

Prediction of 1 Repetition Maximum in High-School Power Lifters

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ABSTRACT

Eighteen elite male power lifters performed 1-repetition maximum (1RM) and submaximal strength tests (70, 80, and 90% 1RM) to develop prediction equations for the squat (SQ), bench press (BP), and deadlift (DL) exercises. For each equation, stepwise multiple-regression prediction procedure included the maximum number of repetitions (REPS) completed at a given %1RM weight (REPWT). For SQ and BP the 70% 1RM yielded the best 1RM prediction equations: (1RM SQ [kg]) = $159.9 + (0.103 \times \text{REPS} \times \text{REPWT}) + (-11.552 \times \text{REPS})$, with a standard error of the estimate (SEE) of 5.06 kg; (1RM BP [kg]) = $90.66 + (0.085 \times \text{REPS} \times \text{REPWT}) + (-5.306 \times \text{REPS})$, with an SEE of 2.69 kg. For DL the 80% 1RM yielded the best prediction equation: (1RM DL [kg]) = $156.08 + (0.098 \times \text{REPS} \times \text{REPWT}) + (-12.106 \times \text{REPS})$, with an SEE of 4.97 kg. The athlete's years lifted (number of years of power lifting experience) was highly correlated with the 1RM strength for BP and DL ($r > 0.70$) but not for SQ ($r < 0.70$). No bodily structural dimension variable had a significant correlation with 1RM strength ($r < 0.70$). The results of this study indicate that 1RM SQ, BP, and DL may be predicted with an acceptable degree of accuracy in elite male high-school power lifter subjects.

Key Words: prediction equations, squat, bench press, deadlift, elite

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Introduction

Coaches, athletic trainers, rehabilitation specialists, and health and fitness professionals routinely use measurement of maximal strength as a guide to quantify the level of strength, assess the severity of injury or strength imbalance, and evaluate the effectiveness of a training or rehabilitation program (1). The 1 repetition maximum (1RM) test is the most frequently

used strength procedure to evaluate the maximum weight an individual can lift once through the complete movement of an exercise (10). However, attempting the 1RM lift requires intense mental focus and physical readiness in the lifter. Novice lifters and weight trainers may find the 1RM test difficult because of an unaccustomed insecurity while handling heavy loads, inadequate spotting assistance, and fear of failure with the lift (11).

Although limited data are available on musculoskeletal injuries related to 1RM lifts (6), the potential for injury may be increased with the use of heavier loads, which place an excessive amount of stress on the muscles, bones, and connective tissues (11). The potential for damage to bone growth patterns also may be a drawback in the use of the 1RM test among adolescent lifters (1, 11).

Based on this realization, several investigators have developed prediction charts and regression equations from performance in submaximal strength tests. In 1955, Clarke and Herman (3) used army personnel as subjects to test maximal knee extension of the quadriceps muscles. The results indicated that a 10-repetition bout correlated to 50% of their maximum knee extension strength. Mayhew et al. (7) found that relative muscular endurance performance using submaximal bench press (BP) intensities could accurately predict 1RM strength in 251 and 184 college-going women and men, respectively. Braith et al. (1) evaluated the validity of using 7–10 repetitions to estimate maximum knee-extension strength in male and female subjects who were initially untrained and then were trained for 18 weeks. The results showed that a prediction equation developed using untrained subjects to estimate 1RM leg extension could be accurately determined with a 7- to 10-repetition load. However, the same prediction equation resulted in an overprediction of 1RM strength in the subjects after 18 weeks of training. Thus, the authors concluded that level of training

must be taken into account in models predicting 1RM strength.

In 1995, Mayhew et al. (10) further investigated the accuracy of predicting 1RM for the BP using 6 relative endurance prediction equations in trained and untrained college students, college wrestlers, soccer players, football players, and high-school athletes. The authors concluded that <10 repetitions to failure could successfully predict maximal BP strength to approximately ± 4.5 kg. Morales and Sobonya (12) conducted a study with 23 male college athletes to predict 1RM from submaximal testing in the squat (SQ), BP, and power clean. They found that the best predictor for the SQ, BP, and power clean was the maximum number of repetitions at 80% of 1RM, 95% of 1RM, and 90% of 1RM, respectively.

Body structural dimension variables also have been investigated in predicting maximum strength. Mayhew et al. (8) found that upper-arm cross-sectional area, percent body fat, and chest circumference could predict 1RM BP strength in college-going males. Using the above structural dimensions, the correlation of predicted 1RM to measured 1RM was $r = 0.83$ with a standard error of the estimate (SEE) of 11.6 kg. In 1993, Mayhew et al. (9) conducted a follow-up study and found body mass, as well as arm and chest circumference, to be distinguishing factors relating to strength in high-school strength athletes.

Investigators have noted that in teenage power lifting it is common for the musculoskeletal system to be exposed to loads that exceed the lifter's body weight by as much as 2 or 3 times (2). Frequent maximal load training may expose these young athletes to excessive training demands and possible injury. Presently, no prediction equations have been developed for the growing sport of high-school power lifting, and yet this tool could be used effectively to modify workouts and update training programs while also possibly helping to prevent overtraining and bodily harm.

Therefore, the purpose of this study was to develop prediction equations based on submaximal repetitions that best predict 1RM in SQ, BP, and deadlift (DL) exercises for high-school power lifters. A second purpose of this study was to determine which structural dimension variables best predict 1RM strength for this population.

Methods

Experimental Approach to the Problem

The stepwise multiple-regression prediction procedure was incorporated to determine which dependent variables best predict 1RM SQ, BP, and DL in highly trained high-school power lifters. Data collection included 7 testing sessions within a period of approximately 3 weeks with the following procedures.

During the first session, each subject was given a

thorough verbal and written orientation of the research protocol and time commitment required for participation in this study. The athletes were informed that their involvement in the study was voluntary. Volunteers then completed pretest assessments for age, height, weight, chest circumference, biceps circumference, bench drop distance, and years in power lifting. After these assessments, specific lifting details for testing the SQ, BP, and DL were explained. These were the same rules the subjects had adhered to in high-school power lifting competitions. The use of standardized power lifting regulations, in conjunction with 3 certified judges from the Amateur Athletic Union (AAU) evaluating every repetition for accuracy according to AAU rules, helped to ensure the reliability and validity of our data. The subjects were instructed to refrain from strenuous physical activity and any type of training at least 24 hours before a testing session.

During the other 6 sessions, subjects were assessed for 1RM for SQ, BP, DL, and the maximal number of repetitions they could perform at 70, 80, and 90% of 1RM for each lift. The following schedule was used for data collection: week 1, Thursday—pretest assessments; week 1, Friday—1RM on the SQ, BP, and DL exercises; week 2, Monday—BP, maximum number of repetitions with 90 and 70% of 1RM; week 2, Tuesday—SQ, maximum number of repetitions with 90 and 70% of 1RM; week 2, Friday—SQ and BP, maximum number of repetitions with 80% of 1RM; week 3, Monday—DL, maximum number of repetitions with 90 and 70% of 1RM; week 3, Friday—DL, maximum number of repetitions with 80% of 1RM.

Subjects

Eighteen male power lifters between the ages of 15 and 18 were recruited from a high-school power lifting team that had recently won the state championship for the third consecutive year and was currently preparing for a national competition. The same coach trained all the athletes. All subjects completed a medical examination and a physical before participation in the sport. A health history screening also was administered during pretest assessments. A signed permission form was received from each subject's parent or guardian before any testing began. Permission to conduct this investigation was obtained from the high-school principal and the university human subjects institutional review board.

Assessment Procedures

Chest and biceps circumference was measured using a cloth tape measure with metric divisions. Height was measured with a meter stick taped against the wall. Weight was determined using a Detecto (Webb City, MO) balance-type scale. Bench drop distance was measured with the arms extended, using a cloth tape, from

the center of the bar to the center of the sternum, directly between the 2 nipples.

During the testing, if more than 1 test was done on the same day for a particular lift, a rest period of 3–10 minutes was allowed. The AAU judges had white and red flags, which they used to signify a good lift or repetition. When at least 2 of the 3 judges held up a white flag, the lift was accepted.

For each testing session a proper warm-up protocol was used. Because testing occurred at the end of a power lifting season, the subjects were allowed to determine their own preferred warm-up protocol.

One-Repetition Maximum Tests

For the 1RM tests, each subject attempted a weight that he believed could be lifted only once using maximum effort. The subject then added weight in increments of 2.2–4.5 kg until the heaviest load that could be successfully lifted once was determined. The subjects rested for approximately 3–5 minutes between attempts.

Squat 1RM

During the SQ 1RM test, each lifter assumed an upright position, with the top of the bar not more than 3.0 cm below the top of the anterior deltoids. With both hands grasping the bar, the bar was removed from the rack, and the lifter moved back to assume a ready position, with knees extended, looking forward at the chief referee. On receiving the start signal, the lifter bent the knees and lowered the body in one smooth descent, until the top surface of the legs at the hip joint were lower than the top of the knees. The lifter then raised himself from the deepest point of the SQ to a standing position, with the knees extended. The chief referee then gave an audible rack command, and the lifter replaced the weight back onto the rack with the aid of 2 spotters.

Bench Press 1RM

In the BP 1RM the lifter placed himself in a supine position, keeping his head, shoulders, and buttocks in constant contact with the weightlifting bench. The lifter's feet remained flat and motionless on the floor during the entire BP attempt. The subject received the bar at full arm's length from a spotter located behind the head of the bench, near the chief referee. The bar was then lowered to the chest at a point 1–2 cm below the nipple line along the chest. When the bar became motionless on the chest, the chief referee gave a press command, and the lifter extended his arms, returning the weight back to its starting position. Once the arms were completely extended, the chief referee gave a rack command, and the spotters aided the lifter in returning the weight back to the racks on the bench.

Deadlift 1RM

For the DL 1RM test the lifter's feet and hands were spaced evenly from the center of the bar and were

Table 1. Subject structural dimension descriptives ($N = 18$).

Variables	Mean $\pm$ SD
Age (y)	16.3 $\pm$ 1.2
Height (cm)	173.9 $\pm$ 7.9
Weight (kg)	82.4 $\pm$ 21.9
Years lifted (y)	1.7 $\pm$ 0.97
Chest circumference (cm)	98.9 $\pm$ 14.0
Biceps circumference (cm)	33.1 $\pm$ 5.2
Bench drop distance (cm)	42.6 $\pm$ 3.4

allowed to be placed close to its center (power style), or farther from the center (sumo style). The lifter lifted the bar vertically from the floor with one smooth motion until the knees and back extended the body to an erect position. When the knees became fully extended, the chief referee gave the verbal down command, and the lifter lowered the bar to the floor.

Maximum Number of Repetitions

For the maximum number of repetitions at 70, 80, and 90% of 1RM, each lifter was instructed to perform as many repetitions as possible, to failure, at the percentage selected for a particular lift. A uniform cadence, with no more than a 2-second pause between repetitions, was allowed. Once again, for correctness, the maximum number of repetition attempts was evaluated by 3 AAU-certified judges using the same procedure as explained above.

Statistical Analyses

All data were entered in the SPSS statistical analysis software program. To establish the best predictor of 1RM strength for SQ, BP, and DL, 3 stepwise multiple-regression procedures were used. Before any statistical analyses were performed, the data were inspected for distribution, normality, homogeneity, independence of error, linearity, outliers, missing values, and collinearity, with no problems identified. The variables entered in the regression analyses were repetition weight at the submaximal %1RM (REPWT), number of repetitions (REPS), $REPS \times REPWT$, age, height, body weight, years in power lifting, chest circumference, biceps circumference, and bench drop distance. The accuracy of the regression equations was determined using a correlation coefficient, the adjusted R^2 value, and the SEE between the measured and predicted 1RM of the SQ, BP, and DL. The SEE was calculated as $Sy/1 - R^2$, where $Sy = SD$ of the measured 1RM and $R^2 =$ the explained variance between the correlated variables. An alpha level less than or equal to 0.05 was required for statistical significance.

Results

The structural dimension characteristics of the subject population are presented in Table 1. Although the sub-

Table 2. Correlations (*r*) between the structural dimension predictor variables and 1RM (the measured/repetition maximum) in squat, bench press, and deadlift (*N* = 18).

Predictors	1RM+ squat	1RM bench press	1RM deadlift
Age (y)	0.428	0.621	0.554
Height (cm)	0.015	0.336	0.137
Weight (kg)	0.389	0.531	0.370
Years lifted (y)	0.644	0.728*	0.765*
Chest circumference (cm)	0.386	0.527	0.425
Biceps circumference (cm)	0.386	0.576	0.462
Bench drop distance (cm)	-0.334	-0.276	-0.362

† 1 RM = 1 repetition maximum.

* *p* < 0.05.

jects had attained national stature as high-school power lifters, they had an average of less than 2 years in the sport. Eleven subjects, or 61.1%, were considered first-year lifters, and all lifters trained under the same coach.

To establish the impact of structural dimension variables on 1RM strength, multiple-regression analysis and Pearson's correlation coefficient (*r*) were used. Two variables were considered to be highly related if the respective correlation coefficients were equal to or greater than 0.70. Table 2 presents correlations between the structural dimension predictor variables and the 1RM strength. The results indicate that only the years lifted (number of years of power lifting experience) was highly correlated with 1RM strength in BP and DL.

The results show that the estimated 1RMs derived from the regression equations were highly correlated with the actual SQ, BP, and DL performance. As specified in Table 3, the best predictors for SQ and BP were the REPS and REPS $\times$ REPWT performed at 70% 1RM. For the DL the best predictors were the REPS $\times$ REPWT and REPS performed at 80% 1RM. Table 4

Table 4. Repetitions performed based on best predictors of %1RM (*N* = 18).*

	70% 1RM squat	70% 1RM bench press	80% 1RM deadlift
Mean (repetitions)	13	16	12
SD	± 3.18	± 2.38	± 3.17
One SD range (repetitions)	10–16	14–18	9–14

* 1 RM = 1 repetition maximum.

presents the mean $\pm$ SD and the repetition ranges of 68% (1 SD) of the subjects using the best REPWT predictor. Stepwise regression analyses produced the following equations to predict 1RM SQ and BP strength: (1RM SQ [kg]) = $159.9 + (0.103 \times \text{REPS} \times \text{REPWT}) + (-11.552 \times \text{REPS})$ (the R^2 value accounted for 98% of the variance, with a SEE of 5.06 kg); (1RM BP [kg]) = $90.66 + (0.085 \times \text{REPS} \times \text{REPWT}) + (-5.306 \times \text{REPS})$ (the R^2 value accounted for 98% of the variance, with a SEE of 2.69 kg.)

The stepwise regression analyses produced the following equation to predict 1RM DL from REPS $\times$ REPWT and REPS performed at 80% 1RM:

(1RM DL [kg]) = $156.08 + (0.098 \times \text{REPS} \times \text{REPWT}) + (-12.106 \times \text{REPS})$ (the R^2 value accounted for 98% of the variance, with a SEE of 4.97 kg).

Discussion

The results of this study suggest that the estimated 1RM derived from the regression equations using REPS and REPS $\times$ REPWT as variables in the estimation equation was adequate for estimating 1RM strength for all lifts. This is supported by the accuracy of the 2-component equation developed in this study.

The results of this study demonstrate a significant positive correlation between predicted and measured 1RM for SQ, BP, and DL in the 18 elite power lifting subjects. These results are consistent with the findings

Table 3. Multiple-regression results (*N* = 18).

	Squat	Bench press	Deadlift
Best predictors	70% REPS $\times$ REPWT and REPS†	70% REPS $\times$ REPWT and REPS†	80% REPS $\times$ REPWT and REPS‡
R^2	0.984	0.985	0.982
Adjusted R^2	0.982	0.983	0.980
SEE (kg)*	5.06	2.69	4.97

*SEE = standard error of the estimate.

† 70% REPS $\times$ REPWT and REPS = number of repetitions $\times$ weight lifted at 70% 1RM and number of repetitions at 70% 1RM.‡ 80% REPS $\times$ REPWT and REPS = number of repetitions $\times$ weight lifted at 80% 1RM and number of repetitions at 80% 1RM.

of studies that have attempted to predict 1RM strength from submaximal strength tests in male subjects (1, 7, 8).

Hoeger et. al. (4) demonstrated that the number of repetitions performed at selected percentages of the 1RM is not the same for all lifts or exercises. The results indicated that the corresponding lifting intensities (%1RM) that represent the best predictors of 1RM strength differ between lifts. The results of this investigation are in agreement, showing the best predictors of 1RM SQ and BP strength to be 70% of 1RM submaximal lifts and that for DL to be 80% 1RM. Factors such as muscle group tested (4), exercise performed (4), specificity of the test (5), gender (4), and athletes' training level and technique (1, 4) are believed to influence 1RM prediction accuracy of the submaximal repetition test.

The use of AAU-certified judges to judge each and every repetition made the study results more reliable and valid. From our review of the literature, this is the first 1RM prediction study with elite-caliber high-school power lifters. Because national-level power lifters were used, however, it is not within the scope of this study to predict how these equations will relate to untrained athletes or nonpower lifting populations.

One of the purposes of this study was to determine which body structural dimension variables were directly related to strength as suggested by others (8, 9). Mayhew et al. (8) determined the relationship between anatomical dimensions and BP performance in college-going men. Multiple-regression analyses selected upper-arm cross-sectional area, percent body fat, and chest circumference as the best items to predict BP strength in college-going men. In another investigation, Mayhew et. al. (9) found body mass as well as arm and chest circumference to be predictor factors associated with strength in high-school strength athletes. This investigation found no structural dimension variables that could be used to predict 1RM strength in the SQ, BP, and DL exercises. Perhaps these variables had a lesser effect on 1RM strength because of the acquired technique of the elite subjects. Learned techniques may compensate for differences in structural dimensions in elite subjects. It may be concluded that these power lifters use their lifting technique to gain strength advantages, which may compensate for any differences in structural dimensions.

The only variable that did correlate to BP and DL strength was years lifted ($r > 0.70$). However, years lifted did not correlate highly to any SQ percentages ($r = 0.64$). In this level of subjects, the SQ may be more of a technique lift than an actual strength lift. Years lifted had a small effect on these lifters because all subjects had at least 1 year of power lifting experience. Because the same technique is used each year, little change occurs once proper form and competitive lift performance have been established.

Direct evaluation of maximal strength with 1RM testing has been shown to be a reliable and useful testing tool, and when properly conducted 1RM tests are safe for most subjects. There are, however, special circumstances when 1RM testing may be contraindicated and the use of valid submaximal repetition maximum tests to estimate 1RM strength would be preferable. The purpose of this study was to ascertain submaximal lifting weights and repetitions that could be used to predict strength without jeopardizing the safety of the lifter. There were no reported incidents of muscular injury and delayed onset of muscle soreness after the submaximal 1RM strength tests. The equations derived in this study are accurate for this selected group and suggest resistance loads of between 70 and 80% of 1RM, where the maximum numbers of possible repetitions to failure fall within 10–16, 14–18, and 9–14 for the SQ, BP, and DL, respectively.

Practical Applications

With the growing enthusiasm in high-school power lifting, the responsibility of the coach and trainer to find safe means to predict maximal strength without jeopardizing the safety of the young athletes is a major concern. The prediction equations developed in the present study demonstrate that 1RM strength can be predicted from REPWT and REPS at 70% of 1RM for SQ and BP and at 80% of 1RM for DL. We recommend using the repetition ranges, performed with the correct technique and to momentary muscular fatigue, provided in Table 4 when completing these 1RM estimations.

However, the use of elite power lifters in this study suggests that the regression equations generated may best be used to predict 1RM SQ, BP, and DL only in this population and not necessarily for all lifting populations. Therefore, cross-validations, using similar performance techniques and procedures, should be considered in further research to ascertain the applicability of these equations to others in power lifting and nonpower lifting populations.

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