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Reliability of one-repetition maximum test in untrained young adult men and women

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Abstract.
BACKGROUND: The one repetition maximum (1RM) test is the most widely used method to analyze muscular strength. However, the 1RM reliability may be dependent on gender.
OBJECTIVE: The purpose of the study was to investigate the reliability of one-repetition maximum (1RM) test in untrained young adult men and women.
METHODS: Thirteen men and eleven women between 18–35 years were recruited. All subjects performed the 1RM tests in the bench press (BP), Smith machine squat (SQ), and arm curl (AC) in four sessions separated by 48 to 72 hours of recovery. At each measurement session, the subjects performed exercise-specific warm-ups and were given three attempts to reach a peak strength level for each exercise.
RESULTS: There was a significant session-by-time interaction ($P < 0.05$) in BP and SQ, while men reached a stabilized load between sessions 2–3, women stabilized their load between sessions 1–2. Significant increases ($P < 0.05$) in maximal strength occurred between session 1 and 4 in BP (men = + 10.5%, women = + 13.1%), SQ (men = +17.6%, women = +20.7%), and AC (men = +7.5%, women = +11.7%).
CONCLUSION: We conclude that the reliability of the 1RM tests in multiple-joint exercises may be gender dependent.

Keywords: Muscular strength, weight exercise, gender, familiarization, motor performance

1. Introduction

Muscular strength is an important component of physical fitness, either to perform daily activities or to improve performance in many sports. Maximal dynamic muscular strength is often assessed to evaluate readiness to participate in certain sports or occupations and/or as a gauge of improvement resulting from various forms of training. The one repetition maximum (1RM) test is the most widely used method to analyze changes in muscular strength derived from resistance training programs or as a method to assign loads for specific training objectives through exercise prescription. The 1RM test advantages include the possibility to assess the maximal strength of almost any muscle group, its ease of administration, the use of inexpensive

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non-laboratory equipment, and the safety of assessing of muscular strength in many populations [1–6].

Studies have shown that for adequate evaluation of maximal strength familiarization sessions for the 1RM test should be conducted until the stabilization of lifting load is achieved [1,3,7–10]. In addition, previous studies [1,3,7–10] have indicated that the number of familiarization sessions required for an accurate assessment of 1RM load may depend on subject characteristics, such as: age, body composition, characteristics of contraction, physical fitness, and gender.

Considering that men and women differ in some important variables that play a role in maximal strength such as: the level of strength and muscle mass, hormonal regulations, muscle architecture, recovery process, pattern of neural settings [10–18], that only a few studies have compared the familiarization in 1RM testing between untrained men and women and that these subjects are frequently recruited for studies to verify the impact of resistance training programs on muscular strength, examination of gender effect on the stability of maximal strength testing is pertinent. Therefore, the purpose of the present study was to analyze the reliability of 1RM test in untrained adult young men and women.

2. Methods

2.1. Subjects

Twenty-four subjects (13 males and 11 females, aged 18–35 years) were recruited from a university and local communities volunteered to participate in this study. All subjects completed a detailed health history questionnaire and were included in the study if they had no signs or symptoms of disease, were not using medications, and had no orthopedic injuries. In addition, they were nonathletic, inactive or moderately active individuals (physical activity less than twice a week) and had no experience in any resistance training program before the beginning of the study. Subjects provided an informed written consent form for participation in the investigation. This investigation was conducted according to the Declaration of Helsinki, and was approved by the local University Ethics Committee (Process 028/2012).

2.2. Procedures

Subjects were required to visit the laboratory on six occasions, at the same time of day: two orientation sessions and four testing sessions. The first visit consisted of preliminary screening (medical history and physical activity form), and anthropometric measurements. Body mass was measured to the nearest 0.1 kilogram using a calibrated electronic scale (Filizola, model ID 110, São Paulo, Brazil), with the subjects wearing light workout clothing and no shoes. Height was measured with a wooden stadiometer to the nearest 0.1 centimeter while the subjects were standing without shoes. The body mass index was calculated as the body mass divided by the square of the height.

In the second visit the subjects were familiarized with the testing equipment and the lifting techniques. This consisted of three sets of 10–15 repetitions, with light load on the specific exercises used in this study, with two-minute rest intervals between sets and exercises. In the subsequent four visits, subjects arrived at the laboratory two hours after having a light lunch without any alcohol-containing beverages and were instructed to avoid strenuous physical activity during the period of the research study. Maximal dynamic strength was evaluated using the 1RM test assessed on a free-weight bench press (BP), Smith machine squat (SQ), and arm curl (AC), performed exactly in that order. Between each session, 48–72 hours of recovery was given. Execution technique and form for each exercise were standardized and continuously monitored to guarantee consistency in maximum strength assessment in the testing sessions. Each exercise test was preceded by a warm-up set (6–10 repetitions), with approximately 50% of the estimated load to be used as the first attempt for each test. This warm-up was also used to familiarize the subjects with the testing equipment and the lifting techniques. The regular testing procedure was initiated two minutes after warm-up.

The initial load for the first attempt in each exercise was based on the OMNI perceived exertion scale for resistance exercise determining the difficult of performing the repetitions executed during the trials prior to the 1RM testing sessions [19]. The more difficult the perception of the repetitions, the lower the percentage of load added to the familiarization weight. The subjects were instructed to accomplish two repetitions with the imposed load in each of the three attempts for each exercise. If the subject was successful in the first attempt, weight was added (3–10% of the first attempt load), a 3–5 minutes 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 minutes rest. If the subject was not successful in the first or second

Table 1
General characteristics of the sample ($n = 24$)

	Men ($n = 13$)	Women ($n = 11$)	ES	P
Age (years)	22.0 ± 2.5	21.2 ± 1.9	0.36	0.440
Body mass (kg)	68.4 ± 11.4	54.6 ± 9.4	1.32	< 0.05
Height (cm)	177.2 ± 6.6	162.8 ± 5.5	2.37	< 0.001
BMI (kg/m^2)	21.7 ± 2.9	20.4 ± 2.6	0.47	0.311

Note: Values are expressed as mean $\pm$ standard deviation. ES = Effect Size.

Table 2
Percentage of subjects that reached the highest 1RM load among the 4 sessions in the bench press, squat, and arm curl ($n = 24$)

	Bench press		Squat		Arm curl	
	n	%	n	%	n	%
Men ($n = 13$)						
Session 1	7	53.8	1	7.7	9	69.2
Session 2	3	23.1	8	61.5	3	23.1
Session 3	3	23.1	1	7.7	1	7.7
Session 4	0	0.0	3	23.1	0	0.0
Women ($n = 11$)						
Session 1	3	27.3	2	18.2	5	45.5
Session 2	4	36.4	2	18.2	5	45.5
Session 3	3	27.3	2	18.2	1	9.1
Session 4	1	9.1	5	45.5	0	0.0

attempt, weight was removed (3–10% of the previous attempt load) and one other attempt was given. The 1RM was recorded as the last resistance lifted in which the subject was able to complete one single maximum execution [9].

The second 1RM session was performed after 48–72 hrs of recovery at the same time of the day. Following the warm-up, the second session was initiated with a load exceeding (3–10%) the highest load achieved on the previous session. The third and fourth sessions followed the same general procedures as the second session, with the subject's first attempt set at the highest load completed during the previous session. The highest load achieved among the sessions and the session in which the highest load was obtained was used for analysis [20]. All sessions were supervised by two experienced researchers for greater safety and integrity of the subject participation during the tests.

The 1RM BP was performed with free weights. The grip was such that the thumbs were at shoulder width when the bar was resting on the support props. Complete range of motion consisted of lowering the bar until it touched the chest, and pressing it upward until locking the elbows at the top of the press. The 1RM in the SQ was performed on a Smith machine with the bar placed at approximately the level of the upper trapezius muscle and rubber padding cushioning the region. The feet were parallel and placed shoulder width apart. The complete range of motion consisted of lowering the body, bending the knees to a 90° angle, then pressing upward until the knees were locked. The 1RM test in AC was performed with free weights. The subjects stood with their back against a wall to prevent any assistive motion, and the knees were positioned with a slight flexion. From a full arm-extended position, hands in supination with distance between a little more than shoulder width, the bar was curled using the anterior arm flexor muscles moved through approximately a 120-deg range of motion, or until the full flexion of the elbow. During all sessions, subjects were allowed to drink water whenever necessary and were encouraged to remain hydrated throughout testing.

2.3. Statistical analysis

The data are presented as mean and standard deviation. Data normality was confirmed by Shapiro-Wilk's test. The homogeneity of variances was verified using Levene's test. The sphericity was assessed by Mauchly's test. Baseline differences between genders were detected with an independent t-test. Two-way analysis of covariance (ANCOVA) for repeated measures with main effects for gender (men and women) and session (1–4) was used to compare changes in maximal strength during the sessions between groups, with baseline values used as the covariate. When F-ratio was significant, Bonferroni's *post hoc* test was applied to identify the differences. Intraclass correlation coefficients (ICC) and percent coefficient of variation (%CV) were used to analyze the reliability among all the sessions. The effect size (ES) was calculated to verify the magnitude of the differences. An ES of 0.20–0.49 was considered as small, 0.50–0.79 as moderated and $\geqslant 0.80$ as large [21]. Bland-Altman plotting was applied to determine the average difference (bias) and limits of agreement between 2 test sessions in men and women. The correlation between bias and mean of the load in the sessions in which the stabilization occurred was assessed by Pearson correlation coefficient. Statistical significance was set at $P < 0.05$. Statistical analyses were processed by STATISTICA software version 7.0. Statistical power exceeded 0.75 for all analyses.

Table 3
Maximal strength in the 4 sessions of 1RM test in the bench press, squat, and arm curl ($n = 24$)

	Men ($n = 13$)	Women ($n = 11$)	ANCOVA	F	P
Bench press (kg)					
Session 1	45.7 ± 9.5	25.1 ± 6.8	Session	6.75	< 0.001
Session 2	48.2 ± 8.6*	26.9 ± 6.5	Gender	4.57	< 0.05
Session 3	50.1 ± 8.9*	28.0 ± 6.3*	Interaction	3.09	< 0.05
Session 4	50.5 ± 9.0*§	28.4 ± 6.6*			
Δ%(S1–S4)	10.5	13.1			
Squat (kg)					
Session 1	89.4 ± 16.4	56.5 ± 9.5	Session	5.00	< 0.05
Session 2	99.4 ± 15.4*	61.1 ± 9.9	Gender	5.36	< 0.05
Session 3	102.6 ± 15.8*	66.0 ± 8.9*	Interaction	2.99	< 0.05
Session 4	105.1 ± 16.8*	68.2 ± 9.8*			
Δ%(S1–S4)	17.6	20.7			
Arm curl (kg)					
Session 1	32.0 ± 4.8	18.8 ± 5.1	Session	0.56	0.983
Session 2	32.7 ± 5.7	19.9 ± 4.8	Gender	0.96	0.338
Session 3	33.2 ± 6.0	20.6 ± 4.8*	Interaction	0.59	0.532
Session 4	34.4 ± 6.2*§	21.0 ± 5.1*			
Δ%(S1–S4)	7.5	11.7			

Note. Values are expressed as mean ± standard deviation. *$P < 0.05$ vs. Session 1; §$P < 0.05$ vs. Session 2.

3. Results

The characteristics of the sample are shown in Table 1. Men presented higher body mass and height scores compared to women ($P < 0.05$). Table 2 presents the percentage of subjects that reached the highest 1RM load during the four sessions in the BP, SQ and AC. Table 3 shows the results of the familiarization sessions for men and women. There was a significant interaction (gender x session) in BP and SQ, in which women stabilized the load between sessions 1–2, while men stabilized the load between sessions 2–3. However, there was no interaction (gender x session) in AC, where both genders stabilized the load between sessions 1–2. The statistical procedures for assessing performance reliability and the magnitude of the difference in the four sessions are presented in Table 4. High ICCs between all the sessions were observed (ICC > 0.77). The small CV for all the measures between the sessions demonstrated homogeneity of data (CV $< 13\%$).

The limits of agreement analysis between maximal strength in the session in which the stabilization of the load occurred are shown in Fig. 1. The bias in SQ and AC were lower for men (SQ $= -3.2$ kg, AC $= -0.8$ kg) than for women (SQ $= -4.5$ kg, AC $= -1.1$ kg), and similar between the gender for BP (-1.8 kg). The limits of agreement in all the three exercises were higher in men (BP $= \pm$ 9.3 kg, SQ $= \pm$ 20.9 kg, AC $= \pm$ 5.3 kg) than in women (BP $= \pm$ 2.7 kg, SQ $= \pm$ 8.7 kg, AC $= \pm$ 4.0 kg). Moreover, there was no significant correlation between the bias and the mean of the load in either of the genders in BP (men: $r = -0.116$, $P = 0.589$; women: $r = 0.183$, $P = 0.590$), SQ (men: $r = -0.075$, $P = 0.807$; women: $r = 0.106$, $P = 0.756$) and AC in women ($r = 0.390$, $P = 0.355$), however there was a significant result in AC for men ($r = -0.734$, $P < 0.05$).

Table 4
Difference in maximal strength in the 4 sessions of 1RM test for bench press, squat, and arm curl ($n = 24$)

	Men ($n = 13$)			Women ($n = 11$)		
	ICC	CV%	ES	ICC	CV%	ES
Bench press (kg)						
Session 1–2	0.956	6.5	0.26	0.971	5.6	0.26
Session 2–3	0.972	4.9	0.22	0.982	5.1	0.16
Session 3–4	0.997	1.8	0.04	0.996	2.9	0.06
Squat (kg)						
Session 1–2	0.770	12.1	0.60	0.892	8.0	0.48
Session 2–3	0.962	4.5	0.20	0.885	8.5	0.49
Session 3–4	0.979	8.6	0.15	0.973	3.5	0.24
Arm curl (kg)						
Session 1–2	0.981	4.1	0.14	0.978	5.3	0.21
Session 2–3	0.993	2.7	0.08	0.976	6.5	0.14
Session 3–4	0.983	3.0	0.20	0.993	3.9	0.08

4. Discussion

The main finding of the present study is that untrained men required more familiarization sessions to achieve their maximal strength level to reach a reliable, stable baseline in multiple-joint exercises compared to women. This illustrates the necessity of employing familiarization trials into initial testing routines and

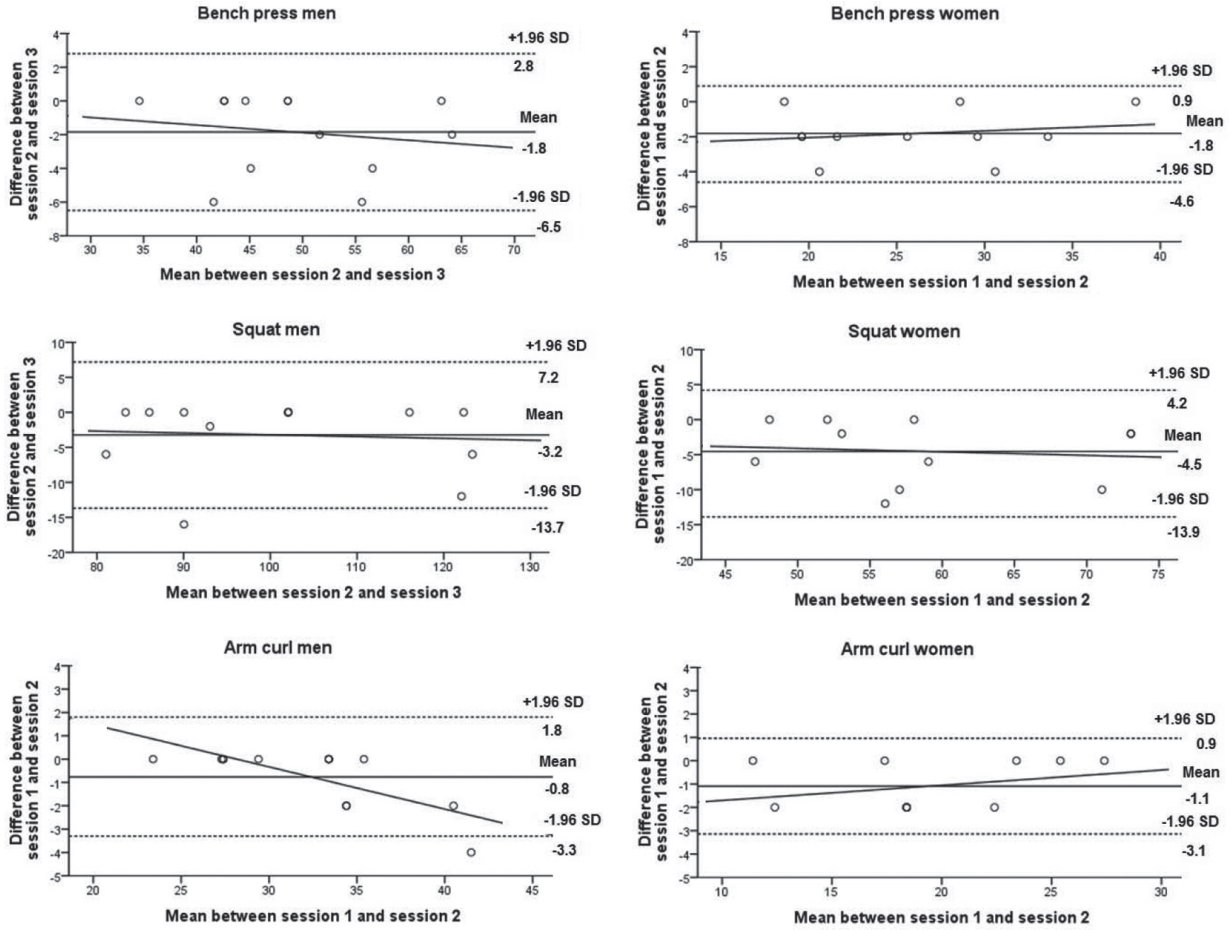

Fig. 1. Average difference and limits of agreement of the maximal strength between the sessions in which the load has stabilized (men = 13 and women = 11).

highlights potential differences in procedures for men and women. Although previous studies have analyzed the reliability of 1RM test in men and women, few have compared genders using the same methodological approach [10,22]. Our results are in agreement with Silva-Batista et al. [10] who investigated men and women without previous resistance training experience and also found differences between genders. However, they found it necessary to have more sessions to stabilize the 1RM load in SQ (4 and 3 sessions for men and women, respectively) than in the current study. However, they did not perform a consistent comparison between men and women and analyzed only one exercise. Furthermore, they opted to control the speed of movement during the SQ whereas our subjects were free to control their own movement speed. Although the standardization of the speed allows the control of exercises intensity, it does not always allow for strength maximization, which might have underestimated their results. Thus, the differences may not have been solely dependent on the subject's gender [23].

In contrast with the present results, Seo et al. [22] submitted 15 men and 15 women to two sessions of 1RM test in 12 exercises and did not find significant differences between genders for any of the exercises tested. The differences among studies may be related to the previous experience of the sample with resistance training exercises; Seo et al. [22] had participants who had at least 3 months of resistance training during the last 2 years before the study. In fact, a recent study showed that previous resistance training experience enhances the process of stabilization of the 1RM load [9]. Since the subjects included in our study had no previous experience with resistance training exercises, this possible confounding effect was attenuated.

Furthermore, another explanation for the controversy among studies may be related to the exercise order. For example, in the Seo et al. [22] study, BP and

SQ exercises were placed in the sixth position, so their performance could have been influenced by the execution of previous exercises such as triceps extension, shoulder press, leg extension, and leg press. Thus, the 1RM load in the BP and SQ could have been underestimated. In both the current results and the study of Seo et al. [22], there was no significant difference between genders and change in AC strength between the first and second. Seo et al. [22] placed AC in the first position, while it was in the third position in our study. A more detailed comparison with the literature is difficult due to the small number of studies that compared men versus women.

The fewer number of familiarization sessions to achieve stable 1RM scores in women compared to men might be related to differences between genders in muscle morphology [13,15] and neuromuscular control [23]. Lemmer et al. [24] reported that nine weeks of unilateral strength training in men and women induced an increase in the muscular strength of the contralateral limb only in women, indicating a possible differentiated neural response between the genders. However, Martin and Rattey [14] found that men had greater contralateral limb deficit in activation than women during a 100-s maximal voluntary contraction. Furthermore, gender differences in muscular strength [23] and muscle fiber characteristics [12,25] could contribute to the differences in load stabilization. These factors may contribute to the difference in familiarization trials between men and women, with a greater probability of establishing a stable load in women. In addition, the magnitude of load increase (1.0 kilogram on each side of the bar on BP and SQ and 0.5 kilogram on AC) between each attempt was relatively higher in women compared to men. Additionally, the aggressiveness and motivation necessary for a 1RM test may also explain these results since women may be less secure in exhibiting muscular strength performance [18].

The mechanisms underlying the increase in maximal strength between test sessions remain unknown and may be a result of many factors. However, improvements in neural adaptations (i.e., increases in motor-unit recruitment and rate coding of motor units, improved synergistic or fixator contribution, and reductions in the coactivation of antagonists muscles) might have promoted the increases in muscular strength between sessions [26].

In addition, we do not support the hypothesis that the increase in muscular strength between familiarization sessions is a result of the intervals used between assessments, which could favor a training effect between familiarization sessions. Cronin and Henderson [27] found a maximal strength increase after 1RM tests (6.8–15% in SQ and 10–13.6% in BP) using seven days interval between sessions, showing that other factors rather than the training effect might cause a muscular strength increase between familiarization sessions. Thus, the difference may be not attributed to the training effect.

The explanation for the difference between exercises that occurred in men can be attributed to a size of the musculature, number of joints involved or the complexity of the lifting technique. Since the BP and SQ are considerably more complex and involve substantially greater muscle mass to perform the lifting task, it is possible that the learning of this task took longer than the simpler exercise such as AC [28]. The greater complexity and heavier loads that were associated with the BP and SQ assessment could potentially result in greater number of sessions to stabilize the load.

Many studies have demonstrated the importance of familiarization sessions to accurately measure maximal strength in men [27,29] and women [3,20,30]. The pattern of familiarization noted in the current study supports previous investigations demonstrating similar familiarization sessions are required to stabilize the maximal strength load in men [31] 2004) and women [27,30,31]. Others studies have found the need for a greater number of sessions in both men [9,10,27, 29] and women [3,10,20,30] to stabilize the 1RM load. This controversy might be caused by the different exercises analyzed and by different methodological procedures among studies. These might include the evaluation protocol (rest interval and number of attempts), number of sessions, and the background of the subjects with resistance training exercises. The strength of the present investigation is that we have attempted to control the experience of the sample by using subjects with no previous exposure to resistance training.

Another important factor that contributes to differences between studies may be due the statistical procedures used in some of them. Over time, many researchers have used different statistical approaches to determine the reproducibility of the maximal strength tests, such as the Pearson correlation coefficient or ICC. Although these parameters are important to show the variability between sessions, they are not well suited to determine differences in means between sessions and to identify the stabilization point, nor do they provide intuitively useful information regarding the session-to-session variability. For example, if all sub-

jects exhibit similarly higher values in successive sessions, a very high correlation coefficient can be found, yet consistency of measurement is not obtained. Therefore, researches have been using the Bland-Altman plotting to compare the differences between the scores of two methods relative to the average of their means. This approach serves to indicate if the bias is low, the limits of agreement are reduced, and there is no significant trend evident between trials. In this study, the bias between the sessions in which the stabilization of the load occurred was higher in women than in men. This indicates that men obtain a higher systematic increase between sessions, whereas women have a more homogeneous response between sessions. Indeed, there was a trend in AC for men, showing that the level of muscular strength may influence the results, with stronger subjects showing a greater bias than the weaker ones.

Our results indicate that the gender of the subject should be taken into account when planning resistance training, since we demonstrated that a different number of familiarization sessions is required for accurate assessment of a baseline for maximal strength in men and women. This information would be helpful to strength and conditioning specialists to allow better determination of training workloads and more accurate assessment of changes resulting from training. Therefore, when applying an exercise training intervention, it is very important to apply the appropriate number of familiarization sessions in the attempt to avoid underestimation of initial muscular strength level, especially in men. Otherwise, there might be a strong possibility of overestimating strength gains achieved from a training program designed to augment muscular strength.

5. Conclusion

The findings confirm the relevance of familiarization sessions to the 1RM test. Our results suggest that at least three sessions for men and two sessions for women may be required for optimal determination of a baseline 1RM for major muscle group exercises in subjects with no experience in resistance training. Thus, part of the muscular strength increase that previously has been attributed to the training program may have resulted from lack of previous familiarization in the 1RM test. This may cause a false interpretation on the adaptations in muscular strength resulting from resistance training programs.

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