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Review

Influence of strength training variables on strength gains in adults over 55 years-old: A meta-analysis of dose–response relationships

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ABSTRACT

Objectives: The importance of strength training to elderly individuals is well established. However, the dose–response relationship of the benefits of strength training in this population is unclear. The purpose of the study was to use meta-analysis to investigate the dose–response of the effects of strength training in elderly individuals.
Design: Fifteen studies with a total of 84 effect-sizes were included. The analyses examined the dose–response relationships of the following training variables 'intensity', 'number of sets', 'weekly frequency', and 'training duration' on strength improvement.
Methods: The studies selected met the following inclusion criteria: (a) randomized controlled trials; (b) trained healthy subjects of both genders; (c) trained subjects aged 55 years or older; (d) strength increases were determined pre- and post-training; (e) use of similar strength evaluation techniques (strength determined by a repetition maximum test) and training routine (dynamic concentric–eccentric knee extension exercise to train the quadriceps muscle group). The effect-sizes were calculated using fixed and random effect models with the main effects determined by meta-regression.
Results: Many combinations of training variables resulted in strength increases. However meta-regression indicated only "training duration" had a significant dose–response relationship to strength gains ($p = 0.001$). Over durations of 8–52 weeks, longer training durations had a greater effect on strength gains compared to shorter duration protocols.
Conclusions: Resistive training causes strength gains in elderly individuals, provided the training duration is sufficiently long, regardless of the combination of other training variables.

1. Introduction

Muscle strength is considered a fundamental component of physical fitness related to quality of life.[1,2] For elderly individuals, strength training is important to maintain functional ability because strength progressively declines with aging,[3,4] which significantly affects the ability to perform activities of daily living.[5–7] Therefore it is important to determine the optimum dose or amount of strength training that should be prescribed to increase strength in this population.

A dose–response relationship between strength increases and training variables such as training volume (number of repetitions per set, number of sets per exercise), training intensity (percent of one repetition maximum), and duration of training may exist in the elderly as such relationships do exist in younger individuals.[8–10] A dose–response relationship may also exist between some combination of the above training variables and strength increases. A previous systematic review by our group[11] concluded that there are very few studies investigating the effects of strength training variables on the strength gains in elderly subjects. Unfortunately, much of the available research has been performed with small sample sizes and consequently low statistical power. Additionally, potential confounding variables, such as the training status of subjects, are frequently not adequately controlled. Hence the dose–response relationship between strength training volume and intensity and strength gains in the elderly remains obscure.

Since the term meta-analysis was coined, recognition has grown that reviewing of scientific literature is itself a scientific approach.[12] Meta-analysis allows examining the combined results of previous research and comparing the effects of strength training variables,

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whether or not individual studies actually compared training variables or included a control group. This makes it possible to identify a dose–response trend for a given training variable, a situation that may be difficult to accomplish in a single experimental design.[8,9] A recent study[13] was the first to use the meta-analysis approach to investigate the dose–response relationship between strength increases and training variables in older subjects. Conclusions from this meta-analysis suggested that training intensity shows a dose–response to strength gains in individuals 65 years and older, with higher intensity programs being more effective than lower intensity programs. However, this previous meta-analysis did not examine the combined effects of different training variables or domains of strength training, such as intervention duration, number of sets per exercise, and intensity.

Many possible combinations of different strength training variables or domains may lead to positive adaptations and strength gains. Possible interactions of strength training variables or domains cannot be taken into account by evaluating the effect-sizes related to each training variable separately. Using meta-regression techniques such interactions between training variables can be examined. Therefore, the purpose of this investigation was to use meta-regression techniques to investigate the dose–response of combined domains of strength training variables such as training intensity, weekly training frequency, number of sets per exercise, and intervention period on the strength gains in elderly subjects.

2. Methods

2.1. Study inclusion criteria

The following inclusion criteria were adopted to select the studies to be included in the meta-analysis: (a) randomized control trials in which only strength training (defined as a structured, planned exercise where the subject exerts an effort against an external resistance) had been performed. The studies having more than one treatment group, using different strength training methodologies, were included in the analysis in the same proportion as the number of treatment groups, as if they were different studies; (b) subject population of healthy individuals of both genders aged 55 years or older; (c) use of similar strength evaluation techniques (only studies measuring muscular strength by means of repetition maximum tests were included) and training routine (analyses were restricted to results related to dynamic concentric-eccentric strength training of the quadriceps muscle group with knee extension exercise).

2.2. Literature search

The *Medline*, *Lilacs*, *Science Citation Index*, *Cochrane Library*, and *Sport Discus* databases were searched for appropriate studies without time limits until March 2012. Reference lists of papers were manually searched for other appropriate articles for inclusion. Two researchers independently searched for titles and abstracts in these databases to identify potentially relevant studies. The inclusion criteria were then used by both researchers to identify appropriate studies to be included in the meta-analysis. In the two researchers disagreed on inclusion of a study, a third researcher's opinion was obtained to decide if the study in question should be included in the analysis.

2.3. Coding of the studies

Each study was read and coded by the primary investigator for the following variables: (a) descriptive information (sample, calculation of the statistical power, age and gender); (b) training intensity (% of one maximum repetition, 1RM); (c) number of sets per sets; (d) training effects (% gain in strength). Coding reliability was assessed[8] in the 15 selected studies by a second evaluator. Per case agreement was determined by dividing the variables coded similarly by the total number of variables. A mean agreement of 0.90 was required for acceptance.

2.4. Statistical analyses

2.4.1. Calculation of effect-sizes and meta-analytical regression

In a meta-analysis, the effect sizes are used as a common measure that can be calculated individual studies and then combined into overall statistical analyses. The term effect size is most frequently used to describe standardized measures of effect. It represents a standard unit for measuring and interpreting changes in an outcome measure, allowing for comparisons of different training methods within a single study as well for combining and comparing the treatment effects of related studies.[8] In brief, the effect size provides information about how much change is evident across all studies and for subsets of studies. In the present study we have focused on the standardized mean difference (SMD) as the effect-size index of the meta-analysis. The SMD was calculated by using differences in strength improvement from baseline between subjects assigned to strength training and those assigned to control groups.[14,15]

The effect-size calculation was based on the mean, standard deviation, and size of the studied samples.[14,15] Fixed and random model effects were used to estimate the effects of all treatments. Under the fixed effects model, it is assumed that all studies come from a common population, and that the effect size (SMD) is not significantly different among the different trials. If this assumption is not possible, then the fixed effects model may be invalid. In this case, the random effects model may be more appropriate, in which both the random variation within the studies and the variation between the different studies is incorporated. When it is not possible to determine whether the effect-sizes are stable among the studies the random effects model is usually performed as a confirmatory analysis.[15] The random effects model gives a more conservative estimate (i.e. with a wider confidence interval), but the results from the two models usually agree when there is no heterogeneity.

A meta-regression was performed to combine the following variables: 'number of sets per exercise', 'weekly training frequency', 'training intensity as percent of 1RM', and 'intervention period', with the goal of identifying which of the variables best explains the differences among the studies for 'strength gain'. All included studies used repetition maximums (sets performed to concentric failure) during training. The number of repetitions per set was not analyzed as an isolated variable due to its direct relationship with training intensity (percent of 1RM used in training in large part dictates the number of repetitions possible in a set in concentric failure). Therefore the inclusion of the number of repetitions could introduce bias into the results as training intensity would affect the number of repetitions per set. The meta-analysis and meta-regression were performed using the macros Metan and Metareg of the software STATA/SE version 10 (StataCorp™ LP, TX, USA). Each one of these macros is well accepted as valid.[16,17] In all cases a p level of 0.05 was adopted for statistical significance.

3. Results

As of May 2012, the electronic search identified 1183 potentially relevant studies and the manual search of reference lists identified another 12 potentially relevant studies. After excluding 119 studies which were indentified more than once in the different search engines, the remaining 1076 studies were manually