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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

Objective: 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[TM] 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

Table 1
Characteristics of the studies included in the meta-analysis.

Studies included	Age (years) mean ± SD or Range	Level of physical activity	Sex	Statistical analysis	*N*	Exercise tested	Strength test
Frontera et al.[37]	68–79	Sedentary	Female	ANOVA	14	Knee extension	1RM
Judge et al.[24]	71–97	Sedentary	Both	Student *t*-test	31	Knee extension	1RM
Judge et al.[25]	75–85	Sedentary	Both	MANOVA	55	Knee extension	1RM
Kalapotharakos et al.[18]	60–74	Sedentary	Both	ANOVA	33	Knee extension	1RM
Morganti et al.[26]	59.5 ± 0.9	Sedentary	Female	Student *t*-test	39	Knee extension	1RM
Pyka et al.[34]	61–78	Sedentary	Both	Student *t*-test	14	Knee extension	1RM
Schlicht et al.[33]	61–87	Sedentary	Both	ANCOVA	22	Knee extension	1RM
Seynnes et al.[19]	81.5 ± 1.4	Sedentary	Both	Pearson's *r*	22	Knee extension	1RM
Taaffe et al.[22]	65–79	Sedentary	Both	ANOVA	46	Knee extension	1RM
Hurley et al.[36]	60 ± 5	Sedentary	Female	ANOVA	35	Knee extension	3RM
Reeves et al.[35]	74.3 ± 3.5	Sedentary	Both	ANOVA	18	Knee extension	5RM
Debeliso et al.[23]	71.6 ± 5.3	Sedentary	Both	ANOVA	26	Knee extension	1RM
Rabelo et al.[20]	60–76	Sedentary	Female	ANOVA	61	Knee extension	1RM
Fatouros et al.[21]	71.2 ± 4.1	Sedentary	Male	ANOVA	52	Knee extension	1RM
Debeliso et al.[27]	71.6 ± 5.3	Sedentary	Both	ANOVA	60	Knee extension	1RM

RM: repetition maximum.

reviewed. Abstract examination for eligibility excluded 799 articles due to failure to satisfy pre-established inclusion criteria. Of the original 1183 studies indentified only 277 articles were fully assessed. Of these, 262 studies were excluded for several reasons – Fig. 1 summarizes the studies selection process. Therefore, 15 studies met all the inclusion criteria for this review. These 15 studies included a total of 528 participants. All studies used a significance level of 0.05 in their statistical analysis.

The 15 studies meeting the inclusion criteria had a total of 84 effect-sizes. Of the included studies 4 involved 2 training groups[18–21] and one involved 3 groups.[21] The study by Debeliso et al.[23] had two treatment groups, but one treatment was a periodized strength training protocol involving substantial changes in the training intensity and volume. Only the group that trained using non-periodized training was included in the meta-analysis.

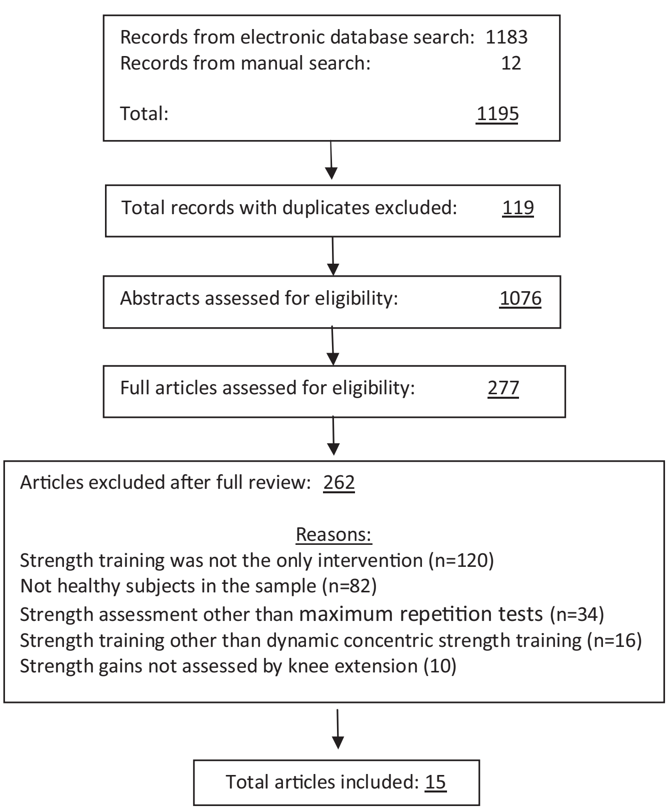

Fig. 1. Results of literature search for resistance training in the elderly.

This resulted in a total of 21 groups that trained exclusively with strength training. Coding reliability of studies was 0.92.

Table 1 presents the 15 studies selected for the meta-analysis. Sedentary individuals with a mean age of approximately 60 years or older were the subjects in all included studies, used RM tests to examine strength gains, and trained with dynamic knee extension exercise. Some studies included subjects over 70 years of age, and at least in one study the age of participants was close to 100 years-old.[24] Four of the 15 selected studies trained exclusively females.

Table 2 presents the variables that were included in the meta-analysis: number of sets per exercise (NS), weekly training frequency (WF), treatment duration in weeks (TT), training intensity in % of 1RM (INT), and strength gains for experimental and control groups (%). Many of the studies followed the American College of Sports Medicine[10] recommendations for young adults [3 sets of 10–15RM of each exercise, frequency of 2–3 days a week] as the training program performed. As for the number of sets, only one of the studies trained with two sets[25] and one with one set[26] of each exercise. All other studies trained with three sets. However in some studies the knee extensors were trained with more than one exercise [knee extension and leg press], which may have affected the strength increase shown. In these cases the total number of sets for the statistical analysis was determined by summing the sets performed in each exercise.

The majority of studies had a training frequency of three sessions per week, with only three studies using a training frequency of less than three times per week. Two studies had several training frequencies. Taaffe et al.[22] trained three groups (one, two and three days a week), while the two studies by Debeliso et al.[23,27] trained groups two days per week. The variable 'intensity' as a percent of 1RM showed high variability (40–84%) among the studies. However, only four studies used intensities lower than 70% of 1RM.

Assuming that the effects caused by strength training in the selected studies were equal, the fixed effects model was used to estimate the overall treatment effect and respective confidence intervals.[13,15] The results are shown in Fig. 2 which also presents the weight adopted for each study based on the quality standards, which were estimated using the sample size (*N*) and the standard deviation of the study.[13,15] The vertical dotted line represents the average result of all studies, that is, the standardized mean difference. The studies that had the smallest differences between 'treatment' and 'control' groups are represented on the left side of the dotted line while studies that showed the largest differences are on the right side of the line.

The random model was used when the effect-sizes of the trials were heterogeneous. The results exhibited in Fig. 3 reveal that even though the studies had received higher weights than in the fixed

Table 2
Variables included in the meta-analysis for each selected study.

Studies Included	NT	MT	SDT	NC	MC	SDC	NS	WF	TD	INT (%)
Frontera et al.[37]	7	18.4	5.1	7	12.5	2.8	3	3	12	80
Judge et al.[24]	18	72.0	5.0	13	55.0	4.0	3	3	12	77.5
Judge et al.[25]	28	71.0	26.0	27	45.0	21.0	3	3	12	75
Kalapotharak et al.[18a]	11	43.1	11.5	10	20.8	7.2	3	3	12	80
Kalapotharakos et al.[18b]	12	31.5	10.0	10	20.8	7.2	3	3	12	60
Morganti et al.[26]	20	16.0	1.9	19	2.5	1.6	6	3	48	84
Pyka et al.[34]	8	57.1	5.1	6	25.4	2.3	6	3	52	72.5
Schlicht et al.[33]	11	89.0	34.0	11	60.0	24.0	4	3	8	75
Seynnes et al.[19a]	8	11.3	1.0	8	6.1	0.6	6	3	10	80
Seynnes et al.[19b]	6	9.7	0.7	8	6.1	0.6	3	3	10	40
Taaffe et al.[22a]	11	67.1	3.3	12	45.0	3.1	6	1	24	80
Taaffe et al.[22b]	12	72.6	3.1	12	45.0	3.1	6	2	24	80
Taaffe et al.[22c]	11	62.6	3.2	12	45.0	3.1	6	3	24	80
Hurley et al.[36]	23	77.0	14.0	12	61.0	18.0	2	3	16	70
Reeves et al.[35]	9	49.4	14.1	9	43.5	12.0	6	3	14	72
Debeliso et al.[23]	13	105.0	40.0	13	58.0	25.0	6	2	18	80
Rabelo et al.[20a]	21	33.7	11.3	20	20.4	5.9	6	3	10	50
Rabelo et al.[20b]	20	41.7	15.9	20	20.4	5.9	6	3	10	80
Fatouros et al.[21a]	18	42.7	4.6	14	0.9	2.1	6	3	24	55
Fatouros et al.[21b]	20	63.1	3.0	14	0.9	2.1	6	3	24	82
DeBeliso et al.[27]	18	66.6	18.0	21	11.5	1.0	6	2	18	80

NT: number of individuals in the training group; MT: mean results of the training group (%) increase; SDT: standard deviation of the results in the training group; NC: number of subjects in the control group; MC: control group mean results (%); SDC: standard deviation of the results in the control group; NS: number of sets; WF: weekly frequency; TD: training duration in weeks; INT: intensity as % of 1RM.
Observation: 'a', 'b', and 'c' beside a given reference represent different experimental groups in the same study. The studies with 2, 4, and 6 sets trained respectively with 1, 2, and 3 sets of each exercise recruiting the quadriceps muscle group [knee extension and leg press]. Therefore the number of sets in the statistical analysis used the total number of sets for both exercises.

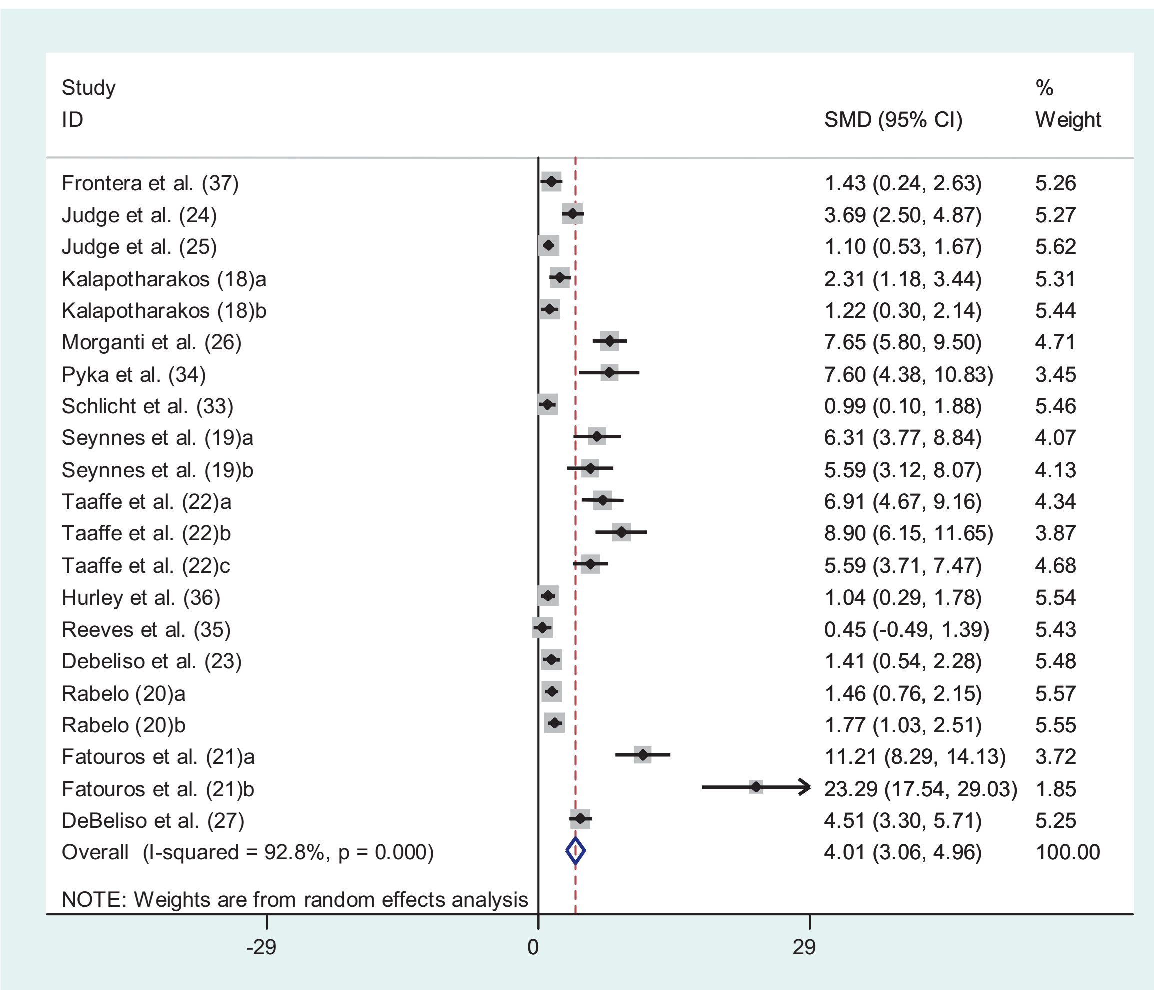

Fig. 2. Graphic representation of treatment effects estimate, confidence interval, and weight of studies calculated using the fixed effects model. 'a' and 'b' besides a given reference represent different experimental groups in the same study. SMD = standardized mean difference; %weight = weight attributed to each study due to its statistical power.

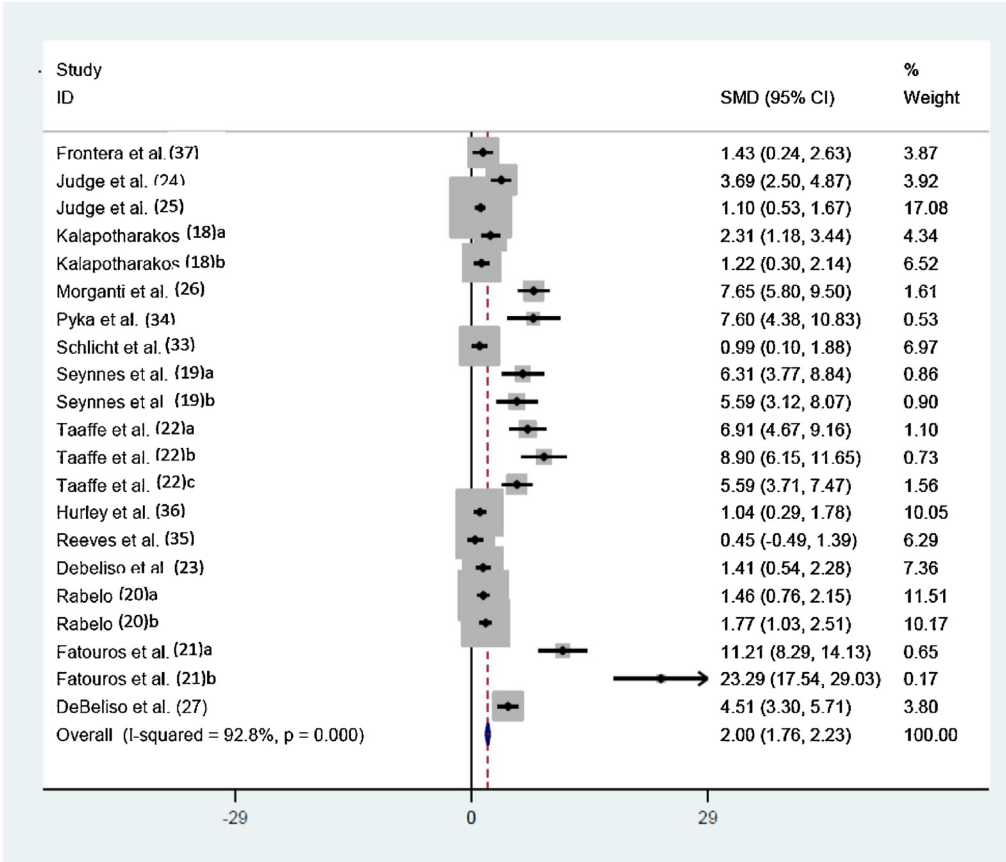

Fig. 3. Graphic representation of treatment effects estimate, confidence interval and weight of the studies calculated by the random effects model. 'a' and 'b' besides a given reference represent different experimental groups in the same study. SMD = standardized mean difference; %weight = weight attributed to each study due to its statistical power.

effects model, in general the dose–response relationships associated with the standardized mean differences were similar.

The results obtained for the meta-analytical regression are presented in Table 3. Only the intervention duration significantly accounted for the observed strength gains.

4. Discussion

To the best of our knowledge the present meta-analysis is the first to provide information about the dose–response relationship of strength training in the elderly, considering the combined effects of different domains such as training intensity, frequency, number of sets, and intervention duration. In a previous meta-analysis, Steib, Schoene and Pfeife[13] also examined the dose–response relationship between strength training variables and strength gains in elderly subjects. However, their analyses focused primarily on the effectiveness of different training intensities comparing high-intensity (defined as 75% 1RM or greater) with either low (55% 1RM or lower) or moderate-intensity (55–75% 1RM) protocols. In addition, strength gains of different muscle groups and performance of daily tasks, such as chair rise and stair climbing ability were main outcomes. The main conclusions were strength increases responded in a dose–response manner to training intensity, but functional performance improvements did not respond to intensity in a dose–response manner. Additionally, Steib, Schoene and Pfeife[12] did not investigate the combined effects of different strength training variables or domains on the strength increases.

Studies included in the present meta-analysis showed a high variability in the subjects' age and training duration. Some studies included subjects over 70 years of age, and in one case the sample age was close to 100 years,[24] a period of life that strength and muscle mass decrease at a fast rate and the neural ability to recruit muscle fibers is also decreased.[3,4,28,29] Both of these factors could affect the change in strength with training. Training duration is potentially important because in untrained people neural adaptations instead of a hypertrophic response are responsible for the majority of strength increases during short duration resistance exercise programs.[30–32] The meta-analytical regression indicated strength increases were greater with longer duration studies. In almost all studies included in the meta-analysis subjects trained for 12 weeks or longer, except for the studies by Shlicht et al.[33] [8 weeks], Seynnes et al.[19] [10 weeks], and Rabelo, Oliveira and Bottaro[20] [10 weeks]. The longest durations were 48 and 52 weeks in studies by Morganti et al.[26] and Pyka et al.,[34] respectively. Thus

Table 3
Meta-analytical regression of the variables number of sets, weekly frequency, training duration and intensity as percent of 1RM.

Variables	Coefficient	Standard error	*Z*	*p*-Value	95% confidence interval	
NS	0.46	0.34	1.34	0.182	−0.21	1.14
WF	0.15	0.98	0.16	0.872	−1.76	2.07
TD	0.15	0.04	3.47	0.001	0.06	0.24
INT	0.91	1.02	0.90	0.370	−1.08	2.92
Constant (intercept)	−1.92	3.55	−0.54	0.588	−8.88	5.03

NS: number of sets; WF: weekly frequency; TD: training duration; INT: training intensity.

for the majority of studies, strength increases would be due to a combination of neural and hypertrophic adaptations.

It is important to acknowledge that, due to strict inclusion criteria the selected studies had high homogeneity, particularly with regard to initial training level (untrained), strength testing (dynamic repetition maximums), and strength outcomes (all programs trained the quadriceps muscle group using dynamic knee extension exercise). Training frequency varied from one session per week to three sessions per week, but the majority of studies trained with a frequency of three sessions per week (17 of 21 treatments) (see Table 2). The number of sets of exercises involving the quadriceps muscle group varied between one and six sets, with most studies training with six sets (12 treatments of 21), followed by those training with three sets (6 of 21 treatments). On the other hand, the training intensity varied between 55 and 84% of 1RM. Low variability of training protocols could limit the statistical power of a meta-analysis. However, in the present analysis there were differences within the studies for training variables, such as the number of sets, training duration, intensity, and frequency. Therefore, the use of meta-analysis to compare the effect of each of these training variables on the strength dose–response relationship was justifiable.

All studies had a positive estimate of the effects from the proposed training program, that is, the strength of elderly subjects significantly improved regardless of the combinations of number of sets, weekly frequency, intensity, and training duration. The only exception was the study by Reeves et al.[35] which did not show a statistical significant increase in strength between pre and post training (SMD = 0.45; IC95% = −0.49–1.39). The consistent finding that strength training increases strength was expected, since it is well accepted that resistance training programs using a wide range of intensity and volume can enhance muscle strength in all ages, especially in sedentary populations.[1,29,31]

The SMD was used as the effect-size index.[13,14] The SMD showed positive results for strength gains, but showed considerable variability. However, the studies by Reeves et al.,[35] Shlicht et al.,[33] Hurley et al.,[36] Judge et al.,[25] Kalapotharakos et al.,[18b] Debeliso et al.,[23] Frontera et al.,[37] and Rabelo, Oliveira and Bottaro[20a,b] showed small effect-sizes and therefore weak dose–response relationships considering the training variables as a whole [0.45; 0.98; 1.03; 1.09; 1.21; 1.40; 1.43; 1.45 and 1.77, respectively]. This occurred even though a higher weight was given to these studies, because they generally had a higher *N* or smaller standard deviations than the other studies, which enhances their statistical power. It was thus expected that these studies would show higher dose–response relationships. In contrast, the studies by Taaffe et al.,[22b] Morganti et al.,[26] Pyka et al.,[34] and both experimental groups studied by Fatouros et al.[21] had larger effect-sizes [8.90; 7.65; 7.60; 11.21, and 23.29, respectively] although they were assigned smaller weights. A possible explanation for these results could be the fact that the studies which had the higher effect estimates had in common long trainings periods (≥24 weeks) compared to the other studies.

Since the tendency for a positive training effect was confirmed in all studies, the relative influence of training variables was investigated, in order to explain why some interventions showed greater strength gains than others. The studies by Taaffe et al.,[22b] Pyka et al.,[34] Morganti et al.,[25] and Fatouros et al.[21] [group b, see Table 2], which showed the higher effect estimates, training programs used higher intensity and higher number of sets to train the quadriceps muscle group [3 sets for the knee extension and 3 sets for the leg press at 70% 1RM or more]. One group in the Fatouros et al.[21] study also showed a high effect estimate, but the intensity was 55% 1RM. Regarding the weekly frequency, the study by Taaffe et al.[22b]–which presented the highest effect estimate–was the only one among the four studies showing higher effect estimates that used a training frequency lower than 3-day/week [2 day/week protocol]. Thus the training protocols across the studies showing higher effect sizes were heterogeneous.

In contrast, the studies with smaller effect-sizes [Reeves et al.,[35] Schlicht et al.,[33] Hurley et al.,[36] Judge et al.,[25] Kalapotharakos et al.,[18b] Debeliso et al.,[23] Frontera et al.,[37] and Rabelo, Oliveira and Bottaro[20a,b]] did not use substantially different training methods than the studies associated with larger effect-sizes. As shown in Table 2, this group of studies also used training protocols with intensities of 70% RM or higher. The exceptions were the studies by Kalapotharakos et al.[18] and Rabelo, Oliveira and Bottaro[20a] [60 and 5% of 1RM, respectively]. The homogeneity was even higher for the weekly training frequency. Almost all of these studies used 3-day/week training protocols, the only exception being the work by Debeliso et al.[23] [training twice a week]. On the other hand, since the training protocols applied sometimes more than one exercise involving the quadriceps muscle group, the total number of sets was less homogeneous. Four training protocols used 6 sets [3 sets of the knee extension and 3 sets of the leg press],[20a,b,23,35] three studies used 3 sets [knee extension],[18b,25,37] one study used 4 sets [2 sets for the knee extension and 2 sets for the leg press],[33] and one study used 2 sets [1 set for the knee extension and 1 set for the leg press].[36] Thus studies showing large as well as small effect sizes used a variety of training intensities, number of sets and frequencies.

The studies showing larger effect-sizes were similar to each other, in that they all had longer training durations [24–52 weeks of training], as can be seen in Table 2. On the other hand the studies having smaller effect-sizes had training durations of 8–18 weeks. This is an indication, which was substantiated by meta-analytical regression, that the training duration was a determining variable for the dose–response in the analyzed programs, regardless of the other training variables.

The result from the fixed and random estimate models indicate that all training variables may play a part in yielding strength increases. However, from a dose–response perspective and considering the characteristics of the studies that have been included in the analysis, the meta-regression suggested that the training duration was the only variable explaining the different effect-sizes. These results support data from Harris et al.[38] and Taaffe et al.[22], showing no significant difference in the strength gain of the elderly with different numbers of sets (2, 3 and 4) and weekly frequencies (1, 2 and 3 sessions per week).

Concerning training intensity, seven studies compared low and high resistance training intensities.[1,18,19,21,38–40] Of these studies five reported significant differences, with high intensities – mostly near 80% of 1RM – being associated with greater strength increases.[18,19,21,39,40] Such significant differences could lead to the conclusion that intensity is an important variable in determining training strength increases which is supported by a previous meta-analysis.[13] However, this was not confirmed by the meta-analytical regression, where the variable 'workload intensity' had a *p*-value of 0.725.

The idea that training duration may be the only variable significantly affecting strength gains in the elderly is important, but this conclusion needs to be tempered because the vast majority of studies included in the present meta-analysis used similar training programs (3 sets, frequency of 3 sessions per week), limiting the generalization of this conclusion to all strength training programs. It is possible to speculate about some possible reasons explaining why duration, but not other training variables, was found to significantly account for strength gains. Firstly, most studies included in this meta-analysis trained for short-term periods. In fact, only four studies used long-term training programs [24–52 weeks].[21,22,26,34] Strength increases in short programs [up to 8 weeks] are primarily due to neural adaptations, especially in untrained people.[30–32]

If the training durations of the majority of studies had been long enough to stimulate hypertrophic adaptations, maybe other variables would have shown a significant dose–response relationship to strength gains.

Secondly, as previously discussed there was relatively little variability for many training variables in the studies included in our meta-analysis. The selected studies were also quite similar for the training level at baseline. Except for Judge et al.,[24] which included in their sample a few individuals with low physical activity level, all other studies trained sedentary elderly subjects. This relative homogeneity of training status at baseline may have decreased the influence of training variables, such as number of sets or weekly frequency. This possibility is supported by the meta-analysis of Wolfe, Lemura and Cole[9], concluding that single set programs can be as effective as multiple set programs in short duration training periods (6–16 weeks), but multiple set programs bring about greater strength increases in long duration training (17–40 weeks). The influence of training intensity may also have been masked by the training level at baseline. Since all subjects were untrained, strength development may have occurred regardless of the type of training program performed. A previous meta-analytical study showing that higher intensities are necessary to elicit optimal strength gains, in trained compared to untrained individuals, supports this possibility.[8]

In conclusion, the present meta-analysis suggested that different combinations of training variables (intensity, number of sets per muscle group, weekly training frequency) may be equally effective to improve the strength of healthy sedentary elderly people, at least in the knee extension exercise (quadriceps muscle strengthening). However, the only training variable investigated showing a significant effect-size for strength gain, within a meta-regression including the other variables, was training duration. This finding indicates that the longer the duration of resistance training programs, the greater the strength gains achieved by elderly individuals, regardless of different combinations of training intensity, frequency, or number of sets. These results may be at least in part explained by the relative homogeneity of training variables of the studies included in the present meta-analysis. Further long-term studies with greater ranges of training intensity, frequency, and number of sets are necessary to provide a better understanding of the dose–response relationships between these training variables and strength gains in elderly individuals.

5. Practical application

From a dose–response perspective the results of the present meta-analysis suggest that the duration of a resistance exercise program is the most determinant training variable in producing strength gains in elderly untrained individuals. Even acknowledging the homogeneity concerning many of the training variables included in the present analysis, it appears that, within the range of 8–52 weeks of training duration, variables such as training frequency, number of sets, and intensity are secondary to training duration in producing strength increases. Thus many combinations of strength training intensity and volume may result in strength gains in untrained elderly subjects, provided the training duration is sufficient.

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