rugby players) from 3 different studies were classified into stronger and less strong subjects based on the 1RM value being multiplied by the correction factor that is used in international powerlifting and were then compared with regard to the percentage of the load that expressed the maximal average power. The results showed that in 2 of the 3 studies, the strong subjects obtained maximal average power at a significantly ($p \leq 0.05$) lower percentage of the 1RM (51.4 ± 3.9% vs. 57.9 ± 3.9% and 46.9 ± 6% vs. 54.1 ± 2.9%, respectively). In the third study, strong subjects showed a tendency to obtain Pmax at a lower percentage of the 1RM (54.5 ± 5.6% vs. 56.5 ± 4.0%), but the difference did not reach statistical significance. Apart from the mechanical difference between the bench press throw performed by the subjects evaluated by Baker (5), the subjects in our study demonstrated lower strength levels. The average 1RM of our subjects was 107 ± 12.2 kg, whereas the rugby players evaluated by Baker averaged 152 ± 8.4 vs. 124.0 ± 6.5 kg, 153.3 ± 8.8 vs. 120.0 ± 7.1 kg, and 131.7 ± 4.1 vs. 91.7 ± 6.8 kg, for the strong and less strong subjects of studies 1, 2, and 3, respectively. If we consider that in the third case the difference with regard to the Pmax value obtained over the %1RM was not statistically significant, it is possible that the stronger subjects will obtain Pmax at a significantly lower percentage of the 1RM when the level of 1RM reaches some threshold that is around 150 kg. To clarify this difference, we decided to divide our subjects into 2 groups: (a) strong group ($n = 6$) with a 1RM > 100 kg and (b) less strong group ($n = 8$) with a 1RM ≤ 100 kg. This procedure shows the same results that were reached by Baker (5). Although the difference did not reach statistical significance ($p = 0.125$, 95% confidence interval of the difference), the strong group showed a marked tendency to obtain the Pmax at a lower percentage of the 1RM with respect to the less strong group (43.23 ± 6.17 vs. 50.75 ± 9.75). According to these results, we can speculate that the percentage of the load where the Pmax is obtained does not show any relationship with the strength or endurance performance in less strong subjects, but may become negatively related to the 1RM or other performance variables in the strongest individuals. However, this is only speculation and there is a need for further investigation that compares the 1RM and endurance performance in subjects with different levels of 1RM and with different exercises.

The method of evaluation utilized in this investigation, in spite of the limitation mentioned by other studies (11,12), has been shown to be a reliable methodology to control the performance variation that can be produced when the resistance exercise to be assessed, like a bench press, is performed over a predominantly vertical displacement (14,17,18). Accordingly, like other previous research (24,26), the methodology and the results of the present work demonstrate the usefulness in evaluating not only 1RM levels but also the force and power produced during the PRT test and the specific endurance test.

Practical Applications

As demonstrated in the current study, maximal strength has a relationship to performance in muscular endurance tasks. In addition, Pmax was shown to be exerted at relative loads around or slightly over 40% of the 1RM. In the case of maximum repetitions on the bench press with a 40-kg load, the current findings can assist in the preparation for optimal performance. For example, training should be designed initially to increase maximal strength in the bench press to a minimum of 100 kg. Thus, the relative load utilized in the firefighter screening test would be below 40% of maximum load. Training could then focus on maintaining maximal strength levels while enhancing test-specific endurance. Other tests of submaximal endurance (i.e., NFL combine 225 lb bench press for repetitions) or occupational tasks may be enhanced according to this strength, power, and muscular endurance model.

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