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Relative Muscular Endurance Performance as a Predictor of Bench Press Strength in College Men and Women

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Abstract

Mayhew, J.L., Ball, T.E., Arnold, M.D. and J.C. Bowen. Relative muscular endurance performance as a predictor of bench press strength in college men and women. *J. Appl. Sports Sci. Res.* 6(4):200-206. 1992. — *The purpose of this study was to determine the accuracy of using relative muscular endurance performance to estimate 1 RM bench press strength. College students (184 men and 251 women) were tested for 1 RM strength following 14 weeks of resistance training. Each subject was then randomly assigned a relative endurance load (rep weight) corresponding to 55-95 percent of the 1 RM and required to perform as many bench press repetitions (reps) as possible in one minute. Men had significantly greater 1 RM strength, rep weight, percent 1 RM, and reps than women. Since the regression of percent 1 RM on reps was not significantly different between the men and women, the data were combined to produce the following exponential equation: percent 1 RM = 52.2 + 41.9e* $^{-0.055 \text{ reps}}$ *($r = 0.80$, $p < 0.001$). Bench press strength could be estimated from the equation 1 RM = rep weight/predicted percent 1 RM/100 with an accuracy of $r = 0.98$ and a standard error of estimate of ± 4.8 kg. Applications of these equations to a comparable cross-validation group (70 men and 101 women) indicated acceptable validity ($r = 0.98$, $p < 0.001$) with an error of only ± 5.4 kg. Applying the same equations to high school male athletes ($n = 25$), high school male nonathletes ($n = 74$) and college football players ($n = 45$) also produced good cross validation ($r > 0.95$, $p < 0.001$) with relatively small standard errors (± 3.1 to ± 5.6 kg). It appears that relative muscular endurance performance can be used to accurately estimate 1 RM bench press strength in a wide variety of individuals.*

KEY WORDS: Bench press, strength predication, muscular endurance

Introduction

The bench press is one of the most popular exercises in a resistance training program and is used by novice and advanced weight trainers alike. The exercise requires the lifter to lower a barbell from a straight-arm position and return it to full arms' length while lying supine on a bench. It is relatively easy to master and is often used as a central exercise in a resistance training program (1). In addition, when using the one-repetition maximum (1 RM) procedure, the bench press is one of the primary tests used for evaluating muscle strength (3).

Attempting the 1 RM lift requires great concentration and involves considerable mental preparation by the lifter. Furthermore, such all-out efforts may consume excess amounts of time, which often detracts from the remaining training routine. For the novice weight trainer, attempts at a 1 RM bench press may be limited by the unaccustomed handling of heavy loads and the fear of failure. Although no injury data are available concerning the use of 1 RM lifts, the potential for injury may be magnified with the use of heavier loads.

The use of a procedure that requires less than the 1 RM load to estimate maximum strength potential has strong appeal. However, recent studies by Hoeger et al. have questioned the use of relative endurance performance with

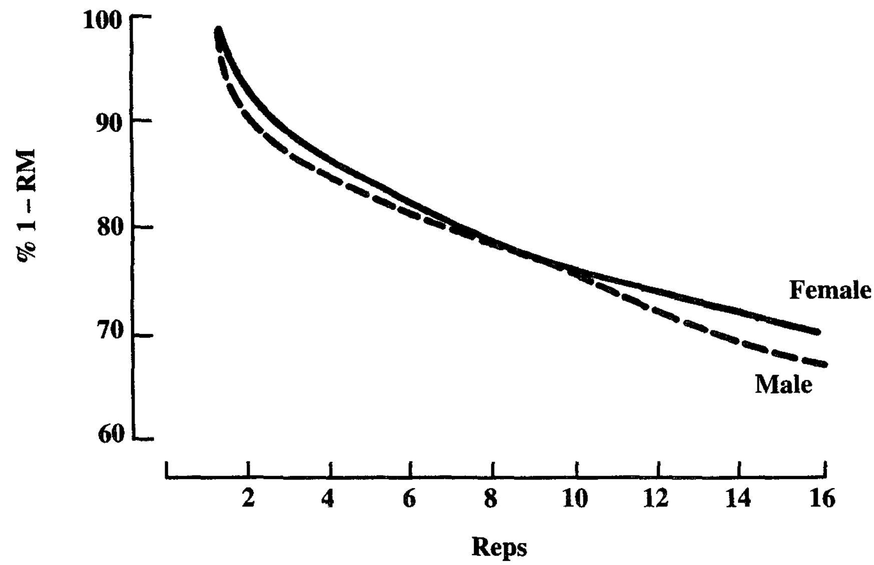

Figure 1. Relationship between percent 1 RM and repetitions in the bench press in college men and women

loads equivalent to 40, 60 and 80 percent of 1 RM to estimate maximum strength ability in various barbell exercises (5, 6). The researchers indicated that stronger individuals could perform more repetitions at a given percent 1 RM than could weaker individuals. These findings appear to invalidate the application of a universal prediction procedure for estimating 1 RM lifts. However, other studies have shown that lighter loads lifted to exhaustion, a cadence of one lift every two seconds, can accurately predict 1 RM bench press strength (4, 8). These studies would appear to be equivocal and point toward the plausibility of a relative endurance model for estimating 1 RM strength in the bench press.

Since many resistance training programs are built around the use of percentages of 1 RM, it would be advantageous to have an accurate method of estimating maximal strength in the bench press lift for individuals of varying weight lifting abilities and strength levels. Therefore, the purpose of this study was to determine the accuracy of using relative muscular endurance performance to estimate 1 RM bench press lifting strength in various groups.

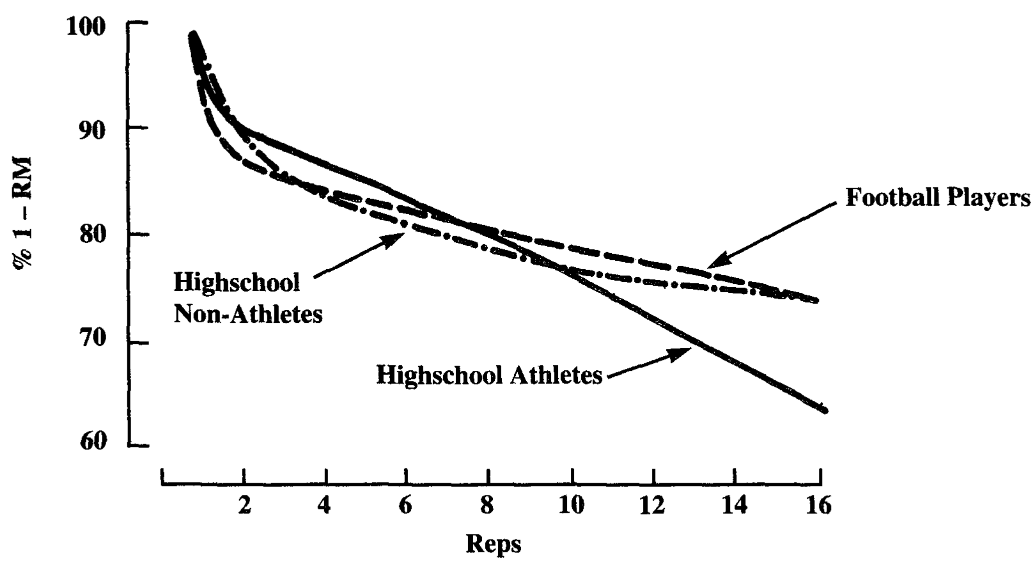

Figure 2. Relationship between percent 1 RM and repetitions in the bench press in high school male athletes and nonathletes and college football players

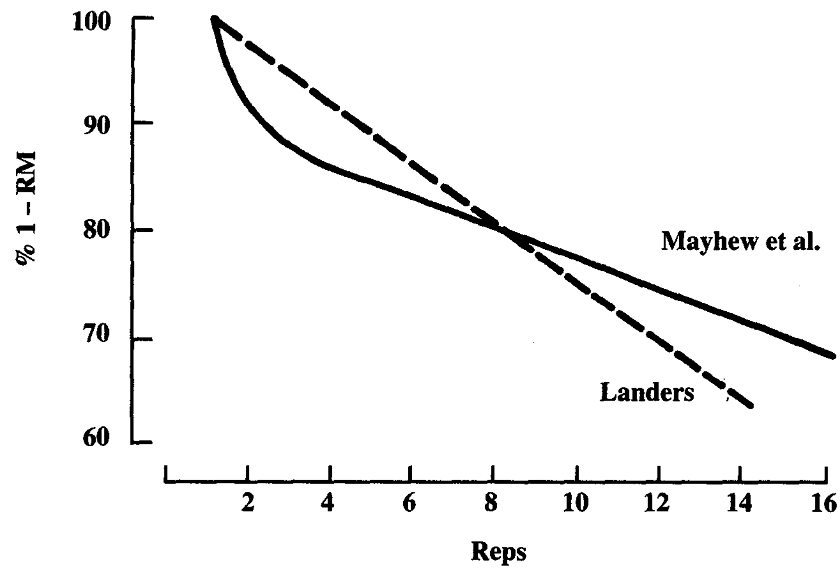

Figure 3. Difference between the Lander equation and the current study for the relationship betweent percent 1 RM and repetitions in the bench press.

Methods

Male (n = 184) and female (n = 251) subjects were members of a college fitness class that agreed to participate after being informed of the risks and benefits of the study. The subjects were tested at the conclusion of a 14-week, three-day-per-week fitness course. The program consisted of 20 minutes of aerobic exercise and 20 minutes of resistance training during each session. Resistance training was performed with both free weights (barbells and dumbbells) and Nautilus equipment (cam and leverage machines). Resistance exercise for the arms, chest, shoulders, back, abdomen, hips, thighs and calves were performed as one circuit. Since a two-partner system was used, both work and rest periods were limited to an equal duration of 50 seconds. A 10-12 RM was used and when more than 12 repetitions could be performed, the resistance was increased at the next session to maintain the number of repetitions at 10-12. It was assumed that after the 14-week course, the training had reduced the neural inhibition thought to limit the full expression of strength during lifting (11).

Bench Press Test

The 1 RM bench press strength was measured using a free-weight Olympic bar and plates. The subject grasped the bar at a position slightly greater than shoulder width. A spotter assisted the subject in lifting the bar from the

Table 1. Physical and performance characteristics of males and females

Variable	Men (n=184)		Women (n=251)			
	$\bar{X}$	SD	$\bar{X}$	SD	%diff	t^b
Age (yrs)	20.0	1.5	19.5	1.5	4.3	3.36
Height (cm)	179.0	6.8	165.4	6.2	7.6	21.67
Weight (kg)	74.5	11.2	62.2	9.4	16.5	12.36
Rep Weight (kg)	59.3	16.4	28.1	7.0	52.6	26.96
Percent 1 RM	76.5	10.6	73.7	10.6	3.7	2.70
Reps	10.9	5.8	14.1	8.0	-29.4	4.50
Bench Press (kg)	77.8	20.5	38.2	8.1	-50.9	27.89

[a] percent diff = (men - women)/men x 100
[b]t= 2.59 significant at p < 0.01.

Table 2. Comparison between predicted and actual bench press performance

Group	Actual Performance (kg)		Predicted Performance (kg)		r[a]	t[b]	SEE[c]
	$\bar{X}$	SD	$\bar{X}$	SD			
College Men (n=70)	77.2	19.0	78.1	19.9	0.96	1.43	5.7
College Women (n=101)	37.0	9.2	36.9	8.3	0.91	0.30	3.6
HS Nonathletes (n=74)	74.0	19.0	72.7	18.0	0.95	1.88	5.8
HS Athletes (N=25)	85.8	17.1	86.8	16.9	0.97	1.78	4.1
College Football Players (n=56)	114.9	19.4	113.7	19.0	0.97	1.78	5.0

[a]All correlations significant at $p < 0.01$
[b]None of the t-ratios were significant at $p < 0.01$
[c]SEE=standard error of estimate in kg

support rack and the subject lowered the bar slowly to touch the chest and then fully extend the arms. The initial weight was subjectively chosen based on previous training history to allow the completion of four to five repetitions. After one to two minutes rest, 2.3 to 4.5 kg was added, and the subject performed one repetition. This procedure was repeated until the subject could not lift the weight. The highest weight lifted successfully was recorded as the 1 RM and was usually achieved in four to six attempts. The reproducibility of this technique has been shown to be quite high ($r = 0.99$) (8).

Relative Endurance Test

Within three to five days after the 1 RM test, a specially-designed computer program randomly assigned a relative endurance load for each subject ranging from 55 to 95 percent of the 1 RM, which was designated the rep weight. After a brief warm-up, the subject performed as many correct repetitions (reps) of the bench press as possible in one minute with the rep weight. It was required that the bar touch the chest and then the arms fully extend on each repetition. Resting was permitted between repetitions if necessary to achieve the full minute of lifting, although most of the subjects reached a state of muscular

Table 3. Accuracy of prediction at different reps and percentages in college men (n=184) and women (n=251)

	Men			Women		
	n	r[a]	SEE[b]	n	r[a]	SEE[b]
Repetitions						
2-5	47	0.95	5.2	38	0.92	3.1
6-10	41	0.93	6.7	55	0.93	3.3
11-15	51	0.96	5.9	56	0.88	4.0
>15	45	0.98	4.8	102	0.87	2.9
Percent						
55-59	6	0.99	4.2	15	0.95	2.2
60-69	56	0.98	4.9	89	0.87	3.7
70-79	51	0.97	4.9	70	0.94	3.0
80-89	42	0.98	3.5	53	0.93	3.1
90-95	29	0.97	4.3	24	0.96	2.6

[a]All correlations significant at $p < 0.01$
[b]Standard error of estimate in kg

fatigue before the required time limit. The reliability coefficient for a similar technique has been shown to be greater than r = 0.97 (4, 8).

Cross-Validation Samples

To determine the broad application of the prediction technique, several cross-validation groups were selected. Group one was composed of 70 men and 101 women randomly selected from the subsequent semester of the same fitness course. They were tested at the end of their training program using the same procedure as in the original sample. Neither the men nor the women differed significantly ($p < 0.05$) from respective original samples on any of the variables under observation.

A second sample was composed of 25 high school male athletes and 74 high school male nonathletes (Group 2). Subjects in this group were enrolled in a six-week weight training course and were familiar with the correct lifting procedures. The training program was similar to that used for the original sample and was performed three days per week. The subjects were tested for the 1 RM as previously described. Later each subject was randomly assigned a rep weight equivalent to either 70, 80 or 90 percent of 1 RM. The subject completed as many reps as possible in one minute with the rep weight.

A third cross-validation sample (Group 3) was composed of 56 first-year players from an NCAA Division II college football team. The players were tested following their winter conditioning program which was composed of low-repetition (2-8 reps/set), heavy-load (80-95 percent 1 RM) resistance training such as squats, bench presses, deadlifts and power cleans. Prior to this 10-week collegiate resistance training program, each subject had a varied background involving weight training but all were experienced to some degree. The 1 RM bench press was tested using the same procedure as described earlier. During a separate lifting session, each subject was randomly assigned to lift 70, 75, 80, 85 or 90 percent of 1 RM. Again, a one-minute time limit was imposed, although many of the subjects stopped when they had completed as many reps as possible.

Statistical Procedures

Unpaired t-tests were used to evaluate the differences between men and women and between the validation and cross-validation groups. Pearson product-moment correlation coefficients were used to determine the interrelationships among the variables. Accuracy of the prediction equation was evaluated using the standard errors of estimate.

Results

The physical and performance characteristics of the original subjects are shown in Table 1. Men were significantly different from women in all variables measured.

The relationship between percent 1 RM and reps was exponential for both men and women (Figure 1). Since the curves were not significantly different ($p > 0.05$) in slope or intercept, the data for men and women were combined to produce the following exponential regression equation:

$$\text{Percent 1 RM} = 52.2 + 41.9\, e^{-0.055\ \text{reps}}$$

This equation had a correlation coefficient of r = 0.80 and a standard error of estimate of ± 6.4 percent. Therefore, the percent 1 RM could be estimated reasonably well from the exponential decay in the number of reps completed in one minute. Although some subjects performed more than 15 reps during the one-minute time limit, most individuals completed less than 15 reps before fatigue halted performance. Therefore, the figures illustrate the relationship between reps and percent 1 RM are limited to 15 reps.

The predicted percent 1 RM was used to estimate the 1 RM using the following formula:

1 RM Bench press (kg) = rep weight (kg)/(predicted percent 1 RM/100)

When this formula was applied to the original sample (n = 435), the correlation between predicted and actual bench press was r = 0.98, with a standard error of estimate of ± 4.8 kg.

When the above equations were applied to a cross-validation group undergoing the same training program (Group 1), the correlations between predicted and actual 1 RM for both the men and women were high (r = 0.96 and 0.90, respectively). The procedure overpredicted the 1 RM of the men by an average of +1.2 percent (SD = 9.6 percent) and the women by +0.2 percent (SD = 13.2 percent). Neither of the differences were significant ($P>0.05$). The standard errors of estimate for the men and women were ± 5.7 kg and ± 3.6 kg, respectively.

Using the adolescent samples (Group 2), the correlation coefficients between the predicted and actual 1 RM for the athletes and nonathletes were r = 0.97 and r = 0.95, respectively. The equations developed on the college-age subjects nonsignificantly ($P>0.05$) overestimated the 1 RM for both the high school athletes (X ± SD = +1.4 percent ± 4.0 percent) and nonathletes (+1.9 percent ± 8.1 percent). The standard errors of estimate were ± 4.1 kg and ± 5.8 kg for the athletes and nonathletes, respectively.

When the prediction equations were applied to the college football sample (Group 3), the correlation between the predicted and actual 1 RM was r = 0.95, and the standard error of estimate was ± 5.0 kg. The procedure nonsignificantly ($P > 0.05$) underestimated the actual 1 RM by an average of -0.9 percent (SD = ± 4.4 percent).

A summary of the cross-validation analysis for all groups is given in Table 2. The relationships between reps and the percent 1 RM for the high school athletes and nonathletes and the college football players were also exponential (Figure 2). Although there appeared to be a slight discrepancy among the curves at the higher reps, the regression equations for these three cross-validation groups were not significantly different from each other or from the original equation.

Discussion

The present study indicated that the number of repetitions completed in one minute with a <1 RM load can be used to estimate accurately the 1 RM bench press in a wide variety of subjects. The relationship between percent 1 RM and the number of repetitions completed in one minute was exponential in groups with various resistance exercise backgrounds (Figures 1 and 2). This finding differed from the estimates given by Lander who proposed a linear relationship between the number of repetitions and percent 1 RM (9). The differences between the Lander model and the current study were not large and tended to be greatest between three and five reps and above 14 reps (Figure 3).

Hoeger et al. (6) recently stated that the 1 RM for various exercises cannot be predicted based on number of reps performed with a submaximal load. Using 40, 60 and 80 percent of the 1 RM, the authors found significant differences among trained and untrained men and women in the number of repetitions completed in most of the seven exercises observed. They did note, however, that there was no significant difference in the number of repetitions completed in the bench press between trained and untrained men, while the trained women performed significantly more repetitions than the untrained women. The results of the present study appeared to agree with the findings of Hoeger et al. with regard to the lack of difference between trained and untrained men in the bench press when tested at 60 and 80 percent of the 1 RM (6).

The results of the present study agreed with those noted by Ball and Rose (4) and Invergo et al. (8). Invergo et al. found that the 1 RM of college-age men could be predicted accurately from the repetitions completed using a constant 36.4 kg load (8). Although this load was an average of only 45 percent of the 1 RM, the correlation between the predicted and actual 1 RM was r = 0.93, and the standard error of estimate was ± 6.0 kg. Using a similar design, Ball and Rose (4) found that 1 RM in women could be predicted with reasonable accuracy ($r > 0.79$) using either a 15.9 kg or 20.4 kg load lifted to failure (11). The standard errors of estimate ranged from ± 3.0 to ± 3.3 kg. These results support the findings of this study which indicate that 1 RM can be predicted accurately from relative endurance performance even with light loads.

The use of submaximal repetitions appeared to estimate accurately the 1 RM in the stronger football players despite their more extensive resistance training. When the college-age men from the original sample (n=26) who were capable of bench pressing greater than 100 kg were analyzed, the results indicated that submaximal-load sets significantly underestimated ($p < 0.05$) their 1 RM by -3.0 percent (S.D. = ± 7.1 percent). Perhaps the enzymatic alterations sometimes noted with strength training may not be as extensive in larger (body mass >100 kg) but less well-trained individuals (14). An alternative hypothesis might be that the neuromuscular adaptations which accompany strength training may occur to a lesser degree in larger muscles (7). It is interesting to note, however, that the relationship between percent 1 RM and the number of repetitions performed was not changed by 14 weeks of resistance training in college-age men and women (10). Therefore, the exact reason for the lower ability of the larger muscles of the stronger subjects (1 RM bench press >100 kg) in the original sample to perform the expected number of repetitions is not clear at this time.

Stone and O'Bryant have suggested that repetitions with loads closer to the 1 RM offer better capability for predicting maximum strength (13). To investigate this question, different repetitions and percent 1 RM loads were analyzed from the men and women in the original groups. All of the correlations between predicted and actual 1 RM were above r = 0.87 with comparably low standard errors of estimate (Table 3). Thus, considering the high correlations and low standard errors, higher-repetition sets with lighter loads appeared to be as effective as lower-repetition sets with heavier loads for estimating 1 RM bench press.

The results of the present study hold the most promise for use with prepubescent and pubescent individuals. It has been recommended that younger trainees avoid using maximum loads when training for muscular development or testing strength (2, 12). The 10 RM has been suggested as the preferred method of evaluating the strength of adolescents (12). However, it may be difficult to reach exactly the 10 RM with each individual, and alternate results may invalidate the evaluation of strength. The current approach of using submaximal-load sets to estimate 1 RM provides an acceptable technique for estimating strength in younger individuals with no loss of accuracy.

Practical Applications

Within the limits of this study, the following applications seemed warranted:

1. Repetitions with a submaximal weight (<1 RM) can be used to accurately estimate 1 RM bench press performance.
2. Higher repetitions with lower loads are as effective as lower repetitions with heavier loads for estimating 1 RM bench press.
3. Repetitions completed in one minute can be used in both men and women with varied training backgrounds to determine 1 RM bench press.
4. Lighter loads lifted to failure provide an accurate prediction of 1 RM bench press in adolescent subjects.

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