Muscular strength and endurance tests: reliability and prediction of one repetition maximum – Review and new evidences

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ABSTRACT

Intra-tester reliability is fundamental in determining the quality of data collected in research. Few controlled studies have reported the reliability of strength tests and, in spite of most published studies reporting it to be good (0.79 to 0.99), differences between test and retest are observed to be statistically significant. Thus, for research purposes, it is suggested that values should be taken from a second test, at least, so that changes in strength may be attributed to treatment effect and not simply to adaptation to the test protocol. The relationships between maximum strength tests and submaximal tests or anthropometric variables have been investigated in order to predict maximal strength without submitting subjects to a maximal load test, so as to avoid the risk of injury. Maximal load, or a percentage of it, is commonly used to better prescribe training. Prediction of one repetition maximum (1RM) from submaximal tests seems to be good (in general, correlation coefficients > 0.90), although studies have mostly failed to cross-validate prediction equations. Thus, care should be taken especially in relation to specificity of the population, of the exercise, and performance technique when developing and applying these equations. Anthropometric variables have not proven to be good predictors of 1RM. The number of repetitions for a given % of 1RM is different for different exercises, so is the load for a given number of repetitions maximum (nRM) when performed at different velocities. Exercise prescription based, indifferently, on number of repetitions or %1RM should be carefully considered.

Key words: 1RM. Muscle strength. Muscle endurance. Anthropometry. Reliability.

INTRODUCTION

An increasing demand for resistance training-RT (weight lifting) has fostered the need for well-established exercise-prescription parameters. The American College of Sports Medicine (ACSM) recommends RT to be included in a physical fitness program for adults[1] and the elderly[2]. Its recommendations include, at least, one set of 8-10 exercises for the main muscle groups, with a frequency of 2-3 times a week. There should be 8-12 repetitions for each exercise, and for the elderly and most frail subjects, 10-15 repetitions may be more appropriate[1]. In a recent position stand on progression models in RT[3], ACSM addressed in more detail the training related variables, but some evidences are still scarce or contradictory.

Maximum strength is the maximum capability of a muscle or muscle group to generate tension. It is often measured by the one repetition maximum test (1RM – also called one execution maximum), which is operationally defined as the heaviest load that can be moved over a specific range of motion, one time and with correct performance. Muscular endurance tests are those in which a number of repetitions are performed with submaximal loads.

Maximal, or even submaximal strength tests are rarely used for exercise prescription in clubs and gyms, perhaps because they are operationally complicated and time-consuming. Training prescription is usually based on a theoretical percentage of the maximum, as the 1RM is hardly performed. It is thus likely that 1RM values are under or overestimated, which causes the prescription to be under or over dimensioned.

Strength tests are applied mainly in scientific investigation, in cases when one has to know the subjects' pre- and post-training strength, and for prescribing the research training protocol.

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Reliability of a measurement tool is fundamental for an investigator to ensure quality and draw meaning from a study's data, such as determining the impact of a training program. Even tools proven by use may not be considered reliable in some specific situations, as when used in a particular population with special needs, or when one of the test parameters is changed (for instance, the movement speed). Maximal and submaximal strength tests are broadly used, but there are only few investigations to prove their reliability, both inter- and intra-tester.

The relationships between 1RM tests and submaximal tests or anthropometric variables have been investigated in order to predict maximum strength without submitting the subject to the nuisance of a maximum test. The long time required for carrying out a 1RM test, and the possible risk of injuries, even if of little evidence[4-6], but that may be present in more inexperienced or frail groups[7], lead the investigators to look for more simple and less hazardous tests to estimate maximum strength. Studying these relationships is also important for prescribing training, when the number of repetitions or a percentage of 1RM (%1RM) are established for a certain objective.

The purpose of this review was to make a critical assessment of the information available in the specialized literature regarding intra-tester reliability of strength tests – 1RM, the load for a set number of maximum repetitions (nRM), and %1RM – and the validity of predicting 1RM from submaximal tests and anthropometric variables. New evidences found in our lab were included to enrich the discussion.

Due to a lack of studies on inter-tester reliability in the specialized literature, this was not addressed in this review, in spite of its importance.

INTRA-TESTER RELIABILITY OF MAXIMUM STRENGTH, SUBMAXIMAL STRENGTH AND MUSCULAR ENDURANCE TESTS

Maximum repetition tests, particularly the 1RM test, are broadly used in the literature on muscle strength and resistance; however, test/re-test reliability is not well documented due to the few studies published. It was assumed, in the discussion that follows, that the reported studies relate to intra-tester reliability, in spite of the fact that only one of them[8] actually reported tests and re-tests being done by the same tester.

Reliability of the 1RM test seems to be from moderate to high, with correlation coefficients ranging between 0.79 and 0.99, depending on the gender of the subjects and the exercise being tested (table 1). However, Braith *et al.*[9] and Pereira and Gomes (unpublished data) in studies with young adults of both genders, and Rikli *et al.*[10] in elderly males report statistically significant differences between the first and the second test, both before and after 18 weeks of training[9], but not between the second and the third test[10]. For the elderly group, the difference between test and re-test at pre-training represented a significant percentage (31.4 to 55.9%) of the gain in strength with a 10-week training program, whereas in the young group, the difference was small (2.7 a 4.4%) in relation to mean 1RM values. The three studies had high reliability coefficients, but Braith *et al.*[9] used Pearson's correlation (r), whereas Rikli *et al.*[10] and Pereira and Gomes (unpublished data) used the intraclass correlation coefficient (R). Pearson's correlation is considered to be inadequate by some authors, as it does not detect variations in the means. According to Vincent[11], the correlation compares deviations (fluctuations in the subjects' means) from the mean in two measurements, but it is not sensitive to changes in the means of the measurements. Hopkins[12] considers the analysis adequate, but with a slight bias upwards for small samples.

The number of sessions necessary to establish consistent 1RM values for knee extension, with a 1 kg accuracy between testing sessions, was investigated by Ploutz-Snyder and Giamis[8]. The results showed that young women needed 2 to 5 sessions for accuracy to be achieved, which is less than for elderly women, who needed 7 to 10 sessions. However, the value for 1 kg was 0.7 to 1.3% of the measurement, which is perhaps too accurate. By comparing the values of the last two tests for each group, the test/re-test determination coefficient was of 0.94 (statistical test was not reported), with no significant differences between the values of these two tests.

Reporting a pilot-study, Hoeger *et al.*[13] presented reliability of the 1RM tests, and of the maximum number of repetitions at 40, 60 and 80% of 1RM, for seven different exercises, in a group of men and women (table 1). Correlation coefficients ranged between 0.79 and 0.98. The statistical analysis used is not clear (reported as "stability"), nor was the existence of test and re-test differences informed. Reliability of tests at 75% of 1RM performed with controlled speeds of 25 and $100^{o} \cdot s^{-1}$ (Pereira and Gomes, unpublished data) in a group of young adults resulted in low to moderate correlations (R = 0.41 a 0.71) for the squat (non-significant at $100^{o} \cdot s^{-1}$), and moderate to high correlations (R = 0.70 to 0.90) for the bench press (non-significant at $25^{o} \cdot s^{-1}$), with no differences between the tests.

Reliability of the 8-10RM test, with controlled speeds of 25 and $100^{o} \cdot s^{-1}$ for squat and bench press were also investigated by Pereira and Gomes (unpublished data). High correlation coefficients (R = 0.99 to 1.00) and small standard errors of measurements (< 3.6 kg or 3.5% for squat and < 1.6 kg or 2.8% for bench press) suggest high reliability of the test, in spite of statistically significant differences found between 8-10RM test and re-test for the squat at 25º·s-1.

The existence of few controlled studies on the reliability of muscular strength/endurance tests in isotonic equipment suggests this quality should be assessed before carrying out studies using such methods, in order to ensure quality of results for the exercises and the sample under investigation. When dealing with an elderly population[10], a period of adaptation to the test is recommended, and so is the carrying out of at least two tests, to use the results of the second one.

Thus, based on the need to reduce measurement error, as suggested by Hopkins[12], and in the few available studies, it is recommended that subjects take part in some adaptation sessions before the tests are carried out. Or, if possible, that at least two tests be conducted, and the results of the second be used, particularly if one wishes to quantify the effects of a specific training.

RELATIONSHIP BETWEEN MAXIMAL AND SUBMAXIMAL STRENGTH TESTS AND/OR ANTHROPOMETRIC VARIABLES

The concern with the risks of injuries from very high load tests and with economy of time lead to a number of studies attempting to establish a relationship between maximal and submaximal strength and/or maximal strength and anthropometric variables, in order to predict 1RM. The adjustment of training to the established purposes has also fostered the study of the relationship between 1RM and submaximal strength, so that the number of repetitions and/or the load set for training (submaximal) allow the development of the required qualities.

Submaximal tests found in the literature may be of a maximum number of repetitions with a load arbitrarily determined, or a percentage of body mass, or a percentage of 1RM, or a maximum load for a set number of repetitions.

TABLE 1
Results from studies on intra-tester reliability of strength and muscular endurance tests

Study	Sample	Test	Exercise	Correlation
Ploutz-Snyder and Giamis[8]	sedentary young (23 ± 4 yr; n = 7) and older F (66 ± 5 yr; n = 6)	1RM	knee extension	young: 2-5 sessions for difference < 1 kg old: 7-10 sessions for difference < 1 kg r^2 = 0.94 between the last two sessions
Pereira and Gomes (unpublished data)	M (n = 4) and F (n = 6)	1RM 8-10RM 25º·s-1 8-10RM 100º·s-1	squat and bench press	R = 0.986 (p < 0.001) and 0.999 (p < 0.001) R = 0.989 (p < 0.001) and 0.999 (p < 0.001) R = 0.990 (p < 0.001) and 0.997 (p < 0.001)
Pereira and Gomes (unpublished data)	M (n = 5) and F (n = 3)	1RM 75%1RM 25º·s-1 75%1RM 100º·s-1	squat and bench press	R = 0.991 (p < 0.001) and 0.997 (p < 0.001) R = 0.711 (p = 0.041) and 0.703 (p = 0.080) R = 0.410 (p = 0.292) and 0.896 (p = 0.002)
Rikli *et al.*[10]	older M (n = 42)	1RM	leg press, knee extension, bench press, seated row	R = 0.97 to 0.98*
Braith *et al.*[9]	M (n = 33) and F (n = 25) sedentary young adults	1RM	bilateral knee extension	pre-training (n = 58): r = 0.98 (p ≤ 0.05) post-training (n = 47): r = 0.99 (p ≤ 0.05)
Hoeger *et al.*[13]	M (n = 16) and F (n = 12)	1RM 40% 1RM 60% 1RM 80% 1RM	leg press, lat pulldown, bench press, knee extension, curl-ups, knee flexion, elbow flexion	M: R = 0.89 to 0.98* F: R = 0.79 to 0.98* M: R = 0.80 to 0.98* F: R = 0.80 to 0.96* M: R = 0.79 to 0.96* F: R = 0.80 to 0.95* M: R = 0.89 to 0.98* F: R = 0.80 to 0.95*

M – males; F – females; R – intraclass correlation coefficient; r – Pearson's correlation coefficient; * p value not reported.

1RM VS. FIXED LOAD

To estimate 1RM through a fixed load arbitrarily established would seem the easiest way to proceed. However, the estimate will be better or worse depending on how close this load is to the actual 1RM value (table 2). Thus, determining the most suitable load for the test will depend on the population under investigation.

Testing the maximum number of repetitions with a fixed load of 225 lb (102.1 kg) performed on the bench press in football players[14,15] resulted in a high correlation with the 1RM test (r = 0.96), with standard error of the estimate (SEE) of 4.9 and 6.4 kg, respectively. Prediction was better when the number of repetitions (7.2 ± 5.5 – from 6 to 21[14] and 10.6 ± 6.4 – from ~1 to 32[15]) was equal or less than 10. Prediction of 1RM from the maximum number of repetitions with 18.2 kg on the chest press for a group of women[16] resulted in a moderate multiple correlation coefficient (R) (R = 0.81 and SEE = 5.0 kg). It is likely that the high number of repetitions in this last study (44.1 ± 20.0 – from 8 to 105) hampered the quality of prediction.

1RM VS. % OF BODY MASS

Predicting 1RM from maximum repetition tests, with the load being a percentage of body mass, seems to generate equations with high correlations (R = 0.91 to 0.96) and SEE < 10 kg (table 3). However, it is hard to select the percentage to be used, as often this may represent a load higher than 1RM. For instance, in Kuramoto and Payne's[17] study, a load of 45% of body mass represented 73% of 1RM for a group of young women, 80% for a group of middle-age

TABLE 2
Results from studies on prediction of 1RM from the maximum number of repetitions with a fixed load

Study	Sample	Exercise	1RM (kg) (mean ± SD)	Repetitions (mean ± SD)	Load (kg)	Prediction
Cosgrove and Mayhew[16]	F (n = 51)	chest press	33.1 ± 8.4	44.1 ± 20.0	18.2	1RM(kg) = 18.1+0.34·reps R = 0.81 SEE = 5.0 kg
Chapman *et al.*[14]	M (n = 98)	bench press	121.3 ± 18.5	7.2 ± 5.5	102.1	r^2 = 0.92 SEE = 4.9 kg*
Mayhew *et al.*[15]	M (n = 114)	bench press	137.1 ± 20.7	10.6 ± 6.4	102.1	1RM(lb) = 226.7+7.1·reps r = 0.96 SEE = 14.1 lb (6.4 kg)

M – males; F – females; SD – standard deviation; R – multiple correlation coefficient; r – Pearson's correlation coefficient; SEE – standard error of the estimate; reps – number of repetitions; * equation to predict 1RM not reported.

TABLE 3
Results from studies on prediction of 1RM from the maximum number of repetitions with a load equivalent to a proportion of body mass

Study	Sample	Exercise	Load (%BM)	Prediction
Kuramoto and Payne[17]	young (20-30 years; n = 23), middle-age (40-50 years; n = 27) and elderly (60-70 years; n = 23) F adults untrained	lat pulldown	45	young and middle-age: 1RM(kg) = 3.41+(-0.2·age)+(1.06·load)+(0.58·reps) R = 0.95 SEE = 1.9 kg elderly: 1RM(kg) = -3.73+(0.92·load)+(0.79·reps) R = 0.91 SEE = 2.0 kg
Schell *et al.*[18]	M (n = 58) trained	bench press	100	1RM(lb) = 1.43·load+6.6·reps-99.4 R = 0.92 SEE = 21.9 lb (9.9 kg)
			110	1RM(lb) = 1.28·load+7.5·reps-74.1 R = 0.94 SEE = 19.7 lb (8.9 kg)
			120	1RM(lb) = 1.15·load+9.1·reps-47.2 R = 0.96 SEE = 16.3 lb (7.4 kg)

M – males; F – females; BM – body mass; R – multiple correlation coefficient; SEE – standard error of the estimate; reps – number of repetitions.

women, and from 75 to 115% for a group of elderly women, so that eight of these women were not able to perform any repetition. In the group of football players investigated by Schell *et al.*[18] the pre-established load was 120% of body mass, and six subjects were not able to perform a single repetition.

1RM VS. % OF 1RM

Training prescription is typically made using a pre-established number of repetitions. Studying the performance for different intensities (% of 1RM) may help understand the behavior of different muscle groups and different fitness levels, and thus determine the ideal number of repetitions according to individual goals. Table 4 presents studies that investigated some relationships with % of 1RM tests.

The maximum number of repetitions from tests of 40, 60, 70 and 80% of 1RM differed for the upper and lower-limb exercises[13,19-21], for both males and females, trained and untrained. Only McNanamee *et al.*[22] did not find differences in the number of repetitions at 85% of 1RM among upper- and lower-limb exercises; furthermore, correlations between maximum repetition tests and 1RM were not significant.

Results from investigations carried out in our lab[23] showed that the number of repetitions at 75% of 1RM, at the speeds of 25 and $100^{o}\cdot s^{-1}$, was also different between squat and bench press exercises, and between velocities for the same exercise. This seems to have been the first study to investigate relationships among tests that included control of movement velocity.

In a study done by Mayhew *et al.*[24] the number of repetitions performed in one minute, with loads ranging from 55 to 95% of 1RM, generated an exponential regression equation for predicting %1RM (table 4). The estimate of

TABLE 4
Results from studies on prediction of 1RM from the maximum number of repetitions, with a load equivalent to a percentage of 1RM

Study	Sample	Exercise	Load (%1RM)	Relationships
Kravitz *et al.*[21]	M (n = 18) adolescents, elite weightlifters	bench press	70	1RM(kg) = 90.66+0.085·reps·load-5.306·reps R^2 = 0.98 SEE = 2.69 kg
		squat	70	1RM(kg) = 159.9+0.103·reps·load-11.552·reps R^2 = 0.98 SEE = 5.06 kg
		dead lift	80	1RM(kg) = 156.08+0.098·reps·load-12.106·reps R^2 = 0.98 SEE = 4.97 kg
Pereira and Gomes[23]	M (n = 5) and F (n = 3)	squat and bench press $25^{o}\cdot s^{-1}$ and $100^{o}\cdot s^{-1}$	75	reps SIG different between exercises and velocities
Hoeger *et al.*[20]	M (n = 38) untrained	leg press, lat pulldown, bench press, knee extension, curl-ups, knee flexion, elbow flexion	40 60 80	reps SIG different
Hoeger *et al.*[13]	M (n = 63) and F (n = 66) trained and untrained	leg press, lat pulldown, bench press, knee extension, curl-ups, knee flexion, elbow flexion	40 60 80	reps SIG different trained SIG different from untrained
Mayhew *et al.*[24]	M (n = 184) and F (n = 251) trained	bench press	55-95	$\%1RM = 52.2+41.9e^{-0.055reps}$ r = 0.80 SEE = 6.4%
Mayhew *et al.*[25]	M (n = 70) and F (n = 51) pre- and post- training	bench press	55-95	reps pre NS different post r > 0.68 SEE < 7.8%
Clairborne and Donolli[19]	F (n = 20) untrained	leg press, elbow flexion, knee flexion, knee extension, lat pulldown	60 80	reps SIG different
McNanamee *et al.*[22]	F (n = 19)	shoulder press, bilateral knee extension	85	reps NS different

M – males; F – females; R – multiple correlation coefficient; r – simple correlation coefficient; reps – number of repetitions; SIG – significantly; NS – non significantly.

1RM from this value (%1RM) was well correlated (r = 0.98 and SEE = 4.8 kg) with the actual value. Another study by Mayhew *et al.*[25] used the same protocol to predict %1RM before and after training, and did not find significant differences between the predictive equations generated (pre- and post-training).

Kravitz *et al.*[21] found that maximum repetitions at 70% of 1RM were better predictors of 1RM for squat and bench press, than at 80% and 90% of 1RM. However, for the dead lift, 80% of 1RM was a better predictor (table 4).

Unpublished data from our lab showed that prediction of the load for 1RM from 75% of 1RM performed at 25 and $100^o \cdot s^{-1}$ for squat and bench press was not good, neither for linear nor for exponential regression ($r^2 < 0.44$ and 0.49, respectively), for both exercises. Furthermore, Pearson's correlation coefficients between 1RM and 75% of 1RM for these velocities were not statistically significant.

1RM VS. nRM

Training prescription is typically based in a predetermined number of repetitions, but the intensity (%1RM) that a number of repetitions represents for one exercise and/or muscle group may be different than that for another.

TABLE 5
Results from studies on prediction of 1RM from the nRM test

Study	Sample	Test	Exercise	Prediction
Pereira and e Gomes[27]	M (n = 11) and F (n = 13)	8-10RM $25^o \cdot s^{-1}$ and $100^o \cdot s^{-1}$	squat bench press	$25^o \cdot s^{-1}$: M: r = 0.83; F: r = 0.86 $100^o \cdot s^{-1}$: M: r = 0.94; F: r = 0.91 $25^o \cdot s^{-1}$: M: r = 0.92; F: r = 0.95 $100^o \cdot s^{-1}$: M: r = 0.94; F: r = 0.95
Pereira and Gomes (unpublished data)	M (n = 4) and F (n = 6)	8-10RM $25^o \cdot s^{-1}$ and $100^o \cdot s^{-1}$	squat bench press	$25^o \cdot s^{-1}$: ~75%1RM 1RM(kg) = 1.79·load-30.02 $100^o \cdot s^{-1}$: ~86%1RM 1RM(kg) = 1.01·load+15.27 $25^o \cdot s^{-1}$: ~70%1RM 1RM(kg) = 1.65·load-4.78 $100^o \cdot s^{-1}$: ~79%1RM 1RM(kg) = 1.30·load-1.70
Kraemer *et al.*[28]	M (n = 8) untrained w/ experience	10RM 15 reps·min^{-1}	bench press, lat pulldown, knee extension, knee flexion	~75%1RM
Braith *et al.*[9]	M (n = 33) and F (n = 25) sedentary	7-10RM pre- and post-training	bilateral knee extension	pre ~70%1RM 1RM(kg) = 1.554·load-5.181 r = 0.94 SEE = 9.3 kg post ~80%1RM 1RM(kg) = 1.172·load+7.704 r = 0.95 SEE = 9.9 kg
Cummings and Finn[30]	F (n = 57) untrained	4-8RM	bench press	1RM(kg) = 1.149·load+0.7119 R = 0.93 SEE = 1.92 kg 1RM(kg) = 1.175·load+0.839·reps-4.2978 R = 0.94 SEE = 1.73 kg
Hopkins *et al.*[26]	M (n = 3) and F (n = 16) untrained (3 w/ no adaptation)	7-10RM pre- and post-training	shoulder press knee extension	~85%1RM pre r = 0.98; post r = 0.99 ~80%1RM pre r = 0.96; post r = 0.98
Abadie and Wentworth[29]	F (n = 30) untrained	5-10RM	chest press shoulder press knee extension	1RM(lb) = 7.24+1.05·load r = 0.91 SEE = 2.5 kg 1RM(lb) = 1.43+1.20·load r = 0.92 SEE = 1.6 kg 1RM(lb) = 4.67+1.14·load r = 0.94 SEE = 2.3 kg

M – males; F – females; R – multiple correlation coefficient; r – Pearson's or simple correlation coefficient; SEE – standard error of the estimate; reps – number of repetitions.

The correlation between 1RM and 7-10RM tests seems to be high (r = 0.94 to 0.99), both before and after training[9,26] (table 5). Correlations between 1RM and 8-10RM tests, the latter performed at 25 and 100$^o \cdot s^{-1}$ [27], were also high (r = 0.83 to 0.95), for both squat and bench press exercises.

However, Braith *et al.*[9] found different equations for pre- and post-training relationships, contrary to Hopkins *et al.*[26], who found similar equations (similar intercept and gradient for pre and post). To Braith *et al.*[9] the load of 7-10RM was 70% of 1RM for bilateral knee extension pre-training, and 80% post-training, while for Hopkins *et al.*[26] the values were similar for both moments, 85 and 80% of 1RM for shoulder press and unilateral knee extension, respectively. Kraemer *et al.*[28] set movement cadence at 15 repetitions.min^{-1} and found a 75% correspondence between 1RM and 10RM load for the four tested exercises (bench press, lat pulldown, knee extension and flexion). A 8-10RM load performed at a speed of 25$^o \cdot s^{-1}$ corresponded to 75% of 1RM for squat, and 70% of 1RM for bench press (Pereira and Gomes, unpublished data). At 100$^o \cdot s^{-1}$ these loads corresponded to 86% for squat and 79% for bench press (figure 1). These relationships were the same before and after a 12-week training program, in both velocities.

According to Braith *et al.*[9], 1RM may be predicted by the 7-10RM test, with an accuracy of ± 10% both for stronger (1RM > 100 kg, r = 0.65 and SEE = 11.0 kg) and less strong subjects (1RM < 100 kg, r = 0.90 and SEE = 6.5 kg). Pereira and Gomes (unpublished data) also found good predictions for 1RM from 8-10RM tests at 25 and 100$^o \cdot s^{-1}$ ($r^2 > 0.94$ and SEE < 8.3% for squat and < 7.2% for bench press).

The 5-10RM tests and the 4-8RM tests also seem to be good predictors of 1RM in untrained women[29,30]. Abadie and Wentworth[29] found correlations of r = 0.91 to 0.94 (SEE = 1.6 to 2.5 kg) in the tested exercises, and Cummings and Finn[30] found R = 0.93 (SEE = 1.92 kg), when using only the load as a regression factor, and R = 0.94 (SEE = 1.73 kg), when load and number of repetitions were used in the equation (table 5).

1RM VS. ANTHROPOMETRIC VARIABLES

Correlations between 1RM and anthropometric variables, and the predictive power of 1RM from these variables are typically very low (table 6). Measurements of cross-sectional area and circumferences of the limb involved in the movement[30-34] and of body mass[30-33,35,36] seem to be the most important variables in relationships with measurements of strength. In a recent study with adolescent elite athletes[21], the variable years of training experience was better correlated to 1RM than any anthropometric variable. More than morphology, technique and experience are probably the best determinants of performance in maximum strength tests.

CROSS VALIDATION OF EQUATIONS TO PREDICT 1RM

Cross-validation studies were carried out to check model adequacy for other populations. Nine equations[9,15,24,37-42] were investigated in seven different studies[15,24,26,30,43-45] (table 7). From these, only two were validated, Mayhew's *et al.*[24] in two studies led by the same author[15,44], and Epley's[38] in Cummings and Finn's study[30].

In spite of the equations to predict 1RM from submaximal tests present quite high correlation values (generally > 0.90) and acceptable SEE (in most cases < 10%), cross validation generally results in over- or underestimated predictions. Likewise, all models to predict 1RM with anthropometric variables[34,46] either over- or underestimated it significantly[31,34] (table 8).

It is possible that specificity has a major influence in the 1RM relationships, being influenced by the sample, the exercise and type of performance.

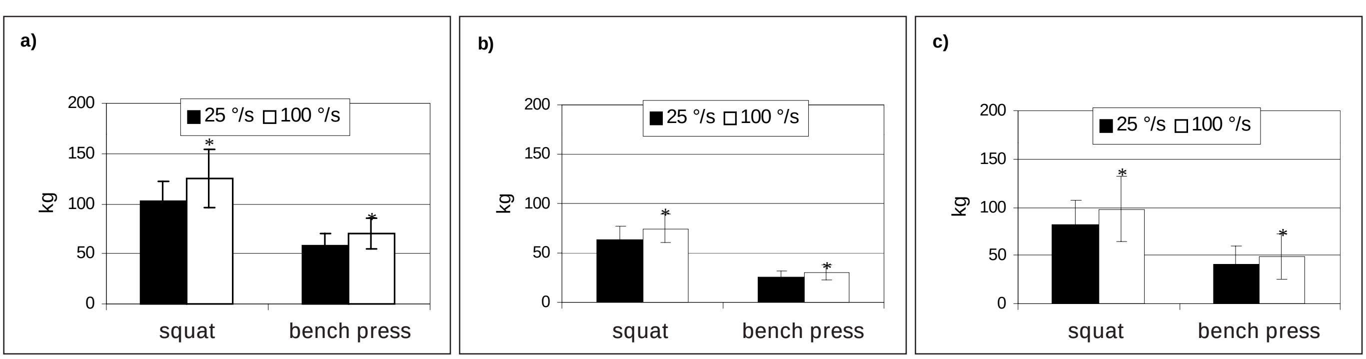

***Fig. 1** – Load for 8-10RM at 25 and 100$^o \cdot s^{-1}$ for squat and bench press exercises, for: **a)** males, n = 11; **b)** females, n = 13; and **c)** the whole group, n = 24*

* significantly different at 25$^o \cdot s^{-1}$ for $p < 0.05$

TABLE 6
Results from studies on prediction of 1RM from anthropometric variables

Study	Sample	Exercise	Variables/Correlation	Prediction
Kravitz *et al.*[21]	M (n = 18) adolescents, elite weightlifters	bench press squat dead lift	height, BM, chest circumference, arm circumference 0.02 to 0.58	not available
Mayhew *et al.*[32]	M (n = 58) trained	bench press squat dead lift	BM, LBM, arm CSA, arm circumference, thigh CSA, thigh circumference 0.50 to 0.79	R = 0.87 SEE = 12.1 kg R = 0.74 SEE = 23.9 kg R = 0.67 SEE = 23.1 kg
Mayhew *et al.*[33]	M (n = 72) trained	bench press squat dead lift	LBM, arm circumference 0.52 to 0.71	R = 0.83 SEE = 13.2 kg R = 0.74 SEE = 21.6 kg R = 0.67 SEE = 18.4 kg
Bale *et al.*[35]	M adults (n = 58) M adolescents (n = 85) trained	bench press dead lift	BM, LBM, ponderal index, endo, meso, ecto adults 0.33 to 0.61 adolescents 0.46 to 0.71	R = 0.52 to 0.80 SEE = 14.5 to 18.5 kg R = 0.43 to 0.65 SEE = 18.0 to 24.9 kg
Mayhew and Hafertepe[36]	F adolescents (n = 15) trained	leg press	BMI, full length of the leg 0.54 and –0.63	R = 0.67 SEE = 20.2 kg
Cummings and Finn[30]	F (n = 57) untrained	bench press	BM, arm CSA, arm circumference, biacromial diameter 0.27 to 0.51	predictor: arm circumference r = 0.47 SEE = 2.3 kg
Ballmann *et al.*[31]	F (n = 124) untrained	bench press	LBM, arm CSA, arm circumference, chest circumference, meso 0.38 to 0.41	R = 0.51 to 0.63 SEE = 5.2 to 5.7 kg
Scanlan *et al.*[34]	F (n = 113) untrained	bench press	arm CSA, arm circumference, forearm circumference, meso 0.42 to 0.45	R = 0.51 to 0.64 SEE = 5.4 to 6.0 kg

M – males; F – females; BM – body mass; LBM – lean body mass; BMI – body mass index; CSA – cross sectional area; endo – endomorphy; meso – mesomorphy; ecto – ectomorphy; R – multiple correlation coefficient; r – simple correlation coefficient; SEE – standard error of the estimate.

CONCLUSIONS

Strength tests are broadly used in research, but few controlled studies report intra-tester reliability. Results from these studies show good reliability of the 1RM and nRM tests, but the maximum number of repetitions at a specific percent of 1RM deserves further investigation. It is recommended that, in studies where accuracy is crucial, reliability of the tests should be checked prior to the beginning of the study. To the best of these authors' knowledge, studies that investigated inter-tester reliability have not been conducted to date.

The predictive power for 1RM from anthropometric variables is weak. Submaximal tests tend to offer better predictive potential, but most established equations do not have their validity proven.

One of the uses of submaximal tests is exercise prescription. However, when an appropriate load is prescribed for an established number of maximum repetitions, one may be prescribing different intensities for different muscle groups, as a same number of maximum repetitions may represent different 1RM percentages, depending on the movement, type of execution and equipment used.

TABLE 7
Results from cross validation studies to predict 1RM from submaximal tests

Study	Sample	Test	Exercise	Equations	Results
Mayhew *et al.*[24]	M (n = 225) and F (n = 101)	repetitions for 1 min w/ fixed load	bench press	Mayhew *et al.*[24]	NS differences
Mayhew *et al.*[44]	M (n = 220)	maximum repetitions w/ fixed load	bench press	Brzycki[37], Lander[39], Mayhew *et al.*[24], Epley[38], Lombardi[40], O'Conner *et al.*[41]	SIG differences ($p < 0.05$)
Ware *et al.*[45]	M athletes (n = 45)	maximum repetitions w/ fixed load	bench press squat	Brzycki[37], Epley[38], Lander[39], Mayhew *et al.*[24]	SIG correlations ($p < 0.01$) SIG differences ($p < 0.01$)
LeSuer *et al.*[43]	M (n = 40) and F (n = 27) untrained	maximum repetitions w/ fixed load	bench press squat dead lift	Brzycki[37], Epley[38], Lander[39], Lombardi[40], Mayhew *et al.*[24], O'Conner *et al.*[41], Wathan[42]	SIG* correlations bench press: SIG differences ($p < 0.01$)** squat: SIG differences ($p < 0.01$)*** dead lift: SIG differences ($p < 0.01$)
Cummings and Finn[30]	F (n = 57) untrained	4-8RM	bench press	Brzycki[37], Landers[39], Epley[38]	Epley: NS differences others: SIG differences ($p < 0.001$)
Hopkins *et al.*[26]	M (n = 3) and F (n = 16)	7-10RM	shoulder press knee extension	Braith *et al.*[9]	SIG* differences pre- and post-training
Mayhew *et al.*[15]	M (n = 28) trained	maximum repetitions w/ fixed load	bench press	Mayhew *et al.*[15]	NS differences

M – males; F – females; NS – non significant; SIG – significant.
* p value not reported; ** except Mayhew *et al.*[24] and Wathan[42]; *** except Wathan[42].

TABLE 8
Results from cross validation studies to predict bench press 1RM from anthropometric variables

Study	Sample	Equations	Results
Ballmann *et al.*[31]	F (n = 124) untrained	5 drawn from Mayhew *et al.*[46] and Scanlan *et al.*[34]	SIG* differences from 7.9 to 21.1%
Scanlan *et al.*[34]	F (n = 113) untrained	3 drawn from Mayhew *et al.*[46]	SIG* differences from 19.5 to 24.3%

F – female; SIG – significant; * p value not reported.

Only three of the reviewed studies[16,17,28] and Pereira and Gomes (unpublished data) used some type of control of movement velocity. This variable may also interfere in the relationships, as shown in the studies by LaChance and Hortobagyi[47], in which the number of repetitions for pull-ups and push-ups varied according to different cadences, and by Silva *et al.*[48], who found differences between free rhythm and paced speed for the number of repetitions for pull-ups. Preliminary results with squat and bench press exercises at speeds of 25 and 100$^{o}\cdot s^{-1}$ [27] indicate significant differences for the 8-10RM load between the two velocities, for both exercises (figure 1).

Prediction of 1RM from submaximal tests and anthropometric variables (circumferences, height, percent fat, somatotype, among others), or even exercise prescription should be carefully considered. The specificity of the sample (males vs. females, trained vs. untrained), of the exercise (upper limbs vs. lower limbs, multi-joint vs. single joint, big muscle groups vs. small muscle groups), of age (young vs. old), of the level of strength (very strong vs. less strong) are factors that may interfere in the relationships.

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