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Local muscular endurance and prediction of 1 repetition maximum for bench in 4 athletic populations

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ABSTRACT

The aim of this study was to determine a predictive equation of 1 repetition maximum (1 RM) from local muscular endurance. Different athletic male populations were assessed: racket/ball games players *(n = 31),* power lifters *(n = 22),* swimmers *(n = 28),* and rowers *(n* = 29). After the 1 RM assessment for the bench press, the maximum number of repetitions (MNR) relative to the 1 RM (85%, 75%, 60%, 40%, and 20%) was tested. No significant differences in strength evolution from 20% to 100% of the 1 RM was found between power lifters and racket/ball games players and between swimmers and rowers. However, differences in the strength evolution appeared between these 2 mixed groups $(p < 0.01)$, with differences appearing from 75% of 1RM to lesser relative strength $(p < 0.05)$. Nonlinear equations fitted best with the actual data for the capacity to repeat lifts. The evolution of strength from 100% to 20% of 1 RM was better described when the groups' specific equations were used as demonstrated by r^2, and residuals range between the predicted minus the measured 1 RM. The strength endurance competences for high loads (100%-75%) were adequately modeled by the equation based on the total population. The accuracy of the 1 RM prediction was better when a reduced number of lifts was performed. For untrained or novice subjects, the use of group-specific equations for the all evolutionary profile of strength allows a good estimate of 1 RM and provides adequate numbers of lifts for all levels of strength, thus optimizing the training programs.

Key Words: training adaptations, prediction equation, maximal strength.

INTRODUCTION

At any level of fitness, successful resistance training requires an appropriate and individualized program. Methodologically, the main variables determining the success of a training program are intensity (represented by the load carried or by the relative strength used) and volume (represented by the number of repetitions and the number of sets) (10,11). To preserve training time and reduce the possibility of injury in novice or untrained individuals, evaluation of the 1 repetition maximum (1RM) is often not performed. In this way, training programs are usually based on predicted 1RM. However, 1RM estimates contain a large variability and when used must be done cautiously (14).

Previous studies measured the ability to repeat lifts at submaximal strength and proposed linear, logarithmic, or exponential equations for 1RM prediction (2,5,13,14). The accuracy of these equations has been linked to specific exercises, to the populations assessed, and to the relative strength used for repetition maximum testing (14,15). Training has been reported to influence the relationship between maximal and submaximal strength without it being integrated in the prediction equation of the 1RM (4). DeLorme and Watkins classic work (8) suggested that a resistance training program using low repetition/high resistance favored adaptation for strength/power, whereas training with high repetition/low resistance increased muscular endurance. This assumption is confirmed by many studies that demonstrate specific muscular strength and endurance adaptations (1,6); however, other studies reported concomitant strength and muscular endurance enhancement alter strength training (7,11). As a result, there is scant information concerning the specific local muscular endurance and the strength continuum according to particular sports training. The purpose of the present study is to identify the pattern of strength evolution according to training-induced physical capabilities to propose prediction equations of the 1RM specific to certain populations.

METHODS

Experimental Approach to the Problem

The focus of the current study was to determine the influence of maximal strength or muscular endurance on the accuracy of 1RM prediction. For this, multiple repetition testing, which is specific to the training context, provides accurate data for estimating the dynamic muscular strength when carefully conducted (14). In addition, the purpose of the study requires the assessment of strength and muscular endurance using a lift usually programmed in varied athletic populations. The bench press, which is one of the most used and popular strength training movements, is easy to administer and control and has been shown to be a valid and reliable measure of muscular function (2). Then, the study tested to failure specific populations in bench press lifts for subsequent variance and regression analyses.

Subjects

A total of 110 male athletes participated in the study. The total population sample comprised 4 groups of athletes trained in different activities. For the first group *(n* = 31) was composed of racket/ball games players, with mean age, body mass, and stature as follows: 20.9 ± 1.7 years, 76.2 ± 6.1 kg, and 182 ± 4 cm. The second group were power lifters *(n* = 22; 27.7 ± 4.8 yr, 78.1 ± 11 kg, 177 ± 6.9 cm), the third group were swimmers *(n* = 28; 21.7 ± 6.6 yr, 69 ± 6.1 kg, 179 ± 5.2 cm), and the fourth group were rowers *(n* = 29; 23.7 ± 4.3 yr, 77.4 ± 9.1 kg, 184 ± 5.6 cm). All participants were experienced athletes with at least 4 years of training. Each of them competed in provincial or national event, but none could be considered as an elite athlete. In the previous 4 months leading up to the study, all subjects had participated in a resistance training program in which the bench press was used. In accordance with the guidelines of the University Institutional Ethics Committee, subjects gave their written informed consent to participate in the study after the risks involved were explained.

Procedures

Total training volume and strength training were determined after discussion with athletes and coaches and by using individual training diaries. AH tests were conducted during the precompetitive period for the athletes.

1RM Bench Press Test. The 1RM strength for the bench press was measured to the nearest kilogram using a free-weight Olympic bar and plates for all groups. Before the test, subjects were instructed on the standardized technique for bench press lifts as used in the study. Proper technique included the following: lying horizontally on the back and minimizing the arch of the lower back; subject held the bar with hands apart at a slightly greater width than the shoulders; subject lowered the bar to touch the chest and then returned it to a full arms' length away from the body. Spotters assisted the subject in lifting the bar from the support rack. Before the test, the subjects performed several warm-up sets using light weights of their choice. Each subject attempted successive bench presses, starting at a weight agreed upon by both the subject and the investigator, and increased the weight by increments of 1 to 5 kg until there were 2 consecutive unsuccessful attempts. Each subject was allowed between 4 and 6 minutes of rest between attempts.

Maximum Number of Repetitions Test. The maximum number of repetitions (MNR) was determined using the same technique as the 1RM test. The bar was required to touch the chest and then be returned to a full arms' length away from the body, with a maximum pause of 2 seconds between each repetition. When the subject was unable to lift the bar to a full arms' length, the set was finished. Durations of each test was recorded in seconds and compared with MNR results to control the influence of movement velocity in results. The subjects carried out the MNR test at 85%, 75%, 60%, 40%, and 20% of their 1RM. Two sessions were organized to prevent fatigue. Between each set of a given percentage of 1RM, a 15-minute recovery period was allowed. The subjects did not carry out prolonged tests at 40% and 20% or high-resistance tests at 85% and 75% in the same session. In other words, the subjects carried out tests at 85%, 60%, and 20% in one session and tests at 75% and 40% in another session.

Statistical Analyses

The subject number (total sample of 110; mixed groups of 57 and 51; athletics populations of 22, 28, 29, and 31) was determined to provide high statistical power for all analyses of variance (ANOVA) according to the repeated-measures nature of the research design. The mean of the statistical power of the MNR tests differences was 0.92. In addition, because 2 mixed groups from the total sample of subjects were used to compute the prediction equations, subjects were recruited of a minimum of 22 in each group to provide appropriate power estimates (i.e., 10 subjects per independent variables).

Cronbach's α was used to assess the reliability and reproducibility of MNR tests (85%, 75%, 60%, 40%, 20% of 1RM) with a minimum level of consistency set at 0.70. Two-way ANOVA was used to determine differences in strength evolution between groups (groups x MNR). When groups differences were detected, Tukey post hoc testing was used to identify significant differences among the groups for a given 1RM percentage.

The profile of strength and MNR for groups was assessed using linear and nonlinear (mono and 2-function exponential decay) curve fitting. The strength of the correlation coefficient was quantified by the explained variance *(r^2)*, by the standard error of estimate *(SEE)*, and by residuals of the 1RM prediction (measured - predicted 1RM). Because prediction of 1RM was usually performed using a fewer number of repetitions, short evolution of strength was also assessed (75-85% of 1RM). To compare the prediction accuracy of our equations with past research, we compared our prediction equations with 1 linear prediction equation (Epley's equation: 1RM = (0.033 reps) x rep_{wt}+ rep,) and 1 nonlinear prediction equation (Mayhew's equation: $\%1RM = 52.2 + 41.9\exp^{(-0{,}055 \text{ X rep})}$ as previously published (9,13).

Linear regression was used to determine relationships between the data recorded. For statistical analysis, the software package STATISTICA (version 6.1, Statsoft, Maison Alfort, France) was used, and curve-fitting was performed using GNU Octave (version 2.1.73, Madison, WI, USA). The level of significance for all analyses was set at $p < 0.05$. Data are expressed as mean *SD.*

RESULTS

The total training volume of power lifters was significantly lower than those of swimmers and rowers < 0.05) (Table 1), whereas total training of rackets/ball games players was similar to those of the other groups. The volume in strength training was higher in power lifters compared with racket/ hall games players, swimmers, and rowers < 0.01).

Figure 1 shows the results recorded in the MNR tests. Reliability of MNR tests was significant, with calculations of Cronbach's α for each tests resulting in α = 0.84. The mean of the 1RM for power lifters was significantly different *($p < 0.01$)* from the other groups (Table 1). The 1RM was significantly higher in racket/ball games players than in swimmers *($p < 0.05$)*. When the total sample population was considered, 1RM was related to MNR performed at 40% ($r^2 = 0.33$) and 20% ($r^2 = 0.38$), but this relationship was not found in specific groups. The 1RM was related to strength training volume ($r^2 = 0.58$), and total training volume was related to MNR tests at 40% and 20% of 1RM (respectively, $r^2 = 0.39$ and $r2 = 0.53$).

No significant differences were found in MNR tests between power lifters and racket/ball games players or between swimmers and rowers. However, results of the first mixed group (power lifters and racket/ball games players) were significantly different from the second mixed group (swimmers and rowers), determining, respectively, a "high-strength" and a "high-endurance" group (swimmers and rowers) ($p < 0.01$). Significant differences between high-endurance and high-strength groups were also found for MNR performed from 75% to 20% of 1RM ($p < 0.05$ at 75%, $p < 0.01$ at 60%, $p < 0.001$ at 40% and 20% of 1RM).

Nonlinear, 2-function exponential decay equations fitted best with actual data for all evolutionary profiles of strength. The use of linear equations provided lower r^2 and *SEE* than nonlinear equations (total population: y = -0.4791x + 81.672, r^2 = 0.7528, SEE = 11.62; high endurance: y = -0.4229x + 83.371, r^2 = 0.8284, *SEE* = 11.23; high strength: y = -0.7125x + 84.255, r^2 = 0.8339; *SEE* = 9.99). The r^2 of the groups, specific equations were higher than the equation of the total population sample, but the *SEE* of these equations was similar, although they were influenced by the difference in the MNR (Table 2). Compared with our equations, the linear equation of Epley appeared to be inadequate to describe all evolutions of strength and to predict 1RM. The fit of Mayhew nonlinear equations appeared better than Epley's but presented lower r^2 and higher *SEE* than those based on the study equation. The range of residuals between predicted minus measured 1RM was lower when group-specific equations were used (Figure 2).

The first segment of strength evolution (75-100% of 1RM) when few repetitions were performed in the MNR test was also better measured with nonlinear equations. Few differences appeared between the equations from the total population results and the equations from the results of the 2 specific groups (Table 3). Epley's linear equation resulted in good r^2, but *SEE* remained high. Although Mayhew's equation provided accurate predictions, they remained lower than those calculated from the equations computed in this study. Linear equations provided lower r^2 and *SEE* than nonlinear equations but still fitted well (total population: y = 2,0417x + 100,19; r^2 = 0,9154; high-endurance group: y = 1,9576x + 100,41; r^2 = 0,9347; *SEE* = 2.55; high-strength group: y = -2,1822x + 100,25; r^2 = 0,9135; *SEE* = 2.85). The *SEE* and residuals between predicted minus measured 1RM were lower when a reduced number of lifts was performed and when using the nonlinear short equation rather than the equation from all evolutions of strength.

DISCUSSION

This study reported that data recorded for maximal strength as well as for strength endurance was different according to populations of diverse sports groups. Thus, the evolutionary profile of strength was better described with computed equations from a specific group. Conversely, each specific equation allowed to accurately determine the maximal number of repetitions that could be performed at any strength level.

The 1RM test as well as the MNR tests demonstrated different strength characteristics. The 1RM of power lifters was twice as high as those recorded in the other groups, whereas the MNR of rowers was twice that performed by power lifters for light loads. For 75% of 1RM to lighter resistances, MNR tests showed large differences in subjects' ability to repeat lifts, with an increase of statistical differences for light resistances. Power lifters and racket/ball games players who displayed "high-strength" competences, whereas rowers and swimmers showed "high-endurance" competences. These particular competences in local muscular endurance or in maximal strength may be a consequence of specific training effects. Indeed, low repetition/high resistance as usually performed by power lifters should improve strength/power adaptations (12). One power-lifting competitive event is the 1RM used for the bench press, as in our study. The higher performance of power lifters in this test should therefore be self-evident. Similarly, the physical training of racket/ball games players principally aims at increases in explosivity. Conversely, training with high repetitions/low resistance as performed by rowers and swimmers is aimed at increases in muscular endurance (16,17). In accordance with Anderson and Kearney (1), our results suggest that muscular adaptations may be related to the repetition combinations used. This was supported by the relationship observed between 1RM and strength training volume and between MNR and total training volume. Moreover, for the total population, sample relationships were found between 1RM and MNR at 40% and 20%, demonstrating that, for light resistances, individuals with high 1RM performed low MNR and individuals with low 1RM performed high MNR. These results suggest that prolonged training improving maximal strength does not result in similar increase of muscular endurance and that training enhancing endurance does not result in maximal strength enhancement. The lack of relationship between 1RM and MNR in individuals with similar training ("high-strength" or "high-endurance" groups) reinforces this hypothesis.

These muscular capacities may be a consequence of specific training effects but may also be genetically determined. This later factor may influence the particular choice of an athlete's sport (18). Therefore, rowers naturally present endurance competences, whereas power lifters present maximal strength competences. According to these hypotheses, our results suggest that a specific training could influence maximal strength or muscular endurance, reinforcing individual characteristics.

These results support the first aim of this study, which was to identify specific muscular endurance in trained populations. Our study is the first to propose specific prediction equations of 1RM, allowing us to adequately determine the repetition combination (repetition number for given strength level) that will lead to particular training effects. In addition, our results clearly demonstrate the nonlinear relationship between strength and repetitions to failure, as particularly observed for all evolutionary profiles of strength. Although linear models for high strength levels provide good fit with actual data, the correlation between strength and repetition ability was stronger with nonlinear equations.

MNR performances and also r^2 and the range of residuals between predicted minus measured 1RM support the calculation of groups-specific equations to describe all evolutions of strength. Indeed, differences in the ability to repeat lifts requires a specifically model because unspecified equations result in a high variability in possible numbers of lifts for moderate to low levels of strength.

Conversely, in high strength levels (75-100% of 1RM), few differences appeared between the equations from mixed groups and from the total population sample that could be linked to a Jack of statistical differences in MNR performed at 85% of 1RM. Moreover, *SEE* was significantly lower when using the short equation rather than the all evolution equation. Finally, according to the training context (fitness and fatigue status, light weight plates available), the low SEE resulting from the high loads equation could be assumed as insignificant.

In accordance with previous studies, our results show that an accurate prediction of 1RM may use repetition tests to failure performed at high relative strengths and a low number of repetition (14,15). In this possibility, the group characteristics and training effects could be ignored, suggesting that if training is unchanged, the relationship between strength and the ability to repeat lifts is not modified.

Strength training could be aimed at improving maximal strength or enhancing muscular endurance gains or both but also could be organized for health benefit purposes. When strength training programs use a large range of strength levels, as can be done for health purposes, the adequate number of lifts has to be determined to induce similar muscular and metabolic stress in all individuals. This suggests the use of specific equations describing the all evolutionary profile of strength, which also provides accurate 1RM estimates and the appropriately adequate number of lifts to perform. The relevancy of this equation type is reinforced for strength endurance training, which in particular uses moderate to light weights, in which marked individual differences appear.

Training programs for maximal strength increase may use the short equation from the total population sample to accurately estimate 1RM. However, maximal strength increase is sought by well-trained athletes who are physically and technically able to perform 1RM. In addition, the errors associated with 1RM prediction could hide the weak improvements of maximal strength over short periods of time. The use of 1RM prediction appears relevant for novice and untrained athletes for whom the regression equation would not be affected by short-term training but is less adequate for highly trained athletes

(3). Therefore, specific equations of the all evolutionary profile of strength may be preferred because they allow adequate predictions of both 1RM and MNR for individuals who require these 2 types of data.

PRACTICAL APPLICATIONS

High differences in the ability to repeat lifts appear until 75% of 1RM of lighter loads, depending on the sport practiced. Prediction of 1RM from repetition tests to failure requires performance at high levels of strength (low number of lifts). However, a prediction equation based on an unspecified population may result in large errors in the number of repetitions an individual can lift. For untrained or novice subjects, the use of group-specific equations for the all evolutionary profile of strength allows a good estimate of 1RM and provides adequate numbers of lifts for all levels of strength, thus optimizing the training programs.

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TABLE 1. Training volume (total and strength training in hr/wk) and 1 RM (in kg) of power lifters, racket/ball games players, swimmers and rowers.*

	Training volume		
	Total	**Strength training**	**1 RM**
Power lifters (*n* = 22)	7.4 ˉf 1.2 §‖	7.2 ± 1.1 ‡§‖	157.2 ± 20.1 ‡§‖
Racket/ball games players (*n* = 31)	8.6 ± 2.5	2.2 ± 0.7	84.5 ± 12.6 †§
Swimmers (*n* = 28)	10.0 ± 2.2 †	2.3 ± 1.1 †	70.1 ± 14.2 †‡
Rowers (*n* = 29)	10.2 ± 3.5 †	3.2 ± 0.8 †	79.3 ± 10.2 †

* 1 RM = 1 repetition maximum.

† Significant differences with power lifters.

‡ Significant differences with racket/ball games players.

§ Significant differences with swimmers.

‖ Significant differences with rowers.

TABLE 2. Complete prediction equations of 1 RM percentage (y) from any number of repetitions performed (x) for total population sample (4 different athletic populations) for high-strength group (power lifters and racket/ball game players) and for endurance group (swimmers and rowers).*†

	Equation from 20% to 100% of 1 RM	**Adjusted r^2**	**Standard error of estimate**
Total population sample (*n* = 110)	Y = 79.3412*exp(-0.0302x) + 20.7706	0.9702	3.43
	Epley's equation	0.4502	21.7
	Mayhew's equation	0.8986	4.52
High strength (*n* = 53)	Y = 83.7677*exp(- 0.0338x) + 17.6846	0.9902	2.64
	Epley's equation	0.6056	26.4
	Mayhew's equation	0.9318	3.97
High endurance (*n* = 57)	Y = 77.7793*exp(-0.0234x) + 20.4082	0.9838	3.56
	Epley's equation	0.6508	10.07
	Mayhew's equation	0.9017	4.72

*1 RM = 1 repetition maximum.

† Standard error of estimate expressed in repetition number.

TABLE 3. Prediction equations of 1 RM percentage (y) from reduced number of repetitions (x; approximately from 1-12 repetitions) for total population sample (4 different athletic populations) for high-strength group (power lifters and racket/ ball game) and for endurance group (swimmers and rowers).* †

	Equation from 75% to 100% of 1 RM	**Adjusted r^2**	**Standard error of estimate**
Total population sample (*n* = 110)	Y = 36.1115*exp(-0.1240x) + 67.9776	0.9623	1.67
	Epley's equation	0.8891	12.26
	Mayhew's equation	0.9312	2.49
High strength (*n* = 53)	Y = 36.1133*exp(-0.1352x) + 68.2982	0.9580	2.06
	Epley's equation	0.8947	11.18
	Mayhew's equation	0.8986	2.41
High endurance (*n* = 57)	Y = 37.4720*exp(-0.1056x) + 66.2090	0.9731	1.97
	Epley's equation	0.9389	2.78
	Mayhew's equation	0.9501	2.07

*1 RM = 1 repetition maximum.

† Standard error of estimate expressed in repetition number.

Figure 1.

Figure 1. Graphical presentation of maximal number of repetitions tests results (MNR) at a relative strength of 1 repetition maximum (1RM, %) for different athletic populations. Power-lifters, $n = 22$ (■); Racket/ball games players, $n = 31$ (○); Swimmers, $n = 28$ (□); and Rowers, $n = 29$ (●). Error bars are *SD*. £ = statistical differences in MNR performed at 75% of 1RM (differences between rowers and power lifters and between rowers and racket/ball games players; $p < 0.05$); $ = statistical differences in MNR performed at 60% of 1RM (differences between swimmers-rowers and power lifters racket/ball games players, $p < 0.01$); ¥ = statistical differences in MNR performed at 40% of 1RM (differences between swimmers-rowers and power lifters racket/ball games players, $p < 0.001$); § = statistical differences in MNR performed at 20% of 1RM (differences between swimmers-rowers and power lifters racket/ball games players, $p < 0.001$).

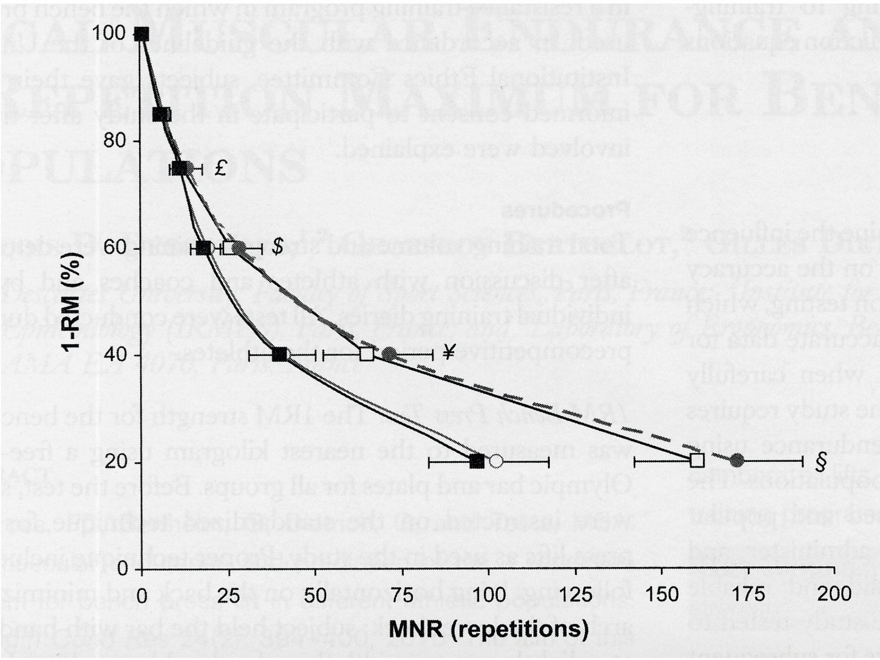

Figure 2. Residuals between predicted minus measured 1 repetition maximum (1 RM) using equations from the all evolutionary profile of strength equations and tests to failure performed at 85%, 75%, 60%, 40%, and 20% of 1 RM. A) Total population sample equation used for all individuals. B) High-strength equation used for power lifters and racket/ball game players. C) High-endurance equation used for swimmers and rowers.