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Relationship Between the Number of Repetitions and Selected Percentages of One Repetition Maximum in Free Weight Exercises in Trained and Untrained Men

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[1]Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut 06269; [2]Department of Sport Sciences, Colorado College, Colorado Springs, Colorado 80903; [3]School of Biomedical and Sports Science, Edith Cowan University, Joondalup, Western Australia, Australia; [4]Department of Movement Sciences, University of Maastricht, Maastricht, Netherlands. [5]Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland.

Abstract. Shimano, T., W.J. Kraemer, B.A. Spiering, J.S. Volek, D.L. Hatfield, R. Silvestre, J.L. Vingren, M.S. Fragala, C.M. Maresh, S.J. Fleck, R.U. Newton, L.P.B. Spreuwenberg, and K. Häkkinen. Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. *J. Strength Cond. Res. 20(4):819–823. 2006.*—Resistance exercise intensity is commonly prescribed as a percent of 1 repetition maximum (1RM). However, the relationship between percent 1RM and the number of repetitions allowed remains poorly studied, especially using free weight exercises. The purpose of this study was to determine the maximal number of repetitions that trained (T) and untrained (UT) men can perform during free weight exercises at various percentages of 1RM. Eight T and 8 UT men were tested for 1RM strength. Then, subjects performed 1 set to failure at 60, 80, and 90% of 1RM in the back squat, bench press, and arm curl in a randomized, balanced design. There was a significant ($p < 0.05$) intensity × exercise interaction. More repetitions were performed during the back squat than the bench press or arm curl at 60% 1RM for T and UT. At 80 and 90% 1RM, there were significant differences between the back squat and other exercises; however, differences were much less pronounced. No differences in number of repetitions performed at a given exercise intensity were noted between T and UT (except during bench press at 90% 1RM). In conclusion, the number of repetitions performed at a given percent of 1RM is influenced by the amount of muscle mass used during the exercise, as more repetitions can be performed during the back squat than either the bench press or arm curl. Training status of the individual has a minimal impact on the number of repetitions performed at relative exercise intensity.

Key Words. weight training, percentage loading, intensity, exercise prescription

Introduction

It is generally accepted that resistance training program periodization focuses on manipulation of the five acute program variables: choice of exercise, order of exercise, number of sets, rest periods, and load (5, 10, 11). Of these variables, exercise load (i.e., intensity) has been the most frequently studied (14). The prescription of resistance exercise intensity is usually based on repetition maximum (RM) or on a percent of 1RM. If an RM-based exercise prescription is used (e.g., 6RM), then the training adaptations are relatively predictable (5). Unfortunately, however, few studies have evaluated the utility of using a percentage of 1RM as a basis for resistance exercise prescription.

Previous studies investigating the relationship between the percent of 1RM and the number of repetitions performed have shown that: (a) as the percent of 1RM increases, the number of repetitions decreases (7, 8); (b) large muscle group exercises (e.g., leg press) allow the completion of more repetitions than small muscle group exercises (e.g., arm curl) at the same relative intensity (7, 8); and (c) the influence of training status is unclear, as trained subjects have been shown to perform the same (12) or greater (3, 8, 16) number of repetitions at a given exercise intensity than untrained subjects, and that this relationship is likely affected by the habitual training habits of subjects (8). It is important to note, however, that a majority of these studies (3, 7, 8, 12) used resistance training machines, as opposed to free weights. This factor is significant since free weight resistance exercises are commonly used in competitive and recreational resistance training programs. Furthermore, free weight exercises require greater motor coordination and balance than exercises using machines (11). Moreover, no study has examined multiple relationships (e.g., percent of 1RM, multiple exercises, training status) using free weight exercise.

The purpose of this investigation was to determine the number of repetitions that trained and untrained men could perform at 60, 80, and 90% of 1RM in 3 different exercises: back squat, bench press, and arm curl. This approach was used to demonstrate, using free weight exercises: (a) the relationship between exercise intensity and the number of repetitions allowed; (b) the relationship between the amount of muscle mass used and the number of repetitions allowed; and (c) any mitigating influence of training status on the number of repetitions allowed.

TABLE 1. Subject characteristics. Values are mean ± *SD*.*

	Trained (n = 8)	Untrained (n = 8)
Age (y)	25.3 ± 3.7	25.8 ± 4.3
Height (cm)	178.9 ± 8.6	173.5 ± 5.7
Weight (kg)	86.4 ± 14.3	73.1 ± 8.0†
Body fat (%)	12.4 ± 4.5	13.5 ± 6.7
1RM back squat (kg)	140.1 ± 25.2	93.9 ± 17.3†
1RM bench press (kg)	115.4 ± 23.2	62.8 ± 11.5†
1RM arm curl (kg)	52.9 ± 7.6	36.0 ± 4.6†

* 1RM = 1 repetition maximum.
† $p < 0.05$ vs. corresponding trained group

METHODS

Experimental Approach to the Problem

The maximal number of repetitions allowed using different percentages of 1RM (60, 80, and 90%) was determined for 3 different exercises that required different amounts of muscle mass (back squat, bench press, and arm curl). Selected percentages (60, 80, and 90%) of 1RM were chosen to span training loads typically used in resistance training programs. Initial 1RM testing was conducted in trained men (i.e., at least 6 months of consistent resistance training experience) and untrained men (i.e., no resistance training during the previous year). Each subject had 3 testing sessions; each session consisted of 3 different exercises at 3 different percentages, in a matched, balanced, and randomized order. This design allowed for the determination of (a) differences in the number of repetitions performed at each percent of 1RM load, (b) differences in the number of repetitions performed in each of the 3 lifts, and (c) differences between trained and untrained subjects.

Subjects

Subjects for this study were 8 trained men (T) and 8 untrained men (UT). T had been undertaking a continual, heavy (i.e., intensity <6RM) resistance weight-training program at least twice a week for more than 6 months using free weight back squat, bench press, and arm curl exercises. UT previously had not been involved in a formal resistance weight-training program during the last year. After explanation of the demands and risks associated with the study, each subject signed a written informed consent that was approved by the Institutional Review Board for Use of Human Subjects at the University of Connecticut.

Subject characteristics are reported in Table 1. Body mass and 1RM strength on all exercises in the T group were significantly ($p < 0.05$) greater than those in the UT group. In 1RM strength, there were significant differences ($p < 0.05$) among back squat, bench press, and arm curl (squat > bench press > arm curl) in both the UT and T groups.

Experimental Design and Procedures

All subjects were familiarized with testing procedures and proper exercise techniques for the 3 exercises before 1RM testing, and proper technique was verified prior to the start of testing by a certified strength and conditioning specialist. During familiarization, subject characteristics (height, weight, and age) were obtained. In addition, body composition (i.e., percent body fat) was determined by skin fold measurements taken at the thigh, abdomen, and midaxillary using the method of Jackson and Pollock (9).

One Repetition Maximum Testing

One RM testing was performed using procedures previously described in detail (13). Briefly, subjects performed a warm-up consisting of 8–10 repetitions using a light weight, 3–5 repetitions using a moderate weight, and 1–3 repetitions using a heavy weight. After the warm-up sets, subjects were tested for 1RM strength by increasing the resistance on subsequent attempts until the subject was unable to complete an attempt using proper technique through a full range of motion. Each attempt was separated by 3–5 minutes of rest. T performed the 1RM protocol once; however, UT performed the 1RM protocol twice to ensure stable baseline measurements.

Experimental Percentages to be Tested

Each subject performed 3 testing sessions. Each session consisted of 1 set to failure for each of the 3 exercises (back squat, bench press, and arm curl) performed at a volitional lifting velocity. The percent of 1RM for each exercise during a given day was different, and the order of the selected percentages was matched, balanced, and randomized. For example, 3 testing sessions may include day 1: 60% of 1RM for back squat, 80% of 1RM for bench press, and 90% of 1RM for arm curl; day 2: 90% of 1RM for back squat, 60% of 1RM for bench press, and 80% of 1RM for arm curl; and day 3: 80% of 1RM for back squat, 90% of 1RM for bench press, and 60% of 1RM for arm curl.

Prior to each session, subjects performed a warm-up for 5 minutes on a cycle ergometer. Also, a warm-up set at 50–60% of 1RM for 5 repetitions was conducted before the subjects performed an exercise at 80 or 90% of 1RM. During an individual session, subjects could rest for 20–30 minutes between exercises; at least 48 hours of rest separated each testing session.

Each exercise was done with proper form as monitored by the investigator. Repetitions performed using poor technique were not counted. A repetition performed for more than a half of the range of motion (but not the entire range of motion) was counted as a half repetition (0.5). The maximum pause allowed between each repetition was 3 seconds, although subjects were encouraged to perform each repetition immediately after the preceding repetition.

Power output for each repetition was measured by a FitroDyne Sports Powerlizer (Tendo sport machines, Trencin, Slovak Republic) and was interfaced by a computer that calculated average power of each exercise percentage; distance and time were measured using a linear transducer and an internal timing mechanism, respectively; the mass of the load was entered into the computer to allow power calculation. Average power output for each set was determined using the average power for each repetition in that particular set. After each exercise, subjects provided a rating of perceived exertion (RPE) using the Borg CR10 scale (2). Verbal encouragement was provided during all testing sessions to ensure adequate motivation and effort (15, 18).

Allometric Scaling

The following allometric scaling equation was used to correct for body mass to determine relationships between

TABLE 2. Number of repetitions at 60, 80, and 90% of 1 repetition maximum (1RM) for back squat, bench press, and arm curl in untrained and trained groups. Values are mean ± *SD*.

	60% 1RM	80% 1 RM	90% 1RM
Untrained			
Back squat	35.9 ± 13.4†‡§‖	11.8 ± 1.8†‖	6.5 ± 1.8‡
Bench press	21.6 ± 4.2‡‖§	9.1 ± 2.7‖	6.0 ± 1.5*
Arm curl	17.2 ± 3.7‖§	8.9 ± 3.9‖	3.9 ± 2.1
Trained			
Back squat	29.9 ± 7.4†‡§‖	12.3 ± 2.5†‖	5.8 ± 2.3†
Bench press	21.7 ± 3.8‖§	9.2 ± 1.6‖	4.0 ± 1.3
Arm curl	19.0 ± 2.9‖§	9.1 ± 2.8‖	4.4 ± 1.9

* $p < 0.05$ vs. corresponding trained group.
† $p < 0.05$ vs. corresponding bench press value.
‡ $p < 0.05$ vs. corresponding arm curl value.
§ $p < 0.05$ vs. corresponding 80% value.
‖ $p < 0.05$ vs. corresponding 90% value.

TABLE 3. Mean power output in watts (W) at 60, 80, and 90% of one repetition maximum (1RM) for back squat, bench press, and arm curl in untrained and trained groups. Values are mean ± *SD*.

	60% 1RM	80% 1RM	90% 1RM
Untrained			
Back squat	269.5 ± 90.7*†‡	280.7 ± 75.5*†‡	265.8 ± 88.9*†
Bench press	162.8 ± 43.8*	155.4 ± 46.7*	132.7 ± 35.4*§
Arm curl	112.6 ± 35.8*	116.6 ± 20.4*	120.4 ± 29.3*
Trained			
Back squat	474.2 ± 98.0†‡	501.0 ± 101.7†‡	476.8 ± 114.6†‡
Bench press	346.4 ± 78.7	285.9 ± 45.0	249.3 ± 70.8†
Arm curl	193.1 ± 40.1	198.4 ± 43.7	199.7 ± 56.5

* $p < 0.05$ vs. corresponding trained group.
† $p < 0.05$ vs. corresponding bench press value.
‡ $p < 0.05$ vs. corresponding arm curl value.
§ $p < 0.05$ vs. corresponding 80% value.

strength and the number of repetitions performed at each of the percentages for each exercise:

$$Y = a \cdot X^b$$

where Y is the 1RM strength, a is the scaling coefficient, X is the body mass, and b is the scaling exponent, which was 0.67 (1). Thus, corrected strength values were determined by an absolute strength (1RM) divided by 0.67 power of body mass.

Statistical Analyses

Data are presented as mean ± *SD*. A two-way analysis of variance (e.g., [2 × 3 × 3] or [training status × exercise × percentage]) was used to analyze the data. When a significant *F* score occurred, a Tukey post-hoc test was used to determine pair-wise differences. Pearson product-moment correlations were used to determine selected pairwise relationships. Significance in this investigation was defined as $P \leq 0.05$.

RESULTS

The number of repetitions (mean ± *SD*) performed at 60, 80, and 90% of 1RM on squat, bench press, and arm curl are described in Table 2. There were no significant ($p > 0.05$) interaction effects for exercise and training status, intensity and training status, or exercise, training status, and intensity. However, a significant interaction ($p < 0.05$) was found in the interaction between exercise and intensity. For all exercises, subjects could complete significantly more repetitions at 60% of 1RM compared with 80 and 90% of 1RM. In addition, subjects performed significantly more repetitions at 80% of 1RM than 90% of 1RM (i.e., number of repetitions: 60 > 80 > 90%).

The only significant difference between T and UT was that UT performed more repetitions than T during bench press at 90% of 1RM. However, there were no other differences between T and UT in the number of repetitions performed at a given exercise intensity for a specific exercise.

Differences among the 3 exercises were partially dependent on the intensity used and the training status of the subjects. At 60% 1RM, T subjects could perform more repetitions during the back squat than either the bench press or arm curl (T: back squat > bench press = arm curl). Additionally, for UT, the number of repetitions of

TABLE 4. Rating of perceived exertion at 60, 80, and 90% of 1 repetition maximum (1RM) for back squat, bench press, and arm curl in untrained and trained groups. Values are mean ± *SD*.

	60% 1RM	80% 1RM	90% 1RM
Untrained			
Back squat	7.5 ± 1.9	7.3 ± 1.8	7.5 ± 1.7
Bench press	7.1 ± 1.8	7.0 ± 1.4	6.9 ± 1.7
Arm curl	6.6 ± 1.9	6.1 ± 2.0	6.4 ± 2.4
Trained			
Back squat	8.8 ± 0.7*†‡§	7.4 ± 1.4	6.9 ± 2.5
Bench press	7.0 ± 1.7	6.9 ± 2.4	7.3 ± 1.5
Arm curl	6.4 ± 2.0	6.6 ± 1.8	6.6 ± 1.8

* $p < 0.05$ vs. corresponding bench press value.
† $p < 0.05$ vs. corresponding arm curl value.
‡ $p < 0.05$ vs. corresponding 90% value.
§ $p < 0.05$ vs. corresponding 80% value.

bench press at 60% 1RM was greater than that for arm curl (UT: back squat > bench press > arm curl). At 80% 1RM, subjects could perform significantly greater repetitions during the back squat than for bench press. This pattern was seen for both T and UT. At 90% 1RM, UT performed more repetitions during the back squat than during arm curl; T performed more repetitions during the back squat than during the bench press at this intensity.

The mean power output during each exercise and intensity for UT and T are presented in Table 3. T had significantly greater mean power output than UT for all exercises and intensities. At 60 and 80% 1RM, T and UT performed the back squat with greater power than either bench press or arm curl (mean power: back squat > bench press > arm curl). At 90% 1RM, UT performed the back squat with greater mean power than the bench press; furthermore, bench press mean power was less than that at 80% 1RM. Also at 90% 1RM, T performed the back squat with greater mean power than for the bench press or arm curl; bench press mean power at 90% 1RM was less than that at 80 or 60% 1RM.

Table 4 shows the RPE at 60, 80, and 90% of 1RM for all exercises in UT and T groups. There were no significant differences based on training status (UT vs. T). RPE at 80 and 90% of 1RM for both UT and T groups was not significantly different among the 3 exercises. The only

Table 5. Correlation coefficients (Pearson *r*) between corrected strength and the number of repetitions for 60, 80, and 90% of 1 repetition maximum (1RM) for back squat, bench press, and arm curl. Values are mean ± *SD*.

	60% 1RM	80% 1RM	90% 1RM
Back squat	0.207	0.337	−0.018
Bench press	0.187	0.203	−0.583*
Arm curl	0.143	−0.226	0.140

* Correlation was significant at $p < 0.05$.

significant finding for RPE was at 60% of 1RM for back squat in T. In this instance, RPE was significantly greater than that for bench press and arm curl and for 80 and 90% of 1RM.

There were no significant correlations observed between the RPE and number of repetitions, or between the RPE and power output. Table 5 shows the correlations between corrected strength and number of repetitions. During bench press at 90% of 1RM, the corrected strength value was significantly correlated to the number of repetitions performed.

Discussion

The primary findings of this study were that (a) more repetitions could be performed in the back squat than the bench press or arm curl and (b) in general, there were no significant differences in the number of repetitions between the UT and T groups (except at 90% of 1RM for bench press). In addition to these findings, we also showed that more repetitions can be performed at a lower intensity. However, this finding is certainly not surprising since a fundamental principle of resistance exercise is that there is an inverse relationship between intensity and volume.

The number of repetitions that can be performed during free weight exercises appears to be dependent on the muscle mass involved in the exercise. At all intensities and for each group, the number of repetitions performed in the back squat was greater than the number of repetitions performed in either the bench press, arm curl, or both. Similar findings have been reported in studies using machine-based resistance exercise (7, 8). Hoeger et al. (7, 8) tested the maximal number of repetitions that could be performed at selected percentages of 1RM using 7 different machine-based exercises; more repetitions could be performed during the leg press than during any other exercise.

One mechanism may have been via asynchronous recruitment. At submaximal exercise intensities, motor units are asynchronously recruited, which serves to delay fatigue. This response allows some muscle fibers to rest, while others are being used to maintain the desired production of force. Perhaps because a greater absolute number of motor units was available for recruitment during the squat, asynchronous recruitment allowed more overall rest for muscle fibers, which delayed fatigue.

In the present study, there were no differences between T and UT in the number of repetitions performed in the free weight back squat using various percentages of 1RM. These findings are in contrast to those of Pick and Becque (16), who showed that T could perform significantly more repetitions than UT during the free weight back squat at 85% 1RM (9.67 ± 0.91 vs. 7.14 ± 0.74, respectively). It is difficult to rectify these differences because both studies used the same exercise and similar relative intensities. However, the differences may be due to the habitual training routine of the subjects; Hoeger et al. (8) found differences between T and UT women, but not men, and attributed this finding to the fact that women habitually performed muscular endurance-type training. Unfortunately, however, comparison of the habitual training programs of the present subjects to those of the Pick and Becque (16) is not possible; therefore, it is difficult to explain the discrepancy in findings.

Untrained performed significantly greater number of repetitions than T during bench press at 90% 1RM, although there were no differences between groups at 60 or 80% 1RM for bench press. No other study has compared T and UT using free weight bench press. Hoeger et al. (8) compared T and UT using a machine-based bench press exercise and found no difference between groups during bench press at 40, 60, and 80% 1RM. The results of the present study, combined with those of Hoeger et al. (8), suggest that there are no differences in the number of repetitions that T and UT can perform at intensities ≤80% 1RM. However, it seems that UT subjects can perform more repetitions during the bench press at very high intensities (>90% 1RM). A potential mechanism for this finding may be because lighter absolute resistances are used.

Based on the "RM continuum" proposed by Fleck and Kraemer (5), strength gains are more pronounced when exercises are performed at intensities of 1–6RM, while hypertrophy is optimized at 6–12RM, and local muscular endurance is greatest at >12RM. According to our results, UT and T can perform ≤6 repetitions at 90% 1RM. Therefore, loads of at least 90% 1RM may be optimal for strength gains in UT and T individuals. However, it should be noted that UT individuals can see large increases in strength during the initial weeks of a strength-training regimen using exercise intensities as low as 50% 1RM (17). For optimal hypertrophy, our results suggest that training should be performed at approximately 80% 1RM, and local muscular endurance training should be performed at loads less than 80% 1RM. However, the amount of muscle mass used during the exercise should be considered when prescribing loads based on a percent of 1RM.

The interpretation of the mean power data obtained in this study is challenging because (a) all sets were performed until exhaustion, and (b) subjects performed repetitions at a volitional speed. However, interestingly, the power output was greater for T than UT during all exercises and intensities. This finding can be explained, in part, by the fact that T performed repetitions using greater loads, which obviously require greater force (and hence greater power). However, it is difficult to state with any certainty the differences between T and UT in repetition velocity; therefore, future research should attempt to elucidate these differences.

Few correlations were observed that were meaningful to the understanding of the interrelationship between RPE and the number of repetitions performed. This was most likely due to the performance of a single set per exercise and the use of exercise to failure as the end point. However, since many competitive and recreational strength-training programs utilize exercise to failure, such data do raise serious questions as to the utility of

RPE to monitor differences in effort between sets performed to failure at different percentages of 1RM.

Studies have demonstrated that performing few repetitions with heavier weight is perceived to be more difficult than lifting comparatively lighter weight with more repetitions (4, 6). However, in these studies, external work was held constant. The results of the present study suggest that if exercise goes to failure, the exertion of subjects is similar within any intensity level, and that RPE may not be an effective tool to reflect the intensity of the loading in such an exercise prescription.

A correlation between strength corrected for body mass and number of repetitions was hypothesized; however, in general, no significant correlations were observed (except bench press at 90%). These data have implications for 1RM prediction equations which use submaximal loadings to estimate the 1RM. However, clearly, more research is needed to further understand such relationships.

In conclusion, the number of repetitions that can be performed during free weight exercises at various percentages of 1RM is influenced by the amount of muscle mass used, as exercises that utilize greater muscle mass allow more repetitions to be performed. Interestingly, however, there were minimal differences between T and UT subjects. Therefore, relative load has a fundamental impact on the number of repetitions allowed, since more repetitions can be performed at a lighter load, and this relationship is not appreciably affected by the training status of the subject.

PRACTICAL APPLICATIONS

If exercise prescription is based on a percent of 1RM: (a) very heavy intensity loads (>90% 1RM) should be used for strength gains in free weight exercises; (b) athletes should be regularly tested for 1RM strength because changes in 1RM will have an effect on the absolute load prescribed during training; and (c) the number of repetitions performed at a given percent of 1RM is, in part, dependent on the absolute muscle mass involved; therefore, when strength coaches prescribe loads based on percent of 1RM, they should be cognizant of the amount of muscle tissue involved in each of the specific lifts. If possible, using RM-based prescriptions is recommended to ensure that the appropriate load is being used for a desired result. However, percent of 1RM can also be used for exercise prescription when free weights are employed to approximate an appropriate exercise intensity.

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