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Accuracy of 1RM Prediction Equations Before and After Resistance Training in Three Different Lifts

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ABSTRACT

This study aimed to assess the accuracy of one repetition maximum (1RM) prediction equations for three resistance exercises in young men and women before and after a resistance training program. Sixty-two women (21.6±3.7 years, 58.5±12.2 kg, and 162.4±6.2 cm) and 57 men (22.8±3.8 years, 70.5±9.3 kg, and 177.0±6.4 cm) performed 16 weeks of a progressive and supervised resistance training. Before and after the 16-week program, the participants performed a 1RM and an endurance test consisting of one set at 80% until muscular failure. The tested exercises were bench press (BP), squat (SQ), and arm curl (AC). The load and number of repetitions performed in each exercise were used to predict the 1RM using nine equations. This design enabled verification of the accuracy of each equation to estimate 1RM scores in young men and women before and after a 16-week RT program. For men, the Lombardi equation was the most accurate for predicting 1RM in BP and SQ, presenting similar results to actual the 1RM before and after RT. All equations presented significant differences for AC before and after training. For women, the Brown, Brzyski, and Lander equations produced similar 1RM scores to the actual values for BP and SQ. For AC, Mayhew, Wathen, and Welday equations produced similar scores to actual 1RM before and after training. Results suggest that using some selected prediction equations to estimate 1RM before and after a resistance training period is a valid method for young men and women in different lifts.

Keywords: strength training, maximum strength, sex difference, prediction equations

INTRODUCTION

Muscular strength is an essential component of physical fitness (Garber et al. 2011). An increased level of muscular strength during the lifespan is desirable because it is directly related to functional capacity (Santos et al. 2017), metabolic syndrome (Sayer et al. 2007), inflammation profile (Tomeleri et al. 2016), depressive and anxiety symptoms (Carvalho et al. 2021), and mortality (Cuenca-García et al. 2014). Moreover, muscular strength is also essential for optimal performance and preventing injuries in many sports (Fleck and Falkel 1986; Hughes et al. 2023; Jarvis et al. 2022). Furthermore, percentage of maximum strength is a traditional parameter for determining training intensity (Buskard et al. 2019; Carroll et al. 2019). Therefore, an accurate assessment of maximum strength may be required to provide information about an individual's performance level.

The most common method for assessing maximal strength is the one-repetition maximum test (1RM). This test requires individuals to lift their maximum weight once through a full range of motion. The

1RM test is versatile and can be applied to different exercises and populations, as well as being low cost and widely accepted by the scientific community (Dias et al. 2013; Grgic et al. 2020). In addition, the 1RM test can be applied to verify the effectiveness of a training program, and data from the 1RM test can be used to classify the training level of practitioner as beginner, intermediate, trained, or advanced, according to the ratio between the weight lifted and their body mass (Junior et al. 2021).

However, some drawbacks to 1RM testing need to be considered. Many studies have observed a significant increase in scores between test sessions, even without training (Amarante do Nascimento et al. 2013; Nascimento et al. 2017, 2017; Ribeiro et al. 2014; Soares-Caldeira et al. 2009). These findings indicate that more than one test session is necessary for a reliable measurement to stabilize the 1RM. Studies have revealed that 2-3 sessions are required for load stabilization (Dias et al. 2013). Furthermore, load stabilization depends on the type of exercise involved, as more complex exercises may require more sessions than single-joint movements (Cronin and Henderson 2004; Dias et al. 2005). Additionally, prior experience with an exercise can also affect the number of sessions for load stabilization, with beginning practitioners needing more sessions to stabilize the load compared to more experienced individuals (Nascimento et al. 2017). In addition, application of the 1RM may not be prudent in practitioners who present joint discomfort or injuries since this type of test generates an overload at the musculoskeletal level, increasing the risk of injury. Considering these issues, applying the test to assess maximal strength or prescribe intensity may sometimes be difficult.

Alternatively, prediction equations have been developed to calculate the 1RM load (Chapman, Whitehead, and Binkert 1998; Mann, Stoner, and Mayhew 2012; Mayhew et al. 1992; Ware et al. 1995). This time-saving approach avoids using maximum loads, reducing the stress on the musculoskeletal system. The equations are based on submaximal loads and repetitions performed until concentric failure. However, although prediction equations may be an attractive alternative for maximal strength testing, it is necessary to mention that most of the equations have typically been developed for a specific exercise, with limited information on the applicability and accuracy of these equations to estimate other lifts. Furthermore, some caveats are necessary when using predictive equations. The prediction accuracy depends on the load used and repetitions performed to failure with studies indicating that the 1RM estimate is more accurate when three to five maximum repetitions are performed, and less precise when the estimate is based on loads greater than ten repetitions maximum (Chapman et al. 1998; Mann et al. 2012; Ware et al. 1995). Optimal testing loads appear to be between 60% and 90% of the participant's estimated 1RM (Brechue and Mayhew 2012). In addition, it is essential to note that the number of repetitions to failure during exercise can be influenced by different factors such as training level, sex, and type of exercise (Eches et al. 2013; Ribeiro et al. 2014; Shimano et al. 2006).

Although prediction equations based on repetition to failure are popular, they are rarely produced for more than one lift, have not been used to determine the influence of training status on prediction accuracy, and have rarely been verified in both sexes. Therefore, the present study aimed to assess the accuracy of 1RM prediction equations for three resistance exercises in young men and women before and after a resistance training (RT) program.

METHODS

Experimental design

The study had a duration of 22 weeks, with testing of 1RM and anthropometric measurements during weeks 1-2 and 21-22. A supervised progressive RT program was performed in two 8-week phases between weeks 3-10 and 13-20. Between the phases (weeks 11-12), a rest interval was given to promote recovery and restructure the RT program. All sessions were supervised by trained personnel. This design allowed verification of the accuracy of prediction equations to estimate 1RM scores in young men and women before and after a 16-week RT program.

Participants

Initially, 140 participants (70 men and 70 women) were recruited from a university and local populations. All participants completed a detailed health history questionnaire. Participants were included in the study if they had no signs or symptoms of disease or orthopedic injuries, were inactive or moderately active (physical activity less than twice a week) and had not been regularly engaged in any RT program during the six months immediately before beginning the study. Sixty-two women and 57 men completed the study and were included in the analyses. The reasons for the drop-outs included insufficient attendance to training sessions (< 85% of the total sessions) and voluntary abandonment for various reasons. We used values from Currier et al. study (Currier et al. 2023) to estimate the sample size necessary to observe changes from pre- to post-training in muscular strength using G*Power (version 3.1.9.6). The analysis indicated that at least 13 participants would be necessary (effect size = 0.75; power = 0.80; α = 0.05). Written informed consent was obtained from all participants after they had received a detailed description of all procedures. The University Research Ethics Committee approved this investigation before any testing procedures.

Anthropometry

Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale (Filizola, model ID 110, São Paulo, Brazil), with participants wearing light workout clothing and no shoes. Height was measured with a wooden stadiometer to the nearest 0.1 cm while participants stood without shoes. Body mass index (BMI) was calculated as body mass (kg) divided by the square of height (m^2).

Muscular strength

Maximal dynamic strength was evaluated using the 1RM in the bench press (BP), squat (SQ), and arm curl (AC), in that order, at baseline and after the intervention period (Ribeiro et al. 2014; Ritti-Dias et al. 2011; Soares-Caldeira et al. 2009). In the BP, the grip was such that the thumbs were at shoulder width when the bar rested on the support standards. The complete range of motion consisted of lowering the bar until it touched the chest and immediately pushing it upward until locking the elbows at the top of the press. The 1RM SQ was performed with a Smith machine. Feet were parallel and placed shoulder-width apart. The complete range of motion consisted of lowering the body by flexing the knees to a 90° angle and moving upward until the knees were locked. For the execution of the AC, participants stood with their back against a wall to prevent any assistive motion and their knees positioned with a slight flexion. From a full arm-extended position, with hands in supination, placed slightly wider than shoulder-width and directly under the bar, the AC was executed using the anterior arm flexor muscles through a range of motion of approximately 120° or until full elbow flexion.

Rest periods between exercises ranged from three to five minutes. The test in each exercise was preceded by a warm-up set (6-10 repetitions) with 50% of the estimated load used in the first attempt of the 1RM test. This warm-up also familiarized the participants with the testing equipment and lifting techniques. Each testing procedure was initiated two minutes after the warm-up. Participants were guided to attempt to accomplish two repetitions with the imposed load and were allowed three attempts in each exercise. If a participant was successful in the first attempt, additional weight was added (3-10% of the first attempt load), a 3-5 min rest was given, and a second attempt was made. If this attempt was successful, a third attempt was given with an increased load (3-10% of the second attempt load), following a 3-5 min rest. If the subject was unsuccessful in the first or second attempt, weight was removed (3-10% of the previous attempt load), and another attempt was given. The 1RM was recorded as the last load lifted in which the subject could complete one full-range maximum execution.
The execution technique and form of each exercise were standardized and continuously monitored to enhance reliability in the maximum strength assessment. All sessions were supervised by three experienced researchers for greater safety and integrity of the participants during the tests. Verbal encouragement was given during every attempt. Four 1RM sessions were separated by 48 hours with interval correlation coefficient of 0.997 (0.996; 0.998) for BP, 0.984 (0.978; 0.988) for SQ, and 0.994 (0.992; 0.996) for AC. The highest load among the four sessions was used for analysis in each exercise. During all sessions, participants were allowed to drink water whenever necessary and were encouraged to remain hydrated throughout testing.

Muscular endurance protocol and prediction equations

A resistance test was performed 2-3 days after the 1RM test sessions. Exercises and order of performance for the muscular endurance test were the same as the 1RM tests. The test protocol consisted of the execution of one set at 80% of 1RM load until voluntary exhaustion. The participants were asked to execute as many repetitions as possible in each exercise. The rest interval between exercises was 3-5 min. The exercises were preceded by a warm-up set of 6-10 repetitions with 50% of the load to be used in the first set. The load and number of repetitions performed in each exercise were used to predict the 1RM in nine equations (Mayhew et al.

Table 1. Prediction Equations to Estimate 1RM from Repetitions-to-Failure.

Source	Equations [a,b]
Adams	1RM (kg) = RepWt/(1- 0.02 RTF)
Brown	1RM (kg) = (RTF x 0.0328 + 0.9849) x Rep Wt
Brzycki	1RM (kg) = RepWt/(1.0278 - 0.0278 RTF)
Lander	1RM (kg) = RepWt/(1.013 - 0.0267123 RTF)
Lombardi	1RM (kg) = $RTF^{0.1}$ x RepWt
Mayhew	1RM (kg) = RepWt/(0.522 + 0.419 $e^{-0.055\ RTF}$)
O'Connor	1RM (kg) = 0.025 (RepWt x RTF) + RepWt
Wathen	1RM (kg) = RepWt/(0.488 + 0.538 $e^{-0.075\ RTF}$)
Welday	1RM (kg) = (RTF x 0.0333) RepWt + RepWt

[a]RepWt = 80% 1RM (kg) used to perform repetitions. bRTF = repetitions-to-failure.

2008), as described in Table 1.

Resistance training

A supervised progressive RT program was performed in two 8-week phases, three times per week, on non-consecutive days (Mondays, Wednesdays, and Fridays). Experienced instructors individually supervised all participants during each training session to reduce deviations from the study protocol and to ensure subject safety. Participants performed the RT using a combination of free weights and machines, with exercises including total and segmental movements of upper limbs, trunk, and lower limbs. The exercises performed according to phase are described in Table 2.

For both training phases, participants performed three sets of 8-12 repetition maximum (RM) for each exercise and were instructed to perform each repetition with a concentric-to-eccentric phase ratio of 1:2. The rest period between sets was 60-90 s, with a 2-3 min interval between each exercise. Participants were encouraged to exert maximal effort during all sets. Training loads were adjusted weekly using the weight test for repetitions maximums (Ribeiro et al. 2015), which consisted of executing the first and second sets in the lower repetition zone (8 repetitions) and as many repetitions as possible in the third set. Adjustments were made according to the following equations:

Upper limb exercises:
FW (kg) = WT (kg) + Repetitions/2

Lower limb exercises:
FW (kg)= WT (kg) + Repetitions

Where: FW = final weight (kg); WT = weight used in the test (kg); RE = repetitions that exceeded the lower limit (8 repetitions). Participants were instructed not to perform any other type of exercise during the study period.

Table 2. Resistance training exercises at different phases.

Phase one	Phase two
Bench press	Bench press
45° angle leg press	Incline dumbbell fly
Wide-grip pulldown	Wide-grip pulldown
Leg extension	Seated cable rows
Side lateral raise	Seated barbell military press
Leg curl	Arm curl
Triceps pushdown	Supine triceps press
Calf raises (on the leg press machine)	Leg extension
Arm curl	45° angle leg press
Abdominal crunch	Leg curl
	Seated calf raises
	Abdominal crunch

Statistical analysis

The Shapiro-Wilk test was used to check normality. Data are expressed as mean and standard deviation. The independent t-test was used to compare baseline differences between men and women. The dependent t-test was applied to compare the equation scores with actual 1RM values. Bland-Altman plotting procedures (Bland and Altman 1986) were used to determine the bias and limits of agreement (LoA) between the 1RM and predictive equations. Two-way mixed intraclass correlation coefficient was used to assess the reproducibility of 1RM measurements. For all statistical analyses, significance was accepted at $P < 0.05$. All data were stored and analyzed using the Statistical Package for the Social Sciences (SPSS for Windows Version 20.0).

RESULTS

Participant characteristics are shown in Table 3. Men presented greater scores ($P < 0.05$) for weight and height compared to women. No difference ($P > 0.05$) was observed between the sexes for age, BMI, and training experience. Considering the actual 1RM scores, men had effect sizes (calculated as the post-raining mean minus the baseline mean divided by the pooled standard deviation) of 0.17, 0.27, and 0.20 in BP, SQ, and AC, respectively, while women had 0.28, 0.20, and 0.31 in BP, SQ, and AC, respectively.

For men, the Lombardi equation was the most accurate for predicting 1RM in BP and SQ, presenting similar results ($P > 0.05$) to actual 1RM before and after RT (Table 4). All equations presented significant ($P < 0.05$) difference for AC before and after RT (Table 4). For women (Table 5), the Brow, Brzycki, and Lander equations produced similar ($P > 0.05$) 1RM scores to actual values for BP and SQ. For AC the Mayhew et al., Wathen, and Welday produced similar ($P > 0.05$) scores to actual 1RM at both moments of the study.

The bias and LoA for each equation before and after training for men are shown in Table 6. The Lombardi equation showed the lowest bias in both BP and SQ at both pre-and post-training testing. The Mayhew et al. equation showed the lowest bias for AC at both moments. Table 7 displays the bias and LoA for each equation before and after training for women. For BP, the Brzycki equation showed the smallest bias before training, and after training, the Brown and Brzycki equations presented the smallest bias. For the squat, Brown and Brzycki equations showed the smallest bias before training, while the Mayhew et al. equation showed the smallest bias for the squat after training. The Brzycki and Brown equations demonstrated smallest bias in the pre-training for AC; however, post-training, the Mayhew et al. equation showed the smallest bias.

DISCUSSION

The present study evaluated the accuracy of nine equations for predicting 1RM on three exercises in young men and women before and after an RT program. The primary outcome showed that some equations can estimate the maximum dynamic strength with reasonable accuracy in men and women in BP, SQ, and AC before and after a period of strength training.

The 1RM has frequently been used by professionals and coaches to assess maximum dynamic strength through exercises for the upper and lower body as a parameter of physical conditioning and performance. Estimations of 1RM using selected prediction equations seem accurate for identifying maximum dynamic strength of young university students of both sexes. Among the nine equations in this study, only the Lombardi equation showed more accuracy in predicting 1RM in BP and SQ exercises for men before and after RT, although this same equation overestimated results in the AC

Table 3. Demographic characteristics of the participants (n = 119).

Variables	Men (n = 57)		Women (n = 62)	
	Mean ± SD	**Range**	**Mean ± SD**	**Range**
Age (years)	22.8 ± 3.8	18 – 32	21.6 ± 3.7	18 - 31
Weight (kg)	70.5 ± 9.3	52.9 – 94.8	58.5 ± 12.2*	39.3 – 96.1
Height (cm)	177.0 ± 6.4	164.0 – 192.0	162.4 ± 6.2*	151.0 – 179.5
BMI (kg/m^2)	22.5 ± 2.5	15.5 – 32.5	21.6 ± 3.3	17.8 – 29.5
Training experience (months)	14.2 ± 15.6	0 – 72	10.3 ± 16.4	0 – 84

*Note: BMI = body mass index. * P < 0.05 vs. men.*

Table 4. Accuracy of prediction equations to estimate 1RM in bench press, squat, and arm curl before and after training in men (n = 57).

Equations	Bench press		Squat		Arm curl	
	Before	After	Before	After	Before	After
Adams	67.0 ± 16.8*	78.5 ± 16.0	119.9 ± 25.2	137.2 ± 25.3	36.7 ± 6.2*	41.3 ± 6.1*
Brown	70.3 ± 17.7	82.3 ± 16.0*	124.2 ± 25.0*	143.3 ± 26.9	38.3 ± 6.4*	42.8 ± 6.5*
Brzycki	70.4 ± 18.5	83.0 ± 17.6*	131.1 ± 35.1*	146.3 ± 30.3*	37.8 ± 6.3*	42.3 ± 6.4*
Lander	71.1 ± 18.5*	83.5 ± 17.6*	128.0 ± 32.7*	143.5 ± 29.1	38.1 ± 6.4*	42.7 ± 6.4*
Lombardi	68.6 ± 16.5	79.8 ± 15.8	117.1 ± 20.2	137.8 ± 23.2	38.4 ± 6.6*	43.1 ± 6.6*
Mayhew	70.7 ± 17.4*	82.6 ± 16.6*	123.0 ± 22.5*	143.3 ± 25.1*	39.2 ± 6.7*	44.1 ± 6.6*
O’Connor	67.3 ± 16.7*	78.7 ± 15.9	118.0 ± 22.4	136.8 ± 24.4	37.1 ± 6.3*	41.7 ± 6.2*
Wathen	72.0 ± 18.2*	84.3 ± 17.4*	126.8 ± 25.3*	146.6 ± 27.9*	39.0 ± 6.6*	43.5 ± 6.7*
Welday	71.3 ± 18.0*	83.5 ± 17.1*	126.1 ± 25.4*	145.4 ± 27.3*	38.8 ± 6.5*	43.5 ± 6.6*
Actual 1RM (kg)	68.9 ± 16.1	79.9 ± 15.6	116.7 ± 19.4	138.2 ± 21.1	40.1 ± 7.1	45.6 ± 6.9

*Note: * P < 0.05 vs. actual 1RM.*

Table 5. Accuracy of prediction equations to estimate 1RM in bench press, squat, and arm curl before and after training in women (n = 62).

Equations	Bench press		Squat		Arm curl	
	Before	After	Before	After	Before	After
Adams	28.1 ± 6.1*	35.7 ± 7.3*	72.2 ± 15.4*	86.9 ± 20.9*	20.8 ± 3.7*	24.9 ± 3.7*
Brown	29.4 ± 6.4	37.4 ± 7.7	75.2 ± 15.3	90.6 ± 21.9	21.7 ± 3.9	25.9 ± 3.8*
Brzycki	29.4 ± 6.4	37.4 ± 8.1	75.7 ± 16.7	91.7 ± 24.0	21.9 ± 4.2	25.7± 3.8*
Lander	29.6 ± 6.4	37.8 ± 8.1	74.5 ± 16.3	90.1 ± 23.2	22.0 ± 4.1	25.9 ± 3.8*
Lombardi	28.9 ± 6.3*	36.6 ± 7.2*	72.8 ± 18.4	88.4 ± 20.1*	21.3 ± 3.8*	25.8 ± 3.9
Mayhew	29.7 ± 6.4	37.7 ± 7.5*	76.1 ± 16.3	91.3 ± 21.2	21.9 ± 4.9	26.4 ± 3.9
O’Connor	28.3 ± 6.1*	35.9 ± 7.2*	72.4 ± 15.5*	87.0 ± 20.4*	20.9 ± 3.7*	25.1 ± 3.7*
Wathen	30.0 ± 6.5*	38.3 ± 7.9*	76.8 ± 16.9	92.5 ± 22.5	22.1 ± 4.1	26.5 ± 3.9
Welday	29.8 ± 6.5	38.0 ± 7.8*	76.4 ± 16.6	91.9 ± 22.2	22.0 ± 4.0	26.3 ± 3.9
Actual 1RM (kg)	29.4 ± 6.5	37.1 ± 7.1	75.5 ± 16.1	90.0 ± 19.8	21.8 ± 3.8	26.7 ± 4.2

*Note: * P < 0.05 vs. actual 1RM.*

exercise. Other equations such as those of Brown and Brzycki were also efficient for BP in the same way as Adams and O’Connor equations were for SQ. Regarding women before training, the Brown equation seemed to be more accurate for the three exercises. Secondarily, the Brzycki, Lander, and Welday equations were also acceptable to estimate 1RM of BP, SQ, and AC exercises; however, after training, the Brown equation proved to be more accurate. The 1RM prediction equations can be used reliably for upper and lower limb exercises in both men and women, since some equations estimated 1RM with reduced bias and LoA.

For men in the BP, only the Lombardi equation presented similar predicted values to those measured before and after training. This equation also showed the smallest bias before and after RT. Therefore, the Lombardi equation seems to be the best alternative to predict maximum dynamic BP strength in men. Regarding SQ in men, three equations (Adams, Lombardi, and O’Connor) presented similar scores to actual 1RM before and after training. However, the Lombardi equation showed the lowest bias among all equations. None of the equations accurately predicted AC in men, but the Mayhew et al. equation showed a reduced bias compared to the other equations.

For women in the BP, three equations (Brown, Brzycki, and Lander) showed similar results compared to the measured value. However, the Lander equation showed reduced bias before and after RT period, making it the most suitable for women in BP. Six equations (Brown, Brzycki, Lander, Mayhew et al., Wathen, and Welday) did not differ in their predicted SQ from the actual 1RM. The Brzycki equation presented the least bias among all equations. Three equations (Mayhew et al., Wathen, and Welday) predicted AC accurately in women

Table 6. Mean differences (kg) and limits of agreement (CI 95%) between actual 1RM and prediction equations on bench press, squat, and arm curl men before and after the 16-week intervention in men (n = 57).

Equations	Bench press				Squat				Arm curl			
	Before		After		Before		After		Before		After	
	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%
Adams	1.9	(7.2; -3.4)	1.5	(8.5; -5.6)	-3.0	(26.2; -32.1)	1.0	(21.3; -19.3)	3.3	(6.7; -0.2)	4.3	(8.8; -0.2)
Brown	-1.8	(4.8; -8.3)	-2.9	(5.3; -11.1)	-8.3	(19.9; -36.5)	-1.0	(24.4; -26.3)	1.6	(5.5; -2.3)	2.6	(8.2; -3.0)
Brzycki	-1.6	(7.2; -10.4)	-3.1	(7.9; -14.0)	-14.1	(38.2; -66.4)	-8.1	(24.6; -40.9)	2.2	(6.8; -2.3)	3.4	(9.4; -2.7)
Lander	-2.1	(6.6; -10.7)	-3.6	(7.1; -14.3)	-14.4	(35.7; -64.4)	-8.9	(23.0; -40.8)	-2.1	(7.0; -11.2)	3.0	(8.9; -3.0)
Lombardi	0.4	(3.2; -2.4)	0.1	(3.8; -3.6)	-0.7	(9.3; -10.7)	0.4	(11.0; -10.2)	1.7	(4.2; -0.9)	2.3	(6.0; -1.4)
Mayhew	-1.8	(2.9; -6.5)	-2.6	(3.2; -8.5)	-6.1	(12.4; -24.6)	-5.1	(10.9; -21.1)	0.9	(3.7; -1.9)	1.5	(5.6; -2.6)
O'Connor	1.6	(6.1; -2.9)	1.3	(7.3; -4.7)	-1.1	(19.6; -21.9)	1.4	(18.0; -15.3)	2.9	(6.2; -0.3)	3.9	(8.3; -0.5)
Wathen	1.6	(6.5; -3.2)	1.2	(7.7; -5.2)	-1.1	(20.5; -22.8)	1.4	(19.3; -16.6)	3.1	(6.7; -0.5)	4.2	(9.0; -0.7)
Welday	-2.4	(4.2; -8.9)	-3.6	(4.6; -11.7)	-9.2	(18.6; -37.0)	-7.3	(15.6; -30.1)	1.2	(5.0; -2.6)	2.1	(7.6; -3.3)

Table 7. Mean differences (kg) and limits of agreement (95% CI) between actual 1RM and prediction equations on bench press, squat, and arm curl women before and after the 16-week intervention in women (n = 62).

Equations	Bench press				Squat				Arm curl			
	Before		After		Before		After		Before		After	
	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%	Bias	LoA 95%
Adams	1.3	(3.7; -1.2)	1.4	(5.3; -2.5)	3.6	(14.0; -6.8)	3.3	(17.9; -11.2)	1.0	(4.2; -2.2)	1.9	(4.5; -0.7)
Brown	-0.2	(2.5; -2.9)	0.4	(4.1; -5.0)	0.1	(11.6; -11.3)	7.9	(31.8; -16.1)	0.0	(3.4; -3.4)	0.8	(3.8; -2.3)
Brzycki	0.0	(3.5; -3.4)	0.4	(5.7; -6.5)	0.2	(16.4; -16.0)	-1.3	(22.8; -25.3)	0.0	(5.1; -5.1)	1.1	(4.7; -2.5)
Lander	-0.2	(3.2; -3.6)	0.6	(5.3; -6.6)	-0.3	(15.3; -16.0)	-1.8	(21.4; -25.1)	-0.4	(5.3; -6.2)	0.9	(4.4; -2.6)
Lombardi	0.5	(1.9; -0.9)	0.5	(2.3; -1.3)	1.7	(7.3; -3.9)	1.7	(8.7; -5.3)	0.5	(2.2; -1.2)	0.9	(2.4; -0.7)
Mayhew	-0.3	(1.6; -2.2)	-0.5	(2.6; -3.7)	-0.3	(7.6; -8.3)	-1.0	(9.7; -11.8)	-0.1	(2.2; -2.4)	0.4	(2.6; -1.8)
O'Connor	1.1	(3.3; -1.0)	1.3	(4.6; -2.1)	3.3	(12.0; -5.4)	3.3	(14.8; -8.2)	0.9	(3.5; -1.6)	1.7	(4.1; -0.7)
Wathen	1.2	(3.5; -1.2)	1.3	(4.9; -2.3)	3.6	(13.0; -5.8)	3.5	(15.8; -8.8)	1.0	(3.7; -1.7)	1.8	(4.5; -0.8)
Welday	-0.4	(2.2; -3.1)	-0.8	(3.8; -5.3)	-0.5	(10.7; -11.8)	-1.6	(14.0; -17.1)	-0.2	(3.1; -3.5)	0.5	(3.5; -2.5)

with similar scores to actual 1RM before and after training. The Mayhew et al. equation showed the lowest bias among these three equations.

For men, more equations were not significantly different from the actual 1RM for SQ (3 equations) than for BP (1 equation), and the least accurate exercise was the AC. Considering the two phases of the study for women, the SQ was also the exercise that presented more equations that did not differ significantly from the actual measured value (6 equations). However, BP and AC showed three equations with no statistical difference with actual value both before and after training. The exact mechanism for the differences among exercises is difficult to explain, but one potential reason for our results may be related to developmental factors within the various equations.

More equations were accurate for predicting BP in women than in men. This difference between men and women for the precision of some equations may be related to factors such as concentration of muscle fiber type (Nuzzo 2024) and difference in anaerobic endurance (Hunter 2009) that affect the capacity to perform repetitions and, consequently, the validity of the equations. However, it is worth mentioning that in the current study, women performed all tests with sets below ten repetitions, perhaps negating the endurance factor when predicting strength. Nevertheless, the bias was not of great magnitude in both sexes in equations that presented similar results to 1RM data.

Some studies have indicated that the maximum number of repetitions performed at a given percentage of 1RM can vary between exercises, as well as between individuals of different sex, ages, or training levels (Eches et al. 2013; Hoeger et al. 1990; Shimano et al. 2006). Nuzzo et al. (Nuzzo et al. 2024) recently carried out a meta-regression study to estimate the maximum number of repetitions for different percentages of 1RM, considering moderators such as sex, age, training level, and exercise. A total of 952 repeat-to-failure tests were performed by 7,270 subjects from 266 studies, and their analysis showed little or no influence of these moderators on the number of repetitions performed. Another relevant feature of our study was the prediction analysis before and after RT with the same participants. A recent study found that trained individuals tend to perform their training repetitions closer to 1RM (Ribeiro et al. 2014). Despite this adaptation, we observed that some equations presented good accuracy in 1RM estimation for both beginners and trained individuals. For some equations, no considerable difference was observed in their biases at pre-training or post-training, and the equations applied equally well to both trained individuals and beginners. This finding agrees with a previous study including a diverse population of men (Ware et al. 1995).

Probabilistic statistics (*P*-value) showed that some equations could estimate the 1RM with no significant difference from the actual score. However, the Bland-Altman plot is considered the quality of a predictor when comparing the differences between an alternative method to a reference standard score. This plot can indicate if the alternative method presents a reduced bias and whether the limits of agreement are within an acceptable range. Our findings indicated that the bias is generally reduced in BP more so than in SQ. In the current study, bias for some equations was lower than 1 kg, suggesting that the estimation of 1RM using those equations is only slightly biased and carries little impact from a practical perspective.

The estimation of 1RM in these three lifts will be better or worse depending on how close the repetition load is to the actual 1RM value. Previous findings showed that the best repetition range lay between 60% and 90% of 1RM when performing fewer than 10 repetitions (4-6). In addition, a caveat with predicting 1RM scores with repetition to failure tests is that practitioners often underestimate the ability to reach failure. Selecting lower rep ranges (e.g., < 6RM) for the repetition to failure tests is a better approach, given that failing is achieved more quickly (Pelland et al. 2022; Steele et al. 2022). In this study, a fixed load of 80% of 1RM was used which allowed performance of approximately 10 repetitions in each exercise. However, in a practical scenario, the trainer will arbitrarily establish the load. Thus, determining the most suitable load to perform the repetition test will depend on the trainer's intuition and background. Fortunately, many of the equations used in the current study have sufficient leeway and accuracy to allow acceptable prediction of the 1RM in these three popular exercises.

Finally, it is worth noting that our findings present some limitations. Results cannot be extrapolated to populations other than resistance-trained men and women. Moreover, findings are limited only to the training time, exercises, and equations investigated. Free-living physical activity was not assessed during the intervention. We did not evaluate the participants' dietary habits, which may have confounded results.

CONCLUSION

The results of the current study suggest that estimating 1RM using several prediction equations for BP, SQ, and AC exercises before and after RT is acceptable for young men and women. Practitioners are encouraged to measure 1RM directly wherever possible. However, predictive equations may help estimate 1RM when a direct measurement is not logistically feasible. From a practical point of view, the 1RM predictive equations can be applied to facilitate the calculation of relative strength for training intensity prescription, verify the efficacy of a given RT program, and classify training levels without testing 1RM. However, it is also necessary to highlight that as in the 1RM tests, coaches should spot practitioners (especially at BP and SQ) to guarantee safety and ensure failure.

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