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The Accuracy of Prediction Equations for Estimating 1-RM Performance in the Bench Press, Squat, and Deadlift

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Reference Data

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ABSTRACT

This study was done to determine the accuracy of 7 equations for predicting a 1-RM from repetitions to fatigue for the bench press, squat, and deadlift. Subjects, 67 untrained college students (40 M, 27 F) who were enrolled in weight training classes, participated in four 45-min practice sessions to learn proper lifting technique and determine the amount of weight to lift for the 1-RM test. All correlation coefficients between predicted and achieved 1-RM lifts were high ($r > 0.95$). For the bench press, however, the average differences between achieved and predicted weights were significantly different from zero in all but 2 equations. For the squat, the average difference was significantly different from zero in all but 1 equation. All equations significantly underestimated the deadlift despite high correlations.

Key Words: strength prediction, muscular endurance

Introduction

The technique used most for evaluating muscular strength is the one-repetition maximum (1-RM) procedure (11). Both novice and experienced weight trainers use the 1-RM to assess strength levels in order to evaluate current training and formulate new training programs. Measurement of the 1-RM can be of concern to weight training instructors and practicing lifters because of the time needed to prepare for and perform the 1-RM and the risk of handling heavy weights. A simple, safe, and accurate procedure for estimating the 1-RM would be a benefit to strength and conditioning specialists, sports medicine physicians, athletic trainers, and weight trainers.

Seven equations (see Table 1) have been reported for predicting 1-RM using weight lifted and repetitions to fatigue. The basis of the formulas is the strong association between 1-RM and number of repetitions (10 or fewer) needed to reach fatigue. The present study examined the accuracy of the predicting formulas using repetitions to fatigue in estimating the 1-RM for the bench press, squat, and deadlift using a common data set.

Method

Subjects were 67 untrained college students (40 M, 27 F) enrolled in weight training classes. Each subject signed informed consent after all the risks and benefits of the study were explained.

During the first four 45-min class sessions, the subjects were given standardized instructions as to the proper lifting technique for each lift. As they became familiar with the techniques, they selected a weight to lift for the 1-RM test and a weight that would fatigue them in 10 or fewer repetitions for the bench press, squat, and deadlift. Prior to the 1-RM attempt, they performed several warm-up repetitions with a light weight. For

Table 1
Prediction Equations for 1-RM

Author	Equation
Brzycki (4)	1-RM = 100 · rep wt/(102.78 – 2.78 · reps)
Epley (5)	1-RM = (1 + .0333 · reps) · rep wt
Lander (8)	1-RM = 100 · rep wt/(101.3 – 2.67123 · reps)
Lombardi (9)	1-RM = rep wt · (reps) **.1
Mayhew et al. (10)	1-RM = 100 · rep wt/(52.2 + 41.9 · exp [–.055 · reps])
O'Conner et al. (14)	1-RM = rep wt (1 + .025 · reps)
Wathan (18)	1-RM = 100 · rep wt/(48.8 + 53.8 · exp [–.075 · reps])

Note. Formulas adjusted to predict 1-RM. Some were listed in the original article as % of 1-RM. Exp (a) means e^a, where e is math symbol for the number approx. 2.7181 whose natural logarithm is 1. The notation ** indicates exponentiation.

the 1-RM test, if the subject was successful, 5 to 20 lbs was added for the next attempt. This step was repeated until the subject could not lift the weight; thus the maximum weight lifted successfully was recorded as the 1-RM. This procedure was achieved in 3 to 6 attempts, with 3 to 5 min rest between attempts.

The 1-RM test for all 3 lifts was performed according to the guidelines established by the National Strength and Conditioning Association (NSCA) (1, 6, 15). The repetitions-to-fatigue for each lift were performed in the same manner as the 1-RM test. In the bench press, the bar had to touch the chest and pause on each repetition before returning to full arm extension. During the squat the thighs had to be parallel to the floor each time. During the deadlift the subject had to stand erect on each repetition and could not bounce the weight off the floor.

Subjects were randomly assigned to 1 of 2 groups. Those in Group 1 were tested for the 1-RM for a given lift first and then allowed 10 min rest before testing repetitions to fatigue. Those in Group 2 were tested for repetitions to fatigue first, for a given lift, then allowed 10 min rest before being tested for 1-RM. A minimum of 48 hrs rest intervened between tests of the 3 lifts.

Seven formulas were used to predict 1-RM in each lift (Table 1). In some cases the formulas were % of 1-RM, but for ease of comparison all formulas were converted to predicting 1-RM.

Statistical Analyses

For each model and each type of lift, a paired (dependent means) *t*-test was used to determine whether the difference between the achieved and predicted 1-RM was significantly different from zero. Failure to reject this hypothesis suggests good prediction by the model. Since several *t*-tests were employed, a significance level of 0.01 was used for individual comparisons to keep the overall Type I error rate down. The Pearson product moment correlation was used to compare the linear relationship between the values achieved and those predicted by the model. Significance levels of the standard test of the hypothesis of no correlation were obtained from SAS statistical software.

Results

The subjects' physical and performance characteristics are given in Table 2. The number of subjects in each group (bench press, squat, deadlift) was not the same because, although all performed the bench press, several declined to be tested on the squat and deadlift for medical reasons.

Table 3 compares repetitions to fatigue and the scores in each lift. All correlation coefficients comparing repetition-to-fatigue scores and 1-RM performance were significant and exceeded $r = 0.95$.

When evaluating the formulas for predicting *bench press* performance, only the Mayhew et al. (10) and Wathan (18) formulas predicted 1-RM values and did not differ significantly from the achieved 1-RM values. The other formulas significantly underestimated 1-RM performance, by an average of 2.2 to 5.4 lbs (0.8–6%). In the *squat*, only the Wathan (18) formula predicted a 1-RM value that did not differ significantly on average from the achieved 1-RM performance. The other formulas significantly underpredicted 1-RM performance

Table 2
Subjects' Physical and Performance Characteristics

	Men			Women		
	N	*M*	±*SD*	*N*	*M*	±*SD*
1-RM bench press (lbs)	40	180.5	40.0	27	73.3	16.2
1-RM squat (lbs)	38	250.9	57.2	22	133.6	27.2
1-RM deadlift (lbs)	36	297.5	54.4	29	136.6	32.4
Age	40	20.4	3.7	23	23.3	6.2
Weight (lbs)	40	176.6	24.2	27	148.2	39.4

Table 3
A Comparison of Repetitions to Fatigue and 1-RM Scores

Authors	Predicted 1-RM (lbs) *M*	±*SD*	Diff. between achieved & predicted *M*	±*SD*	Diff. as % of 1-RM achieved	Correlation	*t*
Bench Press							
Brzycki	131.9	60.6	5.4	7.6	4%	0.993	5.87**
Lander	133.0	61.1	4.3	7.5	3%	0.993	4.68**
Epley	135.1	62.1	2.2	7.5	1%	0.993	2.43**
Lombardi	133.0	61.2	4.3	8.6	3%	0.990	4.14**
Mayhew	136.2	62.4	1.1	8.0	0.8%	0.992	1.16
O'Conner	129.1	59.2	8.2	8.1	6%	0.992	8.22**
Wathan	136.1	62.7	1.2	7.7	0.8%	0.992	1.22
1-RM achieved mean = 137.3, standard deviation = 62.1							
Squat							
Brzycki	197.3	75.1	10.7	18.8	0.05%	0.969	4.4**
Lander	198.9	75.7	9.1	18.8	0.04%	0.969	3.7**
Epley	201.3	76.5	6.7	19.0	0.03%	0.968	2.7**
Lombardi	196.8	74.5	11.2	19.7	0.05%	0.965	4.4**
Mayhew	196.8	74.6	11.2	19.7	0.05%	0.965	2.5**
O'Conner	191.5	72.6	16.5	18.9	0.08%	0.968	6.7**
Wathan	203.4	77.4	4.6	17.2	0.02%	0.969	1.8
1-RM achieved mean = 208.0, standard deviation = 74.6							
Deadlift							
Brzycki	207.4	88.3	29.1	26.8	12%	0.956	8.3**
Lander	209.2	89.1	27.3	26.8	11%	0.956	7.7**
Epley	212.5	90.3	24.0	27.1	10%	0.956	6.7**
Lombardi	209.1	89.2	27.4	28.4	11%	0.951	7.3**
Mayhew	213.9	91.3	22.6	28.0	10%	0.953	6.1**
O'Conner	202.8	86.5	33.7	27.5	14%	0.954	9.3**
Wathan	214.3	91.0	22.2	27.1	9%	0.965	6.2**
1-RM achieved mean = 236.5, standard deviation = 91.7							

**$p < 0.01$

by an average of 4.6 to 16.5 lbs (2–8%). In the *deadlift*, despite high correlations between predicted and achieved 1-RM performance, the formulas significantly underestimated 1-RM performance by an average of 22.2 to 33.7 lbs (9–14%)

Discussion

The results revealed that all correlation coefficients between predicted and achieved 1-RM lifts were high ($r > 0.95$). However, for the bench press the average difference between achieved and predicted weights was significantly different from zero in all but 2 equations (10, 18). For the squat the average difference was significantly different from zero in all but 1 equation (18). All equations significantly underestimated the deadlift despite high correlations.

The results of the present study agreed with findings concerning a mixed population of men and women; Mayhew et al. (10) and Wathan (18) equations were better predictors of the bench press than the other equations. In the Prinster et al. (16) study, the Mayhew et al. (10) formula was found to be the better predictor of the bench press using college men. The general trend in these studies was to underestimate the bench press by 1 to 5 lbs, which agreed with the results of the current study.

In a study using men of different training levels (untrained students, resistance trained students, college wrestlers, soccer players, football players, high school students, and resistance-trained middle-aged men), Mayhew et al. (12) noted that 3 prediction equations overestimated and 3 underestimated the 1-RM bench press.

Brzychi (4) and Ware et al. (17) noted that <10 reps to fatigue were better for estimating 1-RM. In addition, Arnold et al. (2) and Ware et al. (17) noted that the prediction equations provided better estimates for the bench press than for the squat. Arnold et al. (2) reported that a load of 85% 1-RM was better for predicting 1-RM values than was a load of 65% 1-RM.

Mayhew et al. (13) and Wathan (18) found a curvilinear relationship between 1-RM and repetitions to fatigue. The largest drop in % 1-RM occurs between 1 and 2 repetitions. From that point the relationship of 3 to 10 reps with % 1-RM appears relatively linear. Despite this linearity, the equations evaluated in the current study tended to underestimate the achieved lift.

Based on information from the following publications, the authors selected 10-min rest between lifts. Fleck and Kraemer (7) state, "Several minutes of rest must be allowed between heavy sets and maximal lifts to replenish the ATP and PC intramuscular stores; otherwise, they will not be available for use in the next heavy set" (p. 139). "This rebuilding of the ATP and PC stores is accomplished in several minutes" (p. 139). Baechle (3) states, "athletes who seek to accomplish maximal or near-maximal repetitions with a heavy load usually need to take 3 to 5 min between heavy sets" (p. 451).

Practical Application

The data suggest that repetitions to fatigue (10 or fewer reps) can accurately predict 1-RM lifts. In general, the formulas most accurately predicted the 1-RM bench press, followed by the squat and then the deadlift. A follow-up study to determine a specific formula for the deadlift would contribute to the accuracy of predictions for that lift.

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