Accuracy of Prediction Equations for Determining One Repetition Maximum Bench Press in Women Before and After Resistance Training

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[1]*Human Performance Laboratory, Truman State University, Kirksville, Missouri;* [2]*Department of Physiology, A.T. Still University of Health Sciences, Kirksville, Missouri;* [3]*Exercise Science Department, University of Wisconsin–LaCrosse, LaCrosse, Wisconsin;* [4]*Department of Social and Preventive Medicine, University of Buffalo, Buffalo, New York;* [5]*Institute of Sport Sciences and* [6]*Institute of Medical Physics, University of Erlangen, Erlangen, Germany*

Abstract

Mayhew, JL, Johnson, BD, LaMonte, MJ, Lauber, D, and Kemmler, W. Accuracy of prediction equations for determining one repetition maximum bench press in women before and after resistance training. *J Strength Cond Res* 22(5): 1570–1577, 2008–Repetitions to fatigue (RTF) using less than a 1 repetition maximum (1RM) load (RepWt) have been shown to be a good predictor of 1RM strength in men, but such information is scarce in women. The purpose of this study was to evaluate the accuracy of current prediction equations to estimate 1RM bench press performance and to determine whether resistance training changes the capability to predict 1RM from muscular endurance repetitions in young women. Members ($n = 103$) of a required wellness course were measured for 1RM bench press and RTF using randomly assigned percentages between 60% and 90% of the 1RM (RepWt) before and after 12 weeks of progressive resistance training. The %1RM used to perform RTF remained the same for each individual after training (75.6% ± 10.3%) as before. One repetition maximum bench press increased significantly after training (28% ± 21%). Although the change in the group average for RTF (0.6 ± 6.1) was not significant, the correlation between pretraining and posttraining RTF was moderate ($r = 0.66$; $p < 0.01$), and individual differences in percentage change in RTF were substantial (27% ± 99%). The percentage change in 1RM was not significantly related to initial 1RM ($r = -0.05$), but it was negatively related to the change in RTF ($r = -0.40$; $p < 0.01$). Prediction equations were more accurate in the pretraining and posttraining conditions, in which fewer than 10 RTF were used. Resistance training may alter the relationship between strength and muscle endurance across a wide range of RTF in young women without compromising the accuracy of predicting maximal strength.

Key Words muscle strength, muscle endurance, training effect, performance prediction

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Introduction

The most commonly used method for assessing muscular strength is the 1 repetition maximum (1RM), which is typically performed with free weights. This approach requires an individual to lift as much as possible once, through a full range of motion. Although this type of assessment is considered the most accurate way to determine maximal dynamic strength, there are some inherent complications associated with it. Although the 1RM approach is considered safe when performed correctly (15,29), many novice individuals, especially women, may be reluctant to continue adding weight to reach a maximal value. The increase in load may produce a greater risk for injury during free weight exercises, especially if a participant is unaccustomed to moving heavy loads (29). An untrained individual may also be intimidated by trying to lift heavy loads due to the fear of failure. In addition, the proper 1RM assessment may be very time-consuming because adequate rest between attempts is required (40).

Another approach to determining maximal strength is to estimate the 1RM by using repetitions performed to the point of temporary muscle failure, which is termed repetitions to fatigue (RTF). Using this method, a participant selects a load that is believed to be less than his or her 1RM and performs as many consecutive repetitions as possible. The load or RTF are then applied to any of a number of available prediction equations to estimate a 1RM value. Most of the current equations function best when using a load that will produce a range of 2 to 10 repetitions, whereas other equations may be applied by using up to 20 RTF (28). Although many of these equations are reasonably accurate and precise, most of them do not provide information on the population from which they were developed. This is a concern for the use of these prediction equations because the age, gender, and training status of the individuals may affect the accuracy and precision of the 1RM estimation (28).

Although there are some inherent problems with using RTF and their subsequent prediction equations for the determination of a participant's 1RM, this approach may also be very beneficial. For individuals who are unfamiliar with strength training or testing, attempting a 1RM with heavy loads may be a very intimidating task, whereas using a lighter load and performing RTF may be a more welcoming experience. An RTF technique can also be very efficient in that it reduces the time spent testing and allows more time for training (12). After a proper warm-up, only 1 set is needed to predict a hypothetical 1RM (12), which can give an approximation of maximal strength at any point along the training continuum.

Another concern with currently available equations is their application to women. Recent research has suggested that women may not produce muscle fatigue at the same rate that men do (16,17,35). If this is the case, women may be able to produce more repetitions at a given %1RM or produce an equivalent number of repetitions at a higher %1RM. Because few of the currently available prediction equations mention including women in their sample (10,21,26,31,37), it raises the question of the applicability of these equations to women. With the growing involvement of women in resistance training, it would be advantageous to strength and conditioning specialists to determine the accuracy of RTF prediction equations for assessing the strength of women. Furthermore, limited information is available on the effect of training on the relationship between RTF and maximal strength. In men, several studies have found that training does not alter the relationship between muscle strength and endurance, and predictive accuracy is not compromised (27,36). However, such information is scarce in women. Therefore, the purpose of this study was to evaluate the accuracy of current prediction equations to estimate 1RM bench press performance and to determine whether resistance training changes the capability to predict 1RM from muscular endurance repetitions in young women.

Methods

Experimental Approach to the Problem

This study explored the accuracy of using repetitions to prediction 1RM bench press performance in young women and the effect of moderate resistance training on that relationship. The subjects were typical of young women with limited resistance training experience who underwent an introductory level course of resistance training. The objective was to determine whether any currently available prediction equations were accurate for assessing maximal bench press strength both before and after several weeks of resistance training.

Subjects

College women (n = 103) enrolled in university wellness classes volunteered to participate after signing an Institutional Review Board–approved informed consent document. Resistance training background of the participants ranged from never having used weights to infrequent training over the previous 2 years. Previous sports and work participation that might have had a psychosocial bearing on the participation of the subjects were not considered. The physical and performance characteristics of the participants are shown in Table 1.

Table 1. Physical and performance characteristics of the participants before and after resistance training ($n = 103$).

	Before training		After training			
Variable	Mean ± *SD*	Range	Mean ± *SD*	Range	*t* ratio	% change
Age (y)	19.1 ± 1.2	18.0–25.3	19.3 ± 1.2	18.2–25.5	10.88*	1.2
Height (cm)	166.0 ± 6.1	152.0–185.0	166.3 ± 6.2	152.2–185.4	3.64*	0.2
Weight (kg)	61.6 ± 8.8	45.1–92.5	62.7 ± 8.7	46.5–91.0	3.66*	2.3
BMI (weight/height^2)	22.3 ± 3.4	16.8–31.5	22.6 ± 3.4	17.3–31.1	2.69*	1.8
1RM bench press (kg)	28.7 ± 6.7	18.2–61.4	36.4 ± 8.4	22.7–63.6	14.55*	25.5
Bench press·kg^{-1}	0.48 ± 0.10	0.27–0.79	0.59 ± 0.12	0.36–0.92	13.79*	22.9
Repetition weight (kg)	21.5 ± 4.6	13.6–36.4	27.3 ± 6.1	13.6–43.2	14.35*	25.5
%1RM bench press	75.6 ± 10.3	56.3–92.9	75.6 ± 10.3	60.0–94.1	0.13	−0.4
Bench press repetitions	12.5 ± 6.9	2–20	13.1 ± 7.8	1–30	0.97	9.7

% Change = posttraining value − pretraining value.
*$p < 0.01$.

Procedures

Training Program. Each participant underwent a progressive resistance training program 3 days per week for 12 weeks. The resistance exercises performed were the supine bench press, biceps curls, latissimus dorsi pull-downs, upright rows, half-squats, and calf raises. Three sets of each resistance exercise were performed in a modified linear periodization format. During weeks 1 through 4, loads that produced a range of 10 to 12 repetitions were used. During weeks 5 through 9, loads were increased to obtain a range of 8 to 10 repetitions for each exercise. During weeks 10 through 12, participants were encouraged to increase the load for each exercise to elicit a range of 5 to 7 repetitions. If a participant was able to perform repetitions beyond the desired ranges for each set of any given exercise, she was encouraged to increase the load to re-establish the desired repetition range. In addition, 2 sets of 20 to 25 repetitions of unweighted abdominal curl-ups were performed at each session throughout the training program.

One Repetition Maximum Testing. A 1RM using the free weight supine bench press exercise was used to assess upper-body strength in each participant. Before the 1RM assessment, the participants were given instructions on proper lifting techniques and assessment procedures. The participants were instructed to lower the weight slowly, under control, until it touched the chest but not to bounce the weight off their chest. The participants' shoulders, back, and buttocks were required to remain in contact with the bench, and their feet were required to remain on the floor throughout the exercise.

After a warm-up consisting of several sets of 6 to 10 repetitions using a light load, each participant attempted a single repetition with a load she believed to be approximately 90% of her maximum. If the attempt was successful, weight was added depending on the ease with which the single repetition was completed. If the attempt was not successful, weight was removed from the bar. A minimum of 5 minutes of rest was given between maximal attempts (40). This procedure continued until the participant was not able to complete a single repetition through the full range of motion. The heaviest load completed using proper form was determined to be the participant's 1RM and was usually achieved in 3 to 5 attempts. The reliability of this procedure has previously been established at more than 0.98 (17,32).

Repetition Testing. The week after the 1RM assessments, each participant was randomly assigned to lift a weight ranging between approximately 60% and 90% of her 1RM. After an adequate warm-up using a light load, the participants performed repetitions to momentary muscular failure (i.e., RTF) with their assigned %1RM. After 12 weeks of training, each participant performed RTF using the identical %1RM that was used before training. The same lifting techniques used during the 1RM testing were used for the RTF assessments. The reliability of this procedure has previously been established at 0.97 (32).

Prediction Equations. Fourteen 1RM prediction equations using RTF identified from the literature were selected (Table 2). Most of the prediction equations gave no evidence of the population used to develop the equations or how they were derived statistically. Eight of the equations were linear (3,4,6,7,10,23,24,41), and 4 were exponential (24,26,27,37). Of these equations, only 5 (10,21,26,27,37) indicated that women were included in their sample.

Table 2. Prediction equations to estimate 1 repetition maximum from repetitions to fatigue.

Source	Equation
Adams (3)	1RM (kg) = RepWt/(1 −0.02 RTF)
Berger (4)	1RM (kg) = RepWt/(1.0261 −0.00262 RTF)
Brown (6)	1RM (kg) = (Reps × 0.0338 + 0.9849) × RepWt
Brzycki (7)	1RM (kg) = RepWt/(1.0278 −0.0278 RTF)
Cummings and Finn (10)	1RM (kg) = 1.175 RepWt + 0.839 Reps −4.29787
Kemmler et al. (17)	1RM (kg) = RepWt (0.988 + 0.0104 RTF + 0.0019 RTF^2−0.0000584 RTF^3)
Lander (19)	1RM (kg) = RepWt/(1.013 −0.0267123 RTF)
Lombardi (20)	1RM (kg) = $RTF^{0.1}$× RepWt
Mayhew et al. (21)	1RM (kg) = RepWt/(0.522 + 0.419 $e^{-0.055\ RTF}$)
O'Connor et al. (25)	1RM (kg) = 0.025 (RepWt × RTF) + RepWt
Reynolds et al. (26)	1RM (kg) = RepWt/(0.5551 $e^{-0.0723\ RTF\ +\ 0.4847}$)
Tucker et al. (31)	1RM (kg) = 1.139 RepWt + 0.352 Reps + 0.243
Wathen (33)*	1RM (kg) = RepWt/(0.488 + 0.538 $e^{-0.075\ RTF}$)
Welday (35)	1RM (kg) = (RTF × 0.0333) RepWt + RepWt

* Equation calculated from chart provided.
1 RM = 1 repetition maximum; RepWt = repetition weight, a load less than 1RM used to perform repetitions; RTF = repetitions to fatigue.

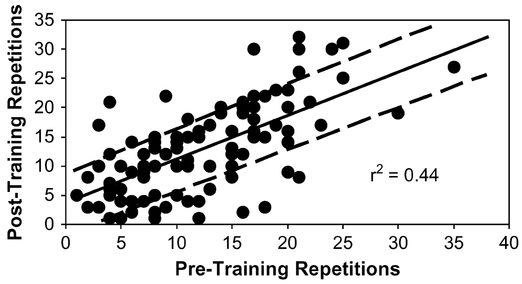

FIGURE 1. Comparison of muscular endurance repetitions before and after training in women (n = 103).

Statistical Analyses

Paired t-tests were used to determine differences between selected variables before and after training. A repeated-measures analysis of variance (ANOVA) was used to determine the difference between predicted and actual 1RM performances. A repeated-measures ANOVA was also used to assess the difference between actual strength improvement and predicted strength improvement. Interclass correlation coefficients (ICC) were used to evaluate the degree of agreement between predicted and actual 1RM values. Pearson correlations were used to assess the degree of relationship between selected variables. The 0.05 level was accepted for statistical significance. Statistical power was greater than 0.90, and the effect size was 0.95 for all analyses.

Results

The resistance training program increased the 1RM bench by 7.7 ± 5.4 kg, or 28.2% ± 20.9%. Although the average change in RTF after training was only 0.6, the range of change was substantial (–15 to 17 repetitions) and caused the correlation between pretraining and posttraining RTF to be only moderate ($r = 0.66$; $p < 0.001$) and indicated considerable variability in the response to training (Figure 1). The pretraining 1RM bench press was not significantly related to the change in 1RM ($r = -0.05$) or the change in RTF ($r = 0.13$) but was significantly related to the percentage change in 1RM ($r = -0.30$, $p < 0.01$).

Only 3 of the 14 equations produced predicted 1RM values that were significantly different from the actual 1RM at the pretraining and posttraining, when the full range of repetitions was used. All of the predicted values were highly correlated ($p < 0.001$) with the actual 1RM values, save for the linear equations by Brzycki (7) and Lander (23) (Table 3). At the pretraining, the equation by O'Conner et al. (30) produced 67% of the predicted values within ±2.3 kg of their actual 1RM values and had a 95% confidence interval (CI) on the difference between the predicted and actual 1RM of –5.9

Table 3. Accuracy of predicting 1 repetition maximum bench press in college women ($n = 103$) by using equations from the literature.

	Before training				After training			
Equation	Predicted Mean ± *SD*	Constant error* Mean ± *SD*	% Error† Mean ± *SD*	ICC	Predicted Mean ± *SD*	Constant error Mean ± *SD*	% Error Mean ± *SD*	ICC
Adams (3)	29.4 ± 7.5	0.7 ± 4.2	2.9 ± 16.1	0.90‡	38.2 ± 10.2	1.7 ± 6.7	5.4 ± 18.2	0.85‡
Berger (4)	21.6 ± 4.6§	−7.1 ± 3.9	−24.0 ± 9.4	0.87‡	27.5 ± 6.0§	−8.9 ± 4.6	−23.9 ± 9.3	0.89‡
Brown (6)	29.7 ± 6.9	0.9 ± 2.9	3.7 ± 10.8	0.95‡	37.9 ± 8.6	1.5 ± 4.6	4.9 ± 13.4	0.92‡
Brzycki (7)	35.9 ± 24.6§	7.2 ± 23.7	26.7 ± 101.7	0.24§	46.9 ± 23.9§	10.5 ± 21.9	29.3 ± 60.0	0.41‡
Cummings and Finn (10)	31.4 ± 6.7	2.7 ± 4.2	10.8 ± 16.9	0.89‡	38.7 ± 7.6	2.3 ± 4.8	7.9 ± 14.4	0.90‡
Kemmler et al. (17)	27.3 ± 6.2	−1.5 ± 2.6	−4.7 ± 9.1	0.96‡	34.6 ± 7.5	−1.8 ± 3.8	−4.2 ±10.0	0.94‡
Lander (19)	35.0 ± 18.2§	6.3 ± 16.8	22.9 ± 70.7	0.40‡	46.1 ± 21.4§	9.7 ± 19.1	27.1 ± 52.2	0.47‡
Lombardi (20)	27.1 ± 5.7	−1.6 ± 3.1	−4.9 ± 9.7	0.93‡	34.2 ± 6.9	−2.2 ± 3.8	−5.1 ± 9.6	0.93‡
Mayhew et al. (21)	28.9 ± 6.2	0.2 ± 2.6	1.2 ± 9.0	0.96‡	36.8 ± 7.6	0.7 ± 3.4	1.8 ± 9.4	0.95‡
O'Connor et al. (25)	28.0 ± 6.2	−0.8 ± 2.6	−2.1 ± 9.0	0.96‡	35.7 ± 7.7	−0.7 ± 3.7	−1.2 ± 9.8	0.94‡
Reynolds et al. (26)	29.6 ± 6.8	0.8 ± 2.8	3.4 ± 10.4	0.96‡	37.7 ± 8.4	1.3 ± 4.3	4.2 ± 11.7	0.93‡
Tucker et al. (31)	29.1 ± 5.1	0.4 ± 3.0	2.8 ± 10.1	0.93‡	35.9 ± 6.4	−0.5 ± 3.7	0.0 ± 9.5	0.93‡
Wathen (33)	30.0 ± 6.9	1.3 ± 2.9	4.9 ± 10.5	0.96‡	38.2 ± 8.5	1.8 ± 4.3	5.7 ± 11.8	0.93‡
Welday (35)	30.1 ± 7.0	1.4 ± 4.2	5.3 ± 11.0	0.95‡	38.5 ± 8.8	2.1 ± 4.6	6.5 ± 12.5	0.92‡
Actual 1RM (kg)	28.7 ± 6.7				36.4 ± 8.4			

ICC = interclass correlation coefficient; 1RM = 1 repetition maximum.
*Predicted 1RM −Actual 1RM.
†(Predicted − Actual)/Actual × 100.
‡p <0.01.
§p <0.05.

to 4.3 kg. At the posttraining, the equation by O'Connor et al. (30) produced 57% of the predicted values within ±2.3 kg of their actual 1RM values and had a 95% CI on the difference between the predicted and actual 1RM of –4.9 to 5.3 kg.

Because many of the existing prediction equations were designed to be used when the repetition range was between 2 and 10, participants at both the pretraining and the posttraining measurements who performed repetitions in that range were evaluated (Table 4). At the pretraining, 9 equations produced predicted 1RM values that were not significantly different from and significantly correlated with the actual 1RM. The equation by Lombardi (24) produced 61% of the predicted values within ±2.3 kg of their actual 1RM values and had a 95% CI on the difference between the predicted and actual 1RM of –5.4 to 4.8 kg. At the posttraining, 5 equations produced predicted 1RM values that were not significantly different from and significantly correlated with the actual 1RM. The equations by Adams (3), Brzycki (7), Cummings and Finn (10), Lombardi (24), and O'Conner et al. (30) produced the highest number of participants with predicted values within ±2.3 kg of their actual 1RM values (i.e., 58% each). Four of the equations (10,21,33,35) produced predicted 1RM values that were not significantly different from actual 1RM values at either the pretraining or the posttraining (Table 4).

A major concern when using a predicted 1RM to determine the improvement from a resistance training program is the degree of agreement between the changes in predicted values (ΔP) versus the changes in actual values (ΔA). Although none of the ΔP were significantly different from the ΔA, the ICCs between the 2 values ranged from –0.09 to 0.95. Further scrutiny of the plots between ΔP and ΔA revealed that the equation by Tucker et al. (37) produced a high correlation between the two (ICC = 0.87; $p < 0.001$) and had 65% of the participants with ΔP values within ±2.3 kg of their ΔA (Figure 2).

A significant negative correlation between ΔA and ΔRTF ($r = -0.55$; $p < 0.001$) indicated that greater increases in strength were associated with greater decreases in the number of RTF the women were able to perform with the same %1RM after training (Figure 3). There was a moderate tendency for those women who performed more RTF at the pretraining to decrease more in RTF after training ($r = -0.29$; $p < 0.01$). The change in RTF after training was not significantly correlated with body mass ($r = 0.00$) or pretraining strength ($r = 0.13$).

Discussion

A limited number of strength prediction studies have acknowledged including women as participants. Several

Table 4. Accuracy of predicting 1RM bench press in college women using no more than 10 RTF and equations from the literature.

	Before training (n = 46)				After training (n = 45)			
Equation	Predicted bench press Mean ± *SD*	Constant error* Mean ± *SD*	% Error† Mean ± *SD*	ICC	Predicted bench press Mean ± *SD*	Constant error Mean ± *SD*	% Error Mean ± *SD*	ICC
Adams (3)	26.5 ± 4.9‡	−1.3 ± 2.6	−4.5 ± 9.1	0.92§	33.4 ± 6.4‡	−2.2 ± 3.6	−5.5 ± 8.9	0.75§
Berger (4)	22.9 ± 4.0‡	−4.9 ± 2.4	−17.4 ± 7.2	0.92§	29.2 ± 6.0‡	−6.5 ± 3.4	−17.7 ± 7.4	0.75§
Brown (6)	27.5 ± 5.2	−0.3 ± 2.8	−1.0 ± 10.0	0.92§	34.5 ± 6.6‡	−1.1 ± 3.9	−2.2 ± 9.9	0.74§
Brzycki (7)	27.2 ± 5.3	−0.6 ± 2.9	−2.0 ± 10.5	0.91§	34.2 ± 6.7‡	−1.4 ± 4.2	−3.1 ± 10.6	0.73§
Cumming and Finn (10)	28.1 ± 5.3	0.3 ± 2.9	1.1 ± 10.6	0.91§	35.3 ± 6.7	−0.3 ± 3.5	−0.1 ± 9.4	0.75§
Kemmler et al. (17)	25.8 ± 4.9‡	−1.9 ± 2.6	−6.9 ± 8.9	0.92§	32.1 ± 6.4‡	−2.8 ± 3.6	−7.8 ± 8.7	0.93§
Lander (19)	27.5 ± 5.3	−0.3 ± 2.9	−1.1 ± 10.5	0.91§	34.5 ± 6.7‡	−1.1 ± 4.1	−2.2 ± 10.5	0.73§
Lombardi (20)	27.5 ± 5.0	−0.3 ± 2.6	−0.9 ± 9.2	0.92§	34.4 ± 6.5‡	−1.2 ± 3.7	−2.5 ± 9.3	0.74§
Mayhew et al. (21)	28.2 ± 5.2	0.4 ± 2.6	1.6 ± 9.4	0.92§	35.5 ± 6.8	0.2 ± 3.5	0.5 ± 9.2	0.74§
O'Connor et al. (25)	26.7 ± 4.9‡	−1.1 ± 2.6	−3.7 ± 9.1	0.92§	33.7 ± 6.5‡	−2.0 ± 3.6	−4.8 ± 8.9	0.75§
Reynolds et al. (26)	27.5 ± 5.3	−0.2 ± 2.9	−0.9 ± 10.4	0.91§	34.5 ± 6.6‡	−1.1 ± 4.2	−2.2 ± 10.4	0.91§
Tucker et al. (31)	28.8 ± 5.1‡	1.0 ± 2.5	3.9 ± 8.6	0.93§	35.9 ± 6.7	0.3 ± 3.2	1.7 ± 8.7	0.95§
Wathen (33)	28.0 ± 5.4	0.2 ± 2.9	0.7 ± 10.6	0.91§	35.1 ± 6.7	−0.6 ± 4.2	−0.7 ± 10.6	0.73§
Welday (35)	27.9 ± 5.3	0.1 ± 2.8	0.5 ± 10.2	0.91§	35.1 ± 6.7	−0.6 ± 3.9	−0.7 ± 10.1	0.74§
Actual 1RM (kg)	27.8 ± 4.8				35.7 ± 7.8			

ICC = interclass correlation coefficient; 1RM = 1 repetition maximum.
*Predicted 1RM −Actual 1RM.
†(Predicted − Actual)/Actual × 100.
‡p < 0.05.
§p < 0.01.

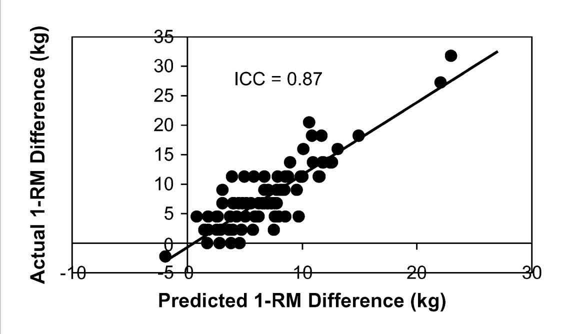

FIGURE 2. Comparison between the change in actual 1 repetition maximum (1RM) bench press (ΔA) and the change in predicted 1RM (ΔP) from the equation by Tucker ($n = 103$).

aspects of some of these equations may render them of limited value in their universal application to women of various levels of ability. The equations by Horvat et al. (18), developed on female college athletes, used absolute weights of 55 or 70 lbs to perform RTF in female athletes. In the current study, only 31 subjects were capable of handling 55 lbs or more for at least 1 repetition. This would suggest that 70% of average women cannot use the weight required for the equations by Horvat et al. (18). The equations by Rose and Ball (32) used untrained to moderately trained young women and absolute weights of 35 and 45 lbs to predict 1RM. The equation by Cosgrove and Mayhew (9) was based on the Young Men's Christian Association (YMCA) test (14) and used the repetitions completed with an absolute weight of 35 lbs to estimate 1RM. Kim et al. (22) also used the YMCA test and had women perform their repetitions at rates of 30 and 60 repetitions per minute. There were too few subjects in the current study using each of these weights to make a comparison feasible. The equation by Abadie and Wentworth (2) used a load that allowed between 5 and 10 repetitions and was adequate in the pretraining sample ($n = 32$; ICC $= 0.85$; $t = 0.96$; $p > 0.05$) but not in the posttraining sample ($n = 27$; ICC $= 0.91$; $t = 2.80$; $p < 0.05$).

Although little information is available on the derivation and statistical support for many of the prediction equations in the literature, it may be safe to say that most were developed by using men. This assumption obviously begs the question of whether such equations would be accurate for use with women. The current study indicates that when the repetitions occurred over a wide range (i.e., 2–30), several of the equations performed adequately in both the untrained and the trained conditions (Table 3). Because there was a substantial curvilinear nature to the relationship between RTF and %1RM over a wide range of repetitions (Figure 4), it appears that the equation by Tucker et al. (37), combining both RTF and load, and the exponential equation by Mayhew et al. (26) performed best. This also seems to hold true when 10 or fewer RTF were used for prediction. That several of the equations developed on men worked adequately on this sample of women suggests that there is little difference between the genders in muscular endurance capacity, despite previous indications that women may have greater fatigue resistance than men have (11,17,35).

A key element for success of any strength prediction equation is whether it is able to track changes resulting from training accurately. Mayhew et al. (27) and Sebelski et al. (34) found no significant change in the average number of RTF after moderate training in young men and women, but neither study reported the degree of variation to be expected. Abadie et al. (1) noted little change in lifting mechanics that would influence performance after resistance training. More recently, Duffey and Challis (11) were able to show changes in the lifting kinematics of recreational weight trainers, as fatigue set in during the latter stages of RTF using 75% of 1RM but made no reference to whether this would change with training. Shimano et al. (36) found no difference between trained and untrained men in the number of RTF

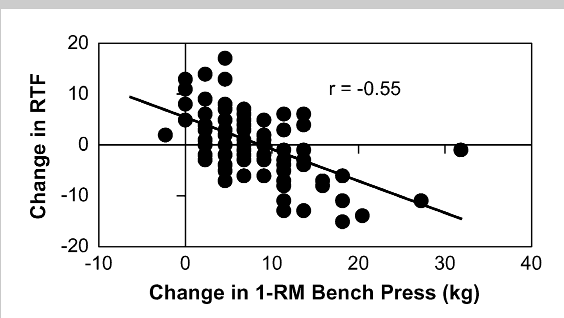

FIGURE 3. Comparison between the change in actual 1 repetition maximum (1RM) bench press (ΔA) and the change in repetitions to fatigue (ΔRTF) after training ($n = 103$).

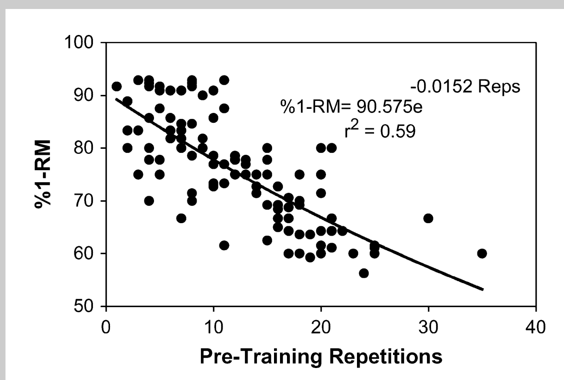

FIGURE 4. Curvilinear relationship between repetitions and percentage of 1 repetition maximum in women ($n = 103$).

performed at 60% and 80% of 1RM. However, untrained men performed significantly more RTF at 90% of 1RM than did trained men. The current findings on women generally support a decrease in RTF at the upper end of the repetition continuum (i.e., >90% 1RM), with increases in 1RM after training, although substantial variation in the change in RTF performed at the same %1RM was noted (95% CI, −11 to 13 repetitions). Despite minor differences when comparing ΔA and ΔP, changes in muscle strength in women can be tracked with acceptable accuracy by using repetition prediction equations.

Recent research indicates that when given the opportunity to select a weight with which to perform repetitions, many individuals will select a lighter weight and hence perform an excessive number of repetitions (13). Many RTF prediction equations available in the literature have a tendency to significantly overestimate 1RM bench press when the repetition range is large (28). This tendency was apparent for some of the equations in the current study, especially the linear ones (Table 3). Previous recommendations have suggested that a repetition range of no more than 10 produces better predictions (7,28,38). When the RTF performed by the current participants were no more than 10, many of the equations worked adequately to predict 1RM before or after training (Table 4).

Strength and conditioning specialists may prefer to perform an RTF prediction rather than a 1RM assessment for women for several reasons. An RTF assessment can be considerably more time-efficient. After an adequate exercise-specific warm-up, only 1 maximal set is needed when using the RTF approach. In addition, women may not be as accustomed to lifting heavy weights with their arms as men are, and hence, their apprehension may prevent them from adequately reaching a true 1RM. The current study suggests that using RTF prediction equations can be an accurate and time-efficient way to assess maximal strength in women at various stages along the training continuum.

Another reason often given for using a repetition equation to predict maximal strength is safety. However, there is little scientific literature to suggest that the 1RM technique, when performed properly, is more dangerous than other lifting techniques for assessing maximal strength (15,29). Indeed, it is possible that an approach using maximal repetitions may also have inherent dangers accompanying it. As the lifter fatigues, the mechanics of the lift may deteriorate and place the individual in an awkward position (11), thus offering the potential for muscle strain or joint injury. In addition, the fatigued condition of the lifter in the latter stages of a repetition assessment could result in an uncontrolled dropping of the weight when she is unable to complete the last repetition. Because of the concerns many individuals have about strength testing, it would be wise for strength and conditioning specialists to be vigilant when having individuals perform either a 1RM or an RTF to assess strength to ensure lifter safety.

Strength and conditioning specialists should also consider the population and reason for strength testing their participants when choosing a method to assess maximal strength. If a precise and accurate measurement of maximal strength is needed, for use on a strength athlete for example, an RTF assessment may not be appropriate due to the potential error involved with these equations. However, an RTF assessment may be more appropriate to estimate strength for an individual who is starting a fitness program that includes resistance training. It may also be used throughout the training process as a gauge of progress with specific lifts and to allow transition between phases of a periodization model (12).

Practical Applications

Maximal repetition tests using a submaximal load can be used to estimate 1RM bench press strength levels in women with acceptable accuracy by using several existing equations. The accuracy of these predictions appears to be enhanced if fewer than 10 RTF are used. The use of estimated 1RM values can allow women to track their progress more easily in a resistance training program. The placement of prediction charts in a training facility may encourage women to place greater emphasis on strength development, which has been shown to enhance bone health (20,25,33) and alter body composition (8).

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