A Meta-analysis to Determine the Dose Response for Strength Development

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ABSTRACT

RHEA, M. R., B. A. ALVAR, L. N. BURKETT, and S. D. BALL. A Meta-Analysis to Determine the Dose Response for Strength Development. *Med. Sci. Sports Exerc.*, Vol. 35, No. 3, pp. 456–464, 2003. **Purpose:** The identification of a quantifiable dose-response relationship for strength training is important to the prescription of proper training programs. Although much research has been performed examining strength increases with training, taken individually, they provide little insight into the magnitude of strength gains along the continuum of training intensities, frequencies, and volumes. A meta-analysis of 140 studies with a total of 1433 effect sizes (ES) was carried out to identify the dose-response relationship. **Methods:** Studies employing a strength-training intervention and containing data necessary to calculate ES were included in the analysis. **Results:** ES demonstrated different responses based on the training status of the participants. Training with a mean intensity of 60% of one repetition maximum elicits maximal gains in untrained individuals, whereas 80% is most effective in those who are trained. Untrained participants experience maximal gains by training each muscle group 3 $d \cdot wk^{-1}$ and trained individuals 2 $d \cdot wk^{-1}$. Four sets per muscle group elicited maximal gains in both trained and untrained individuals. **Conclusion:** The dose-response trends identified in this analysis support the theory of progression in resistance program design and can be useful in the development of training programs designed to optimize the effort to benefit ratio. **Key Words:** TREATMENT EFFECTS, WEIGHT TRAINING, MUSCULAR FITNESS, RESISTANCE EXERCISE

Medical research, especially research with pharmaceutical interventions, attempts to identify a dose-response relationship between the amount of a prescribed drug and the effect on an illness or disease. Identifying such a relationship facilitates the prescription of such medications in the proper and most effective doses. Paralleling this medical model, exercise scientists and fitness professionals are searching for a quantifiable relationship between dose (exercise) and response (specific health or fitness adaptations). For strength training, this dose-response relationship is vital to the prescription of proper doses of training. Over-prescription of resistance training exercise may result in over-stress injuries, whereas under-prescription will result in a failure to achieve the necessary or desired strength improvement. By optimizing the effort to benefit ratio (the amount and intensity of work to the degree of strength gain), exercise professionals can help their clients achieve the necessary or desired magnitude of strength gain in the most effective and efficient manner.

For strength development, a quantifiable relationship between the volume, intensity, and/or frequency of training and strength improvements has been somewhat elusive and controversial. Whereas much research has examined strength increases accompanying training interventions, most have examined only one or two training programs, providing only glimpses of a dose-response relationship. One of the most notable scientific studies was performed in the early 1960s (11). College-aged students were divided into nine groups, each being prescribed a different combination of sets and repetitions. Strength increases were analyzed between training programs, and it was concluded that three sets of six repetitions resulted in the greatest strength increases. This study demonstrated that different training volumes and intensities elicit different magnitudes of strength gains but only hinted toward a dose-response trend.

Of the various training variables, volume has received the most research attention. This attention has centered primarily on the debate concerning single-set training versus multiple-set programs. Numerous studies have compared such programs, and several narrative reviews (21,33) have summarized the results of these studies based on probability values, concluding that single-set programs elicit similar gains in strength as multiple sets. Unfortunately, much of

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this research has been performed with small sample sizes and consequently low statistical power (116). Methodological control may also have confused the issue as some past studies have failed to maintain stringent control of extraneous variables such as training intensity or periodization. In such situations, it may be difficult to identify accurate differences or trends in the data when relying solely on P values.

The American College of Sports Medicine (ACSM) recently issued a position stand after reviewing a large number of studies examining strength-training interventions (78). In this position stand, a follow-up and clarification of a previous statement (3), numerous issues including progression and variation of training, the application of training loads, and the differences in training prescription for trained and untrained populations were addressed. The statement concludes that as one progresses in training time and experience, the volume and intensity of training must be increased in order to continue to sufficiently stress the neuromuscular system. It did not, however, provide a quantifiable distinction between the magnitude of strength increases with specific volumes, intensities, or frequencies of training.

Fortunately, procedures exist that allow for a systematic and quantitative evaluation of strength-training research. The effect size (ES) proposed by Cohen (25) and the meta-analysis, popularized by Glass (44), provide for statistical evaluation of separate but related studies. The ES provides several benefits to researchers. First, it represents a standard unit for measuring and interpreting changes. Second, it allows for comparisons of different training methods within a single study. Finally, when used as part of a meta-analysis, the ES provides an acceptable method for combining and comparing the treatment effects of related studies.

Meta-analytical techniques provide a process by which treatment effects from various studies can be statistically combined and evaluated. The advantageous use of such techniques was recently illustrated in a meta-analysis of one-set versus three-set comparison studies (116). This analysis identified an added strength increase with three-set training by systematically and statistically evaluating the ES from 16 studies employing single- and triple-set comparison groups. This meta-analysis demonstrated that by combining the results of multiple studies and specifically analyzing the magnitude of the treatment effects, a greater understanding of the differences between the strength gains elicited by the different volumes was gained.

Unfortunately, a paucity of studies comparing one, two, three, four, or more sets of training limited the previous examination to a relatively few studies employing single- and triple-set comparison groups, providing limited information regarding the full dose-response relationship. This situation applies to research with frequency and intensity as well. However, the pre/post ES, representing a standardized mean difference (25), can also be computed in which an ES is calculated for a single treatment without comparison to a control group. With this procedure, past research examining strength-training programs can be combined, regardless of whether or not they included multiple comparison groups or a control group. This makes it possible to calculate an abundance of ES data from the existing strength-training literature to identify dose-response trends, a situation that may be impossible to accomplish in a single experimental design. The purpose of this investigation was to identify a quantitative dose-response relationship for strength development by calculating the magnitude of gains elicited by various levels of training intensity, frequency, and volume, thus clarifying the effort to benefit ratio.

METHODS

Literature search. Searches were performed for published and unpublished studies that included strength measurements before and after strength-training intervention programs. Computer searches of Science Citation Index, National Library of Medicine, Sport Discus, ERIC, and MEDLINE were performed. Hand searches of relevant journals and reference lists obtained from articles were conducted. Relevant studies were selected and searched for data necessary to compute ES and descriptive information regarding the training protocol.

Coding of studies. Each study was read and coded by the primary investigator for the following variables: descriptive information including gender and age, frequency of training, mean training intensity, number of sets performed, and training status of the participants. Frequency was determined by the number of days per week that participants trained a particular muscle group. Intensity was coded as the average percent of one repetition maximum (1 RM) used throughout the training program. Volume was recorded as the number of sets performed (per muscle group) during each workout. Training status of the participants was divided into trained and untrained classifications. Participants must have been weight training for at least 1 yr before the study in order to be considered as trained.

Coder drift was assessed (104) by randomly selecting 10 studies for recoding. Per case agreement was determined by dividing the variables coded the same by the total number of variables. A mean agreement of 0.90 was required for acceptance.

Calculation and analysis of ES. Pre/post ES were calculated with the following formula: [(Posttest mean − pretest mean)/pretest SD] (25). ES were then adjusted for sample size bias (55). This adjustment consists of applying a correction factor to adjust for a positive bias in smaller ($N < 20$) sample sizes (55). Descriptive statistics were calculated and univariate analysis of variance by groups was used to identify differences between training status, gender, and age with level of significance set at $P \leq 0.05$.

RESULTS

The mean ES were calculated for both trained and untrained participants (Tables 1–3) and were found to differ significantly ($F(2,1282) = -4.98$, $P < 0.05$). ES for men and women were found to be similar ($F(2,916) = 0.98$, $P > 0.05$). Populations of 26- to 45-yr-olds experienced slightly

TABLE 1. Treatment effects per group and condition by intensity.

% of 1 RM	Trained Mean (SD)	*N*	Untrained Mean (SD)	*N*
40	—	—	2.1 (2.5)	15
50	—	—	1.4 (2.0)	35
60	—	—	2.8 (2.3)	33
70	0.70 (0.65)	24	1.2 (1.8)	172
75	0.74 (0.99)	90	2.1 (2.2)	484
80	1.8 (1.3)	40	2.0 (3.3)	240
85	0.65 (0.77)	46	1.6 (2.7)	34
90	—	—	0.54 (0.39)	50

N, total number of ES at that level.

TABLE 3. Treatment effects per group and condition by volume.

Sets	Trained Mean (SD)	*N*	Untrained Mean (SD)	*N*
1	0.47 (0.57)	25	1.16 (1.59)	233
2	0.92 (0.52)	14	1.75 (1.98)	82
3	1.0 (1.26)	122	1.94 (3.23)	399
4	1.17 (0.81)	12	2.28 (1.96)	321
5	1.15 (0.99)	23	1.34 (0.89)	38
6	—	—	0.84 (0.42)	46

Sets, number of sets per muscle groups per workout; *N*, total number of ES at that level.

larger treatment effects than other age groups ($F(8,1424) = 7.44$, $P < 0.05$); however, the dose-response curves were similar in shape for all ages. Training status was the only variable found to affect the dose-response curves. In untrained populations, 60% of 1 RM, 3 $d \cdot wk^{-1}$, employing four sets elicited the greatest magnitude of strength increases. In trained populations, 80% of 1 RM, training 2 $d \cdot wk^{-1}$, employing four sets per muscle group elicited maximal gains. Coder drift was calculated to be 0.91; thus, the coding process used in this study was found to be reliable.

DISCUSSION

This meta-analysis, the first of its kind to calculate the magnitude of strength increases with various levels of intensity, frequency, and volume, provides detailed information regarding the dose-response relationship for strength development. Analyzing the magnitude of strength gains in a large number of studies has resulted in quantitative information that researchers have struggled to pinpoint for many years. This information can help exercise professionals prescribe the appropriate dose of training programs designed to address the specific needs or goals of their clients.

An issue that should be considered when interpreting these data is the disparity between the numbers of ES calculated at certain levels of each variable. This disparity may result in a skewing of the dose-response trend at certain points. At least 10 ES were required for a specific level to be included in the analysis in hopes of avoiding such a skewing effect; however, the magnitude of the ES may change if the number of ES were equated. In spite of these disparities, these data have identified specific trends in the magnitude of strength increases at varying dosages of training. It should also be noted that only 21 studies involved subjects over the age of 55 yr, 13 studies included competitive athletes, and only six involved younger populations (<18 yr). Therefore, additional reviews are needed in order to verify the applicability of the dose-response trends to those populations.

TABLE 2. Treatment effects per group and condition by frequency.

Days/Week	Trained Mean (SD)	*N*	Untrained Mean (SD)	*N*
1	—	—	0.5 (0.2)	17
2	1.4 (1.2)	69	1.2 (3.1)	158
3	0.70 (0.9)	133	1.9 (2.3)	965

N, total number of ES at that level.

Intensity. Untrained individuals (those with less than 1 yr of consistent training) experience maximal gains with a mean training intensity of 60% of their 1 RM or approximately a 12 RM (Fig. 1). In trained individuals, a mean intensity of 80% of 1 RM or 8 RM elicits the greatest strength increase. This difference may be a result of the ability of a trained neuromuscular system to recover from and adapt to a higher intensity of training. It is also indicative of the need to increase the training load (progression) to sufficiently overload the neuromuscular system as one becomes more accustomed to training.

The trend in untrained populations becomes somewhat unstable with training intensities above 60% of 1 RM. This may be a result of differing numbers of available ES calculated in the studies reviewed; however, diminishing returns appears to begin in untrained individuals who train at higher intensities as the magnitude of strength improvements decreases as mean training intensity exceeds 60% of 1 RM. This drop occurs in trained populations who train above an average training intensity of 80% of 1 RM. Therefore, caution should be used when prescribing mean training intensities these levels for extended periods of time.

Frequency. The ES for frequency of training also differed by training status (Fig. 2). Untrained individuals see a consistent dose-response as the number of days each muscle group is trained increases up to 3 $d \cdot wk^{-1}$. For trained individuals, 2 $d \cdot wk^{-1}$ (per muscle group) elicited the greatest strength increases. Programs in which each muscle group was trained 2 $d \cdot wk^{-1}$ at higher volumes were common among the training interventions for trained populations. This type of program results in more strenuous training and more recovery time between workouts. Such an approach may be too aggressive for untrained individuals who should

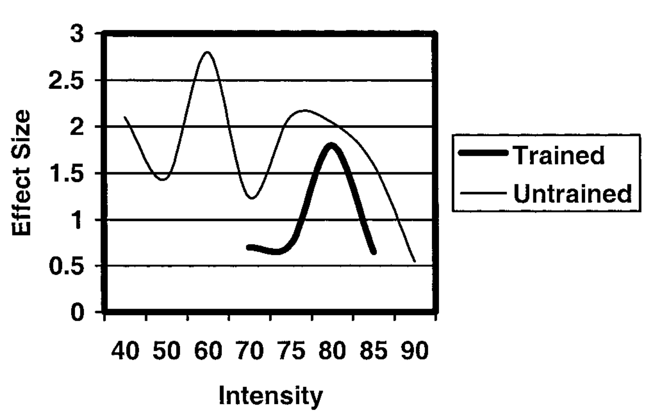

FIGURE 1—Dose-response curves for intensity.

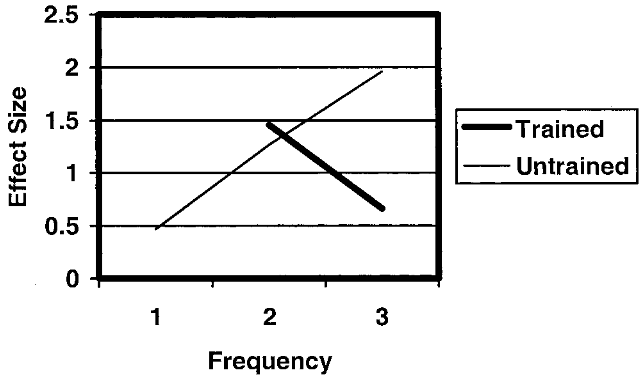

FIGURE 2—Dose-response curves for frequency.

perform three less strenuous workouts per week for maximal gains; however, additional research is needed to examine such training in untrained populations.

Volume. The effect size data calculated in the 140 studies reviewed clearly demonstrate that additional strength increases accompany training beyond single-set protocols (Fig. 3). In fact, both trained and untrained individuals experience the greatest gains (~ twice the treatment effect of single sets) with a mean training volume of four sets per muscle group. These data support the previous meta-analysis (116), which determined that three-set programs elicit greater strength gains than single-set protocols and contradict the suggestions that single-set protocols elicit maximal or even similar strength gains as multiple sets (21,52). The additional contribution of this study to the scientific literature is the identification of the magnitude of strength increases with two, four, five, and six sets of training.

Previous authors (52) have concluded that in healthy, untrained adults, multiple-set training regimens provide little, if any, additional stimulus for improving adaptations during the initial training periods when compared with single-set protocols. They also suggest that single-set training regimens in recreationally trained individuals will continue to produce similar strength benefits as multiple-set programs. The magnitude of treatment effects from the 140 studies reviewed in this analysis fails to support either of these conclusions.

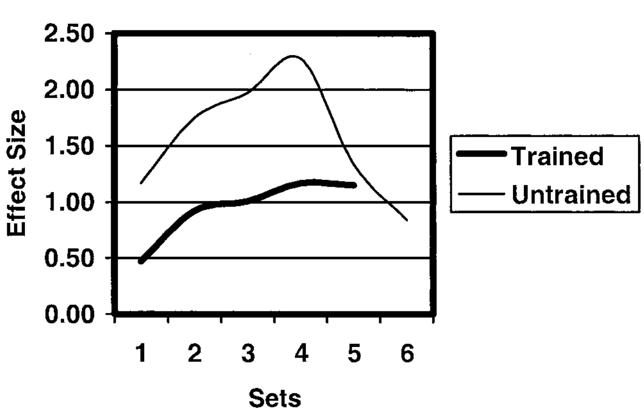

FIGURE 3—Dose-response curves for volume.

The magnitude of strength gain with multiple-set training in untrained populations identified here also contradicts the notion that untrained individuals are less sensitive to volume as compared with trained individuals (78). In fact, based on the differences in ES of one and four sets, untrained populations are more sensitive to increases in volume (+1.12) than trained populations (+0.7). This may relate to the greater potential for strength increases among untrained populations but demonstrates that they too follow a dose-response trend as volume is increased. However, caution should be used when prescribing high-volume training to untrained populations as adequate time is needed to become accustomed to the stress of resistance exercise and avoid over-stress injuries in the early phases of training. These individuals may also lack the desire to commit to a training program requiring the additional time needed to perform multiple sets and thus reduce adherence to the exercise regimen. These issues must be considered before prescribing multiple-set programs to those who have not been training consistently for at least 1 yr.

An examination of the ES for each set performed reveals that untrained individuals do experience a greater magnitude in strength gains at all volumes than do trained individuals. In fact, trained individuals must perform four sets to experience the same magnitude of strength gains as untrained individuals achieve with one set. This, again, is a result of an increased potential for strength improvements among those who are untrained or less trained as compared with those who have been training for an extended period of time and may be approaching a genetic limitation in overall strength development. It also represents the progression to higher volumes of training necessary as training experience increases.

It appears that diminishing returns begins in untrained individuals who perform more than four sets as the ES for five and six sets drop dramatically. For trained individuals, the mean ES for five sets is just slightly lower than four sets and insufficient ES were available for six sets. Therefore, the point at which this drop begins to occur in trained subjects is still speculative but may also occur with training above four sets. Caution should be used when prescribing strength-training programs of more than five or six sets until further data are available.

A note of particular importance regards the manner in which studies were coded for training volume. The number of sets performed per muscle group is a better indicator of the amount of training stress that a muscle experiences during a training session than sets per exercise. Programs professing to be single-set protocols may include multiple exercises stressing the same muscle group. This may result in a particular muscle group experiencing a stress similar to a multiple-set protocol for a single exercise. Previously overlooking such an issue may have confused the dose-response issue for volume by increasing the strength gains elicited by these single-set per exercise (but multiple set per muscle group) protocols.

Applications to exercise prescription. A reoccurring theme in the current data relates to the importance of progression or progressive overload. Progression, with regard to strength training, is the gradual increase of stress placed upon the body during exercise (78). Such a principle is a vital characteristic in training programs of extended periods as the adaptive processes will only respond when faced with a stress to which they are not accustomed. As discussed in the ACSM's position stand regarding progression models in resistance training (78), the initial standard of one set of 8–12 repetitions as suggested in previous position statements (3) was deemed appropriate for those individuals in the initial stages of training. However, that position statement did not include prescription guidelines for those individuals desiring continued gains in muscular fitness who must progress to higher volumes and intensities to avoid plateaus in adaptations. This analysis supports that conclusion.

Variation is also an important concept brought out by the current analysis as many of the studies included involved periodized training programs. Such programs did not involve the performance of solely four sets at 80% of 1 RM but incorporated varied training volumes and intensities (i.e., 3–5 sets at 70–90% of 1 RM). Therefore, the dose-response curves presented here represent mean training levels and should not be construed as supporting training at a particular volume or intensity on a constant basis. Rather, effective programs should incorporate varied training doses around the level of volume, frequency, and/or intensity corresponding to the degree of strength gain desired.

The issue of desired outcomes arises when applying the dose-response relationship to exercise prescription for strength gains. The desired magnitude of strength should be evaluated by the exercise professional and identified before attempting to prescribe a training program. It is apparent that lower levels of volume and intensity can result in improvements in strength. However, for maximal and continued adaptations over time, additional work at higher intensities must be performed. Exercise professionals should ascertain how much strength gain is needed or desired by their clients and then explain the effort-to-benefit ratio. This will enable them to make an informed decision regarding the amount of time and effort needed to achieve the desired/needed strength gains. For example, it would be unnecessary for an individual deemed to have adequate strength levels and simply desiring to maintain or slightly increase their current fitness to spend the time/effort needed to perform four sets at a high intensity. However, individuals seeking larger gains in strength will need to commit additional time and energy to their exercise sessions.

CONCLUSION

Resolution of the dose-response controversy among researchers, exercise and conditioning professionals, as well as the general public, is important as much confusion has resulted. The ACSM position statement on progression models (78) addressed this confusion, suggesting the necessity of progressive increases in volume, intensity, and frequency of training to facilitate the adaptive processes. The current study has presented additional evidence regarding the amount and intensity of work needed to elicit maximum gains. It also identifies the magnitude of strength gains with lower levels of training. Exercise prescription for strength increases is a complex process involving the manipulation of each of the variables discussed in this report. These dose-response curves should be consulted when designing resistance-training programs in order to prescribe the appropriate volume, intensity, and frequency to achieve the desired magnitude of strength increase.

References included in the analysis: (1, 2, 4–20, 22–24, 26–32, 34–43, 45–51, 53, 54, 56–77, 79–103, 105–115, 117–148).

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