

Reliability and smallest worthwhile difference in 1RM tests according to previous resistance training experience in young women

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ABSTRACT: The objective of this study was to determine the familiarization and smallest worthwhile difference (SWD) of one-repetition maximum (1RM) tests in detrained women according to their previous resistance training experience. Three groups of women with varying amounts of previous resistance training experience were recruited: Novice ($n = 27$, 1 to 6 months), Intermediate ($n = 13$, from 7 to 12 months), and Advanced ($n = 20$, 13 to 24 months). All participants performed four 1RM test sessions in the bench press (BP), squat (SQ), and arm curl (AC). A significant ($p < 0.05$) (group vs. time) interaction was observed in SQ suggesting that more experienced participants needed fewer 1RM test sessions to reach a stable load compared to the less experienced groups. Strength changes ($p < 0.05$) observed in BP and AC occurred with no significant interaction for groups ($p > 0.05$), suggesting that experience had no impact on familiarization for these lifts. SWDs suggest that strength gains greater than 2-4% in these lifts would indicate a meaningful improvement in strength beyond random variation from trial to trial no matter the experience of the subject. Women with limited previous resistance training experience do not require more trials to reach load stabilization than those with more experience. Stability of 1RM loads for BP and AC may require only two sessions, while SQ may require at least three trials.

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INTRODUCTION

The one-repetition maximum (1RM) test is the premier method used to determine relative loads for prescribing resistance training (RT) program intensity and to assess changes in muscle strength during RT [1, 2]. Its popularity is related to factors such as the possibility of evaluating various muscle groups, ease of administration, low cost, and lack of need for sophisticated equipment. It is considered to be a safe and valid indicator for the estimation of muscle strength in different populations [3-11].

The most widely used exercises utilized for measuring strength are the bench press (BP) and squat (SQ) [12-15]. In addition, the arm curl (AC) is a common component of training programs [16, 17] and provides measurement of a smaller muscle group frequently utilized for upper-body manual tasks. Several studies have shown that to obtain stable 1RM measures in these exercises, previous familiarization sessions are needed [18-22]. Variables such as age [18, 19], gender [18, 20-23], and previous experience on

RT [18-22] can influence the process of obtaining a stable 1RM measurement. Among these factors, previous experience in RT can have a major impact on the process of load stabilization in the 1RM [18, 19]. Since several physiological adaptations are preserved after detraining periods [22], we cannot dispute the hypothesis that individuals who were exposed to longer practice with RT exercises may require fewer sessions to achieve stabilization of the 1RM load.

In many cases, participants who have previous RT experience may be interested in restarting a training program and thus may need to re-establish a baseline 1RM to aid in program determination [19]. However, information on the influence of previous RT experience for re-establishment of a stable 1RM appears to be lacking. Furthermore, there appear to be no studies in women that have suggested the amount of improvement in 1RM necessary to represent real gain in strength beyond random test-to-test variation. Determination of the smallest worthwhile difference (SWD) would provide a value by which

true improvement could be judged. Such information would aid strength and conditioning professional, rehabilitation clinicians, and researchers in determining how many familiarization sessions would be required to reach a stable baseline 1RM in various lifts and how much change would constitute real strength gain. Therefore, the aim of this study was to analyze the familiarization and SWD of 1RM testing in upper and lower body exercises in detrained young women according to their previous RT experience.

MATERIALS AND METHODS

Participants

Sixty detrained young women were recruited based on their previous RT experience. All participants 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, had no orthopedic injuries, were non-athlete, were inactive or moderately active less than twice a week, and had not performed RT for at least six months before the beginning of the study. Participants were divided into one of three groups according to their previous RT experience. Written informed consent was obtained from the participants after a detailed description of all procedures was provided. This investigation was conducted according to the Declaration of Helsinki and was approved by the local University Ethics Committee (Process 028/2012). The characteristics of the groups according to their previous experience on RT are shown in Table 1.

Anthropometric Measurements and Familiarization

Participants 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 kg using a calibrated

electronic scale (Filizola, model ID 110, São Paulo, Brazil), with the participants wearing light workout clothing and no shoes. Height was measured with a wooden stadiometer to the nearest 0.1 cm while the participants were standing without shoes. Body mass index (kg/m²) was calculated as the body mass divided by the square of the height.

In the second visit, the participants were familiarized with the testing equipment and lifting techniques, which consisted of performing three sets of 10-15 repetitions with light loads (subjectively selected by each participant) on the specific exercises used in this study. Two-minute rest intervals were given between sets and exercises. In the four subsequent visits, participants arrived at the laboratory two hours after having a light lunch without any caffeine and alcohol-containing beverages and having avoided strenuous physical activity throughout the period of the research study. One-repetition maximum (1RM) strength was evaluated with free-weight bench press (BP), squat on a Smith machine (SQ), and free-weight barbell arm curl (AC), performed in that order. Between each session, 48-72 hours of recovery were given [19].

Experimental Trials

Execution technique and form for each exercise were standardized and continuously monitored to guarantee consistency in maximum strength assessment during 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 participants with the testing equipment and lifting techniques. The regular testing procedure was initiated two minutes after warm-up.

BP grip placed the thumbs at shoulder width when the bar was resting on the support rack [14, 23]. 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 [13, 15].

TABLE 1. Physical and performance characteristics of participants based on previous experience with resistance training (n = 60).

	Novice ≤6 months n = 27	Intermediate 7-12 months n = 13	Advanced >12 months n = 20
Age (years)	20.1 ± 1.1	22.0 ± 2.3	23.0 ± 3.0
Height (cm)	164.1 ± 6.3	161.9 ± 4.2	163.7 ± 6.6
Body mass (kg)	61.0 ± 11.7	57.6 ± 8.9	62.0 ± 8.8
BMI (kg/m ²)	22.5 ± 3.2	22.0 ± 3.3	23.1 ± 2.9
Experience (months)	4.3 ± 1.4	10.9 ± 1.8*	34.5 ± 21.1**
Bench Press (kg)	26.0±4.8	28.8±7.8	30.3±5.1*
Squat (kg)	67.6±13.4	66.0±18.8	70.9±19.2
Arm Curl (kg)	19.4±4.0	20.7±5.2	20.5±4.1

Note: * = p < 0.001 vs. Novice, ** = p < 0.001 vs. Novice and Intermediate.

For the SQ, the bar of the Smith machine was placed at approximately the level of the upper trapezius muscle with a rubber pad cushioning the region [15]. The 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 then pressing forward and upward until the knees were locked [14, 15, 22]. For the AC, participants stood with their back against a wall to prevent any assistive motion, with the knees in a slightly flexed position [18, 19, 22]. From a full arm-extended position with hands in supination and the distance between them approximately 5 cm greater than shoulder width, the bar was curled using the anterior arm flexor muscles, moving through approximately a 120-deg range of motion or until full flexion of the elbow. During all sessions, participants were allowed to drink water whenever necessary and were encouraged to remain hydrated throughout testing.

The initial load for the first attempt in each exercise was based on the OMNI perceived exertion scale for resistance exercise for determining the difficulty of performing repetitions executed during the trials prior to the 1RM testing sessions [24]. The more difficult the perception of the repetitions, the lower the percentage of load added to the familiarization weight.

The participants were instructed to accomplish two repetitions with the imposed load in each of three attempts for each exercise. If the participant was successful in the first trial, weight was added (3-10% of the first attempted load), a 3-5 minute rest was given, and a second attempt was made [18, 19, 22]. If this attempt was successful, a third attempt was given following a 3-5 minutes rest, with an increased load (3-10% of the second attempt load). If the subject was not successful in the first or second attempt, weight was removed (3-10% of the previous attempt) and one other attempt was given. The 1RM was recorded as the last load lifted in which the subject was able to complete one single maximum execution [18].

The second 1RM session was performed after 48-72 hrs of recovery at the same time of the day [18, 19, 22]. Following the warm-up, the second session was begun at a load 3-10% greater than the load achieved in the previous session. The third and fourth sessions followed the same procedures as the second session. The highest load achieved among the sessions and the session in which the highest load was obtained were used for analysis [18]. All sessions were supervised by two experienced researchers for greater safety and integrity of the subject participation during the tests.

Statistical Analysis

Normality of the data was checked by Shapiro-Wilk's test, and data were presented as mean and standard deviation. The homogeneity of variances was verified using Levene's test. Sphericity was assessed by Mauchly's test. Baseline differences between groups were detected with a one-way analysis of variance (ANOVA). Two-way ANOVA for repeated measures with main effects for groups (Novice, Intermediate and Advanced) and sessions (1-4) was used to compare changes in maximal strength. When an F-ratio was significant, Bon-

ferroni's *post hoc* test was applied to identify the differences. Intraclass correlation coefficient (ICC) was used to evaluate the relative reliability of successive sessions [25]. Effect size (ES) was used to evaluate the practical significance of the change from one session to the next [26] and was evaluated by the criteria suggested by Hopkins [27]. Typical error of measurement was computed to estimate trial-to-trial variation using the formula: $TEM = SD_{diff} / \sqrt{2}$, where SD_{diff} was the standard deviation of the difference between successive trials [28]. Coefficient of variation (CV%) for each test was calculated from the ratio of the average of individual SD_{diff} for successive trials divided by the mean of successive trials [29]. The 95% Limits of Agreement (LoA) was estimated by the method suggested by Bland and Altman [30] to estimate the bias between trials. The correlation between bias and mean of the load in the sessions in which the stabilization occurred was assessed by Pearson correlation coefficient. SWD was calculated using a 95% confidence interval with the formula: $1.96 \times TE \times \sqrt{2}$ [28] in order to differentiate meaningful physiological change from trial-to-trial variation and learning effects. Intraclass correlation coefficient (ICC) was calculated according to the method detailed by Weir [20] to assess trial-to-trial reliability. Statistical significance was set at $p < 0.05$, and statistical analyses were processed by SPSS software (Version 24.0).

RESULTS

There was no significant difference ($p > 0.06$) among the three groups on any physical characteristic (Table 1). The advanced group had a significantly higher BP ($p < 0.01$) at Session 1 than the novice or intermediate groups (Table 1); however, there was no significant difference among the groups for initial SQ ($p = 0.81$) or AC ($p = 0.43$). The majority of each experience group had achieved a stable 1RM BP (>83.3%) and AC (>76.9%) by the second session (Table 2). Stabilization in SQ was not reached until the third session in each experience group (>76.9%). In both BP (83.3%) and SQ (75.0%), the advanced group had the lowest percent of participants who reached a stable 1RM by the second trial. In AC, it was the intermediate group that took the longest to reach stability, but it was achieved by the third session (76.9%).

No significant difference was noted for change scores between successive trials on BP ($p = 0.08$) or AC ($p = 0.19$) and no significant interactive effect occurred due to previous RT experience (Table 2). For SQ, change scores were significantly different between sessions 1 and 2 but not between sessions 2 and 3 or 3 and 4. The intermediate group made a significantly greater change between sessions 1 and 2 than did the novice and advanced groups; thereafter the changes were not significantly different among the experience groups. There were no significant changes between successive sessions (Table 2).

The effect sizes between successive sessions for each group were small, indicating the changes between sessions were of no practical significance (Table 3). ES for SQ were slightly larger than for BP and AC for each group but not large enough to indicate a substantial

TABLE 2. 1RM performances and percentage of subjects that reached the highest 1RM scores among the four 1RM test sessions on bench press, squat, and arm curl (n = 60).

	Novice (n = 27)			Intermediate (n = 13)			Advanced (n = 20)		
	Mean ± SD	n	%	Mean ± SD	n	%	Mean ± SD	n	%
Bench Press (kg)									
Session 1	26.0±4.8	18	66.7	28.8±7.8	7	53.8	30.3±5.1	7	58.3
Session 2	27.0±4.3	7	25.9	30.3±6.6	4	30.8	31.5±5.7	3	25.0
Session 3	27.4±4.4 ^a	2	7.4	31.4±4.4 ^a	2	15.4	32.6±5.6 ^a	2	16.7
Session 4	28.2±4.2 ^{ab}	0	0.0	31.9±6.9 ^{ab}	0	0.0	32.9±5.5 ^a	0	0.0
Squat (kg)									
Session 1	67.6±13.4	10	37.0	66.0±18.8	1	7.7	70.9±19.2	4	33.3
Session 2	70.5±13.2 ^a	6	22.2	74.0±19.7 ^a	7	53.8	73.8±18.3	3	25.0
Session 3	73.3±13.7 ^{ab}	5	18.5	75.1±19.9 ^a	2	15.4	76.3±18.5 ^a	2	16.7
Session 4	75.9±14.2 ^{abc}	6	22.2	76.3±19.5 ^a	3	23.1	78.8±19.0 ^{ab}	3	25.0
Arm Curl (kg)									
Session 1	19.4±4.0	14	51.9	20.7±5.2	8	61.5	20.5±4.1	5	41.7
Session 2	20.4±3.9	10	37.0	21.6±4.7	2	15.4	21.7±4.0	6	50.0
Session 3	20.9±4.0 ^a	1	3.7	22.2±4.8 ^a	2	15.4	22.0±4.0 ^a	1	8.3
Session 4	21.6±4. ^{ab}	2	7.4	22.7±5.4 ^a	1	7.7	22.5±4.0 ^a	0	0.0

Note: ^a = P < 0.05 vs. Session 1, ^b = P < 0.05 vs. Session 2, ^c = P < 0.05 vs. Session 3. S1 = Session 1 of 1RM test, S4 = Session 4 of 1RM test.

TABLE 3. Intraclass correlation coefficients (ICC), coefficients of variation (CV), effect size (ES) and typical error of measurement (TEM) between 1RM test sessions on bench press, squat, and arm curl (n = 60).

	Bench press				Squat				Arm curl			
	ICC	CV	ES	TEM	ICC	CV	ES	TEM	ICC	CV	ES	TEM
Novice (n = 27)												
Sessions 1-2	0.949	0.030	0.21	1.3	0.972	0.031	0.22	2.4	0.962	0.039	0.25	0.8
Sessions 2-3	0.990	0.009	0.09	0.6	0.976	0.028	0.21	2.2	0.983	0.017	0.13	0.6
Sessions 3-4	0.978	0.022	0.18	0.7	0.983	0.024	0.19	1.8	0.979	0.023	0.18	1.3
Intermediate (n = 13)												
Sessions 1-2	0.973	0.046	0.19	1.3	0.941	0.082	0.43	3.5	0.975	0.037	0.17	0.9
Sessions 2-3	0.976	0.025	0.17	1.2	0.997	0.013	0.06	1.5	0.986	0.020	0.13	0.7
Sessions 3-4	0.991	0.008	0.11	0.8	0.997	0.013	0.06	1.2	0.991	0.011	0.10	1.4
Advanced (n = 20)												
Sessions 1-2	0.968	0.026	0.24	1.0	0.987	0.030	0.15	3.3	0.965	0.040	0.29	0.8
Sessions 2-3	0.979	0.025	0.19	0.8	0.992	0.024	0.14	1.6	0.990	0.011	0.08	0.5
Sessions 3-4	0.995	0.007	0.05	0.8	0.985	0.023	0.14	1.5	0.985	0.015	0.13	1.1

Note. ICC = Intraclass correlation coefficient, CV = coefficient of variation, ES = effect size.

change between successive sessions. ES was also slightly larger between sessions 1 and 2 for the Intermediate group than for the Novice and Advanced groups (Table 3). A major portion of each experience group reached acceptable 1RM scores between sessions 1 and 2 for BP and AC exercises. An equivalent percent of participants did not reach stability in SQ until the third trial (Table 2).

The statistical procedures employed to analyze relative reliability produced high intraclass correlation coefficients (ICC), small TEM,, low CV%, and small limits of agreement for each lift (Table 3). Furthermore, absolute reliabilities for all experience groups were high for BP (rho>0.94), SQ (rho>0.97) and AC (rho>0.95), indicating participants maintained the same group ranking with successive

trials of each lift. The changes noted between successive trials produced a slightly larger SWDs for SQ (4.5 kg) than for BP (2.7 kg) and AC (2.0 kg). The CV% for each exercise indicated that increases greater than 3% for BP, 2% for SQ, and 4% for AC would suggest a meaningful gain in strength above the random variations noted between trials. These values were not significantly different for each lift for each experience group.

DISCUSSION

This study sought to determine the ability of detrained individuals with differing levels of experience to produce stable 1RM performances in three common exercises. The main finding indicated that the degree of previous RT experience may have little effect on load stabilization in young women for simple movements such as BP and AC, allowing an acceptable baseline to be reached by the second test session. The small difference between session 1 and 2 for both lifts in each experience group in the current study (1.0 to 1.5 kg) was similar to those noted in previous studies [7, 8, 18, 19, 31]. Because previous RT experience may play more of a role in 1RM SQ load stabilization, the greater complexity of the movement suggests that at least three sessions may be necessary for the majority of individuals to reach a stable baseline regardless of experience [18, 19, 30, 31].

The exact mechanisms underlying the slight increase in maximal strength between early test sessions remain unknown and are most likely to be multifactorial. One possibility might involve the nervous system where adaptations can occur quickly. Increases in motor-unit recruitment, rate coding of motor units, improved synergistic muscle contribution, and reductions in the coactivation of antagonists muscles might promote increases in muscular strength between sessions [32-34]. Moritoni and deVries [35] were among the first to indicate that neurological factors might play a significant role in the early increases in strength performance. This phenomenon has been termed neural disinhibition [35, 36] or autogenic inhibition [37] and is theorized to reduce the inhibitory function of Golgi tendon organs (GTO) to allow greater force output from muscle. Thus, the restrictive function of GTO on muscle contraction may be reduced when participants are subjected to repeated episodes of maximal muscular contraction [33-37]. In their review, Gabriel, Kamen, and Frost [33] discussed the possibility of an increased rate of motor unit activation early in RT which could account for enhanced muscular force and the slight increase in 1RM performance with successive trials. Such a possibility must be considered as a confounding factor in establishing a true baseline for strength. While previous work has shown an inability of some individuals to initially produce complete voluntary activation of muscle [37], a later study noted that an external stimulation could produce 2-5% additional muscle force [38], which is similar to the increases noted between sessions in the current study for each exercise. Although most of the research relating muscle activation to strength gains has been long-term [38-41], Friedelbold, Nussgen, and Stoby [42] were able to show an increase in EMG

activity during the early stages of RT. Additional studies on the short-term change in neural activation may help clarify the mechanism producing the slight gains noted with repeated sessions of 1RM testing.

A second potential contributing factor for the small increases in muscle strength during repeated 1RM sessions is the possibility of enhanced muscle protein synthesis that leads to muscle hypertrophy sooner than previous thought [43, 44]. Although previous studies have suggested that measureable increases in muscle fiber area may require several weeks [45-47], recent investigation using computerized tomography has shown that two RT sessions can result in a 3.5% increase in muscle cross-sectional area [48]. Thus, we cannot discount the possibility that certain individuals may microscopically increase muscle size enough to work in conjunction with increased neural drive to produce slight gains in the early sessions of 1RM testing.

Another issue which has not been widely explored concerning the slight increases with subsequent 1RM trials is the possibility of rapid acquisition of the mechanics of a lift which could result in slight improvements in performance. An early study showed that three sessions of BP practice using a wooden bar produced a 6.3% gain in 1RM, which was comparable to the gain noted for a group training at 70% of 1RM (9.8%) [49]. It is possible that warm-up repetitions in the current and previous studies [18-22] might have been sufficient to activate neural patterns and motor unit firing that produce movement pattern improvements resulting in slight increases in 1RM performance. The fact that more sessions were required to reach stability in the SQ could reinforce the idea that the complexity of a lift might be a factor explaining the need for additional sessions to allow motor patterns to reach a stable baseline. Interestingly, it was the Intermediate group that made the greatest improvement between the first and second session amounting to a 12% increase, while the Novice and Advanced groups made smaller 4% gains. However, by the third session, 75-78% of all groups had reached a stable, non-significantly different baseline.

In AC, 1RM values increased slightly across all four sessions, although 77-92% of all groups had achieved their maximum values within the first two sessions. The trivial ES between sessions 1 and 2 suggests there was no practical difference between these sessions and that one or two trials might suffice for this exercise in young women regardless of previous experience [18, 19, 22].

Relative to the trial-to-trial variation noted here, a second major finding of the current study was the identification of the SWD in each of the three lifts that would provide criteria for assessing how much of a training program was due to actual strength increase. Several previous studies have noted acceptable reliability for BP [7,11,14,34-37], although less reliability information is available for SQ [7,11,13,36,37] and AC [36,37]. These are major lifts utilized for evaluating specific muscle groups and widely used in research and training. The information in this study is one of the first to provide a guide as to the amount and relative degree of improvement neces-

sary to indicate a meaningful increase in muscle strength for BP, SQ, and AC resulting from RT. Thus, it appears that increases greater than 2-4% in these lifts would denote actual improvements in strength in young women beyond what would be expected from random trial-to-trial variation.

The present study is not without some limitations. The participants reported their previous RT experience by questionnaire, thus limiting quantifying important variables related to RT such as volume and intensity. Additionally, the study did not identify which exercises the participants performed in the past. On the other hand, our investigation is among the first to investigate the influence that different levels of previous RT experience can exert on assessing the maximal strength in detrained women. However, these findings are limited to young women and should not be extrapolated to older women or young and old men. Further research is necessary to establish the number of familiarization sessions and the size of the SWD in other groups.

CONCLUSIONS

In conclusion, it appears that young women can attain a stable baseline in these three lifts with one familiarization session for BP and AC and two sessions for SQ. Our findings confirm the relevancy of at least one familiarization session even in individuals who were exposed previously to a RT program. In addition, we would suggest a gain greater than 2-4% is required to indicate a statistically meaningful strength improvement in young women in most lifts. Such information may be useful to researchers, strength coaches, and exercise professionals enabling them to better determine the relative training load as well as more precisely assess the alterations resulting from RT programs.

Conflict of interest declaration:

The authors declare no conflict of interest.

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