Review

Comparing the effects of variable and traditional resistance training on maximal strength and muscle power in healthy adults: A systematic review and meta-analysis

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A B S T R A C T

Objectives: The aim of the study was to aggregate different effects between variable resistance training and traditional resistance training on maximal muscle strength and muscle power and identify potential sex- and training program-related moderator variables.

Design: Meta-analysis.

Methods: A systematic literature search was conducted in SPORTDiscus, PubMed, and Web of Science. Interventions were included if they compared variable resistance training and traditional resistance training in healthy adults and examined the effects on measures of maximal muscle strength and/or muscle power of the lower and/or upper body. A random-effects model was used to calculate weighted and averaged standardized mean differences. Additionally, univariate sub-group analyses were independently computed for sex and training-related moderator variables.

Results: Seventeen studies comprising a total of 491 participants (341 men and 150 women, age 18–37 years) were included in the analyses. In terms of maximal muscle strength, there were no statistically significant differences between variable resistance training and traditional resistance training for the lower (p = 0.46, standardized mean difference = −0.10) or the upper body (p = 0.14, standardized mean difference = −0.17). Additionally, there were no significant training-related differences in muscle power for the lower (p = 0.16, standardized mean difference = 0.21) or upper body (p = 0.81, standardized mean difference = 0.05). Sub-group analyses showed a significant moderator effect for training period and repetitions per set for maximal muscle strength in the lower body (p = 0.03–0.04) with larger strength gains following traditional resistance training when performing more repetitions per set (p = 0.02, standardized mean difference = 0.43). No other significant sub-group effects were found (p = 0.18–0.82).

Conclusions: Our results suggest that variable resistance training and traditional resistance training are equally effective in improving maximal muscle strength and muscle power in healthy adults.

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1. Introduction

Traditionally, the external load in resistance training provided by the equipment (e.g., free weights) is constant throughout the whole range of motion. Noteworthy, when performing resistance training using free weights, the maximal load that can be lifted is often dependent on a small range of motion called the sticking region. Beyond this region, there is a mismatch between the capacity of the muscle to develop force/torque and the force/torque created by the equipment/external load in favor of the muscle. Variable resistance training (VRT) can be defined as resistance training where the resistance/load varies throughout the joint range of motion to match the external load and the changing muscle force potential. VRT has become a popular training modality to ensure that the force capacity of the muscle is sufficiently stimulated throughout the whole joint range of motion.
Importantly, utilizing variable resistance to increase the resistance in one part of the movement, will decrease the load in the other parts of the movement. For example, by attaching elastic bands to the barbell in the squat exercise to increase the load in the upper parts of the movement when the bands get stretched, the load will eventually reduce in the lower parts of the movement when the bands are close to their original shape. Hence, an optimal stimulus throughout the whole joint range of motion can only be achieved in isokinetic devices performing repetitions with maximal effort.

VRT can be induced by different equipment which increases either the external load/force and/or its lever arm. The most popular equipment to gain a variable resistance throughout the range of motion is elastic bands/tubes, chains, and cam-based and pneumatic machines. For example Melo et al. reported that 12 weeks of VRT using elastic tubes induced significantly larger increases in maximal lower body muscle strength (i.e., isometric leg extensions) in physically active participants when compared with traditional resistance training (TRT). The training consisted of 2–4 sets at 6–12-RM performed three times per week. Further, Ataee et al. used chains for the VRT program and found a significantly greater increase in maximal lower body muscle strength (i.e., squat 1-RM) following 4 weeks of VRT versus TRT in male power-trained athletes. The training protocol consisted of three sets of 5 repetitions at 85% of 1-RM performed three times per week. Importantly, in the VRT group, the load was set at 85% of 1-RM in the bottom position of the movement and increased throughout the lift to 100% of 1-RM in the top position. Therefore, larger training-induced gains in 1-RM in the VRT-group could be explained by using a higher training load. Finally, maximal upper body muscle strength and lower/upper body muscle power did not differ between groups following the intervention period.

Interestingly, four meta-analyses have been performed to compare the effects of VRT and TRT on measures of maximal muscle strength in different populations. All the studies included original work that only used elastic bands/tubes to provide the variable resistance. Further, only de Oliveira et al. conducted a meta-analysis on studies including healthy participants only. More precisely, they examined the effects of VRT using elastic bands compared with passive and active control conditions. The active control varied from training programs with bodyblade, aquatic resistance to weight machines. Based on their findings, the authors concluded that VRT programs with elastic bands were more effective than a passive control condition, but not superior to an active control. However, the study did not perform sub-group analyses for sex.

When attaching elastic bands or chains to free weights in order to generate variable resistance, the load increases throughout the range of motion. Therefore, differences in anthropometrics, such as stature, could influence the effectiveness of VRT. Further, VRT might not be optimal for strong individuals or in exercises with large force production and/or movement trajectory distances (e.g., the back squat). Hence, effects of VRT compared with TRT could be affected by participants’ strength level and/or stature. Given the sex-specific differences in strength levels and stature, it could be of interest to examine the effects of VRT on muscle strength in men versus women. Notably, this has not previously been addressed in the literature.

Theoretically, VRT may lead to superior improvements in muscle power and force development compared with TRT. The suggested mechanism is a shorter deceleration phase and reciprocally higher mean power for each repetition with VRT than TRT. For instance, Etzioni et al. showed that, ~52% of the time in the ascending movement was used to decelerate the barbell when performing the bench press exercise with free weights at 80% of 1-RM. Likewise, Newton et al. observed that 40% of the lift was used to decelerate the barbell when lifting bench press with maximal intended velocity (not throwing the barbell) using constant resistance at 45% of 1-RM. Notably, it could be argued that using variable resistance would shorten the deceleration phase and hence increase the barbell velocity throughout the movement. In fact, this was examined by Frost et al. who compared bench pressing with free weights versus pneumatic resistance in resistance-trained men. The results showed that pneumatic resistance led to higher velocity, acceleration, and power output over a spectrum of different loads. Importantly, the study of Frost et al. was a cross-sectional study. Therefore, causality cannot be established and the results may not be extrapolated to long-term effects of VRT. Of note, no previous meta-analysis has compared the effects of VRT and TRT on muscle power.

Despite a growing interest in elastic bands, machines, and chains as tools to provide variable resistance during resistance training, the effect on maximal muscle strength and power, particularly when directly compared with TRT, is not conclusive. To date, there is no systematic review of the literature regarding the effects of VRT versus TRT on maximal muscle strength and muscle power in healthy adults. This knowledge would be valuable for e.g., athletes and coaches, as well as for physically active individuals. Thus, the aim of the present systematic review and meta-analysis was to compare the effects of VRT versus TRT on maximal muscle strength and muscle power of both the lower body and upper body in healthy adults. Further, sub-group analyses were performed to examine whether factors such as sex, training volume, and training intensity were significantly modulating the training-induced effects.

2. Methods

This study was not registered with PROSPERO because systematic reviews in the field of sport science are not accepted with this platform. However, the present systematic review and meta-analysis adhered to the recommended PRISMA guidelines.

2.1. Search strategy

A systematic search was conducted (February 2022) in three separate databases (SportsDiscus, PubMed, and Web of Science). An independent researcher (VA) conducted the search using keywords related to variable resistance, resistance training, and muscle strength (maximal and explosive). With respect to previous meta-analyses, Boolean operators “AND” and “OR” were used to combine different keywords (“variable resistance” OR “elastic band” OR “elastic tube” OR “rubber band” OR “Thera-band” OR “rubber tube” OR “elastic resistance” OR “CAM-based machine” OR “pneumatic machine” OR “pneumatic resistance” OR “chain resistance” OR “chains free weight”) AND (“resistance training” OR “strength training” OR “explosive training” OR “power training” OR “plyometric training” OR “ballistic training”) AND (“maximal strength” OR “repetition maximum” OR “RM” OR “MVC” OR “height” OR “speed” OR “velocity” OR “distance” OR “acceleration” OR “power” OR “power output” OR “force” OR “RFD” OR “rate of force development” OR “horizontal jump” OR “vertical jump” OR “SJ” OR “CMJ” OR “CMJas” OR “squat jump” OR “counter movement jump” OR “maximal strength” OR “explosive strength” OR “repetition maximum” OR “RM” OR “MVC” OR “maximal voluntary contraction”). Review articles published before February 2022 were analyzed (by VA) to identify potential studies eligible to be included in the present analysis. Additionally, the reference lists of all articles fulfilling the inclusion criteria were screened (by TES) for publications not identified by the original search. Only full-text articles written in English or in one of the Scandinavian languages were included. Hence, conference abstracts, unpublished data, or studies not published in peer reviewed journals were excluded.

2.2. Selection criteria

The studies had to meet the following criteria to be included in the analysis: participants: 1) healthy and free from injury; 2) aged ≥18 and ≤60 years of age; 3) intervention: exercise movement resisted by
variable resistance (minimum: 3 weeks of training); 4) reported indicator of maximal muscle strength and/or muscle power; 5) included comparator (similar program using traditional resistance, e.g., free weights, body weight, and traditional machines). Studies comparing only different VRT programs were excluded as none of the groups could serve as a comparator (i.e., conducting TRT).

Several articles were discovered in the initial search (Fig. 1). Many of these were excluded due to the following reasons: 1) did not compare the VRT with a TRT; 2) differences in training related variables (e.g., load and volume) between the interventions; 3) participants were children or adolescents, patients, injured, had diseases, or were elderly (i.e., >60 years of age); 4) did not measure maximal muscle strength or muscle power; 5) the intervention was shorter than three weeks; 6) used machines which controlled the velocity (i.e., isokinetic machines); 7) means and standard deviations were not reported in the articles, and 8) the authors did not respond to our inquires. An overview of the exclusion process is shown in Supplementary material 1.

2.3. Study quality and assessment of risk of bias

The methodological quality of the studies was assessed using the Physical Therapy Evidence Database (PEDro) scale.19 The scale consists of eleven items of which ten items give a point if they are fulfilled. In training interventions, it is problematic to blind the participants, and assessors and therapists/instructors are rarely blinded. Therefore, items 5, 6, and 7 were excluded from the assessment. Hence, the maximal score was seven. The included articles were assessed against the remaining criteria of the scale. Points were only scored if the criteria were clearly met. Based on previous reviews of exercise interventions,20,21 a score of 6–7 was defined as “excellent quality”, 5 as “good quality”, 4 as “moderate quality”, and 0–3 as “poor quality”. Further, a score of ≥6 was defined as having a low risk of bias.19 The articles were divided between two pairs of researchers (pair 1; VA and KTC and pair 2; AHS and NS). If there was a disagreement between the researchers within the pair, a third researcher (VA or AHS, respectively) was included to achieve consensus through discussion.

2.4. Data extraction

A template from a previous systematic review and meta-analysis from our research group was used in the data extraction.22 The data were extracted by one author (VA) while a second author (AHS) double-checked the data. Disagreements were solved through personal communication between the two authors. Each study was coded for the following variables: sex, number of participants, training volume (training period, total number of sessions, number of sets per session, and number of repetitions per set), training intensity, intended training velocity and outcomes (i.e., measures of maximal muscle strength and/or muscle power). Strength/power measures were further divided into maximal muscle strength of the lower body, maximal muscle strength of the upper body, and/or muscle power.

Fig. 1. The effects of variable resistance training (VRT) on maximal muscle strength in the lower body (A) and upper body (B) compared to traditional resistance training (TRT). CI = confidence interval, df = degrees of freedom, IV = inverse variance, Random = random effects model, SE = standard error, SMD = standardized mean difference.
of the upper body, lower body muscle power and upper body muscle power.

According to previous recommendations,23,24 if multiple outcomes were reported in the same study, the outcomes were ranked based on their significance for the fitness component tested (i.e., maximal muscle strength and muscle power) and their resemblance to regular training. The variable with the highest ranking was included in the analysis (Supplementary material 2).

2.5. Statistical analyses

The effects of VRT versus TRT on maximal muscle strength and muscle power were determined by the following equations: pre/post-test between-subject standardized mean differences (SMDs) = (mean1 − mean2) / SDpooled with mean1 being defined as the mean pre/post-test value of the VRT group and mean2 as the mean pre/post-test value of the TRT group, and SDpooled as the pooled standard deviation. The SMD was adjusted for sample size using the factor (1 − (3 / 4N − 9)), with N representing the total sample size.26 Additionally, adjusted weighted mean adjusted SMDs, a random effects model was applied. At least two intervention groups had to be included in order to aggregate SMD values for each outcome.28 The meta-analysis was conducted by OP using Review Manager 5.4.1 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark).

Sub-group analyses were performed (by OP and VA) for sex and training-related programming parameters (training period, total number of sessions, number of sets per session, and number of repetitions per set), training intensity and intended training velocity. More specifically, participants aged 18–60 years were defined as adults. Participants were categorized according to sex (men, women, mixed) based on potential differences in training-related adaptations to resistance training.29 To analyze the potential contributions from training programing moderator variables, parameters were categorized as follows: training period (≤8 weeks, >8 weeks), number of training sessions (16 vs. 16–23 vs. >23 sessions), number of repetitions per set (≤8 vs. >8 vs. >8 sets per session), number of repetitions per set (≤8 vs. >8 vs. >8 sets per session), and intended training velocity (≤60 % of 1-RM). Additional models of training intensity (low intensity (≤60 % of 1-RM) vs. high intensity (>60 % of 1-RM)) and intended training velocity (maximal intended velocity vs. controlled velocity). These analyses were only performed if two or more studies were included in the different sub-groups. Studies which did not report a specific variable were deleted from those sub-group analyses.

A p value of <0.05 indicated a statistically significant effect. SMD values were classified as trivial (SMD < 0.2), small (0.2 ≤ SMD < 0.5), medium (0.5 ≤ SMD < 0.8), and large (SMD ≥ 0.8).30

The level of between-study heterogeneity was assessed using the I² statistic.31 I² outcomes of 25, 50, and 75 % correspond to low, moderate, and high heterogeneity.32 Values above 75 % were rated as heterogeneous. In addition, chi-square statistic (χ²) was included to determine whether the results of the analysis were due to chance. In such cases, low p values, or high χ² statistics, relative to degrees of freedom (df), would be observed.

3. Results

3.1. Study characteristics

The systematic search process is presented in Supplementary material 1. A total number of 718 potential articles were identified in the original search, of which 18 studies met the inclusion criteria. One of these26 was excluded due to being an outlier and the remaining 17 studies were included in the analyses. The included studies comprised of 491 participants (n = 256 in VRT group and n = 235 in TRT group, Table 1). For sub-group analyses according to sex, three studies included only females (n = 113), eleven studies included only males (n = 294) and three studies included both sexes (n = 84).

Regarding the training program variables, three studies did not report the number of sets per session33-35 and two studies did not report the number of repetitions per set.33,35 The mean duration of the training period was 9 weeks (range 3–24) and the mean number of training sessions was 23 (range 7–72) sessions. The mean number of sets per session was 5 (range 3–11) with a mean of 7 repetitions per set (range 3–20). Nine studies used training intensities of ≥60 % of 1-RM,34-41 two studies used training intensities <60 % of 1-RM42,43 while six studies varied the training using intensities both higher and lower than 60 % of 1-RM.33,44-48 Furthermore, in six of the studies the participants were instructed to lift with maximal intended velocity,42-46,48 while in four of the studies the participants were instructed to use a controlled tempo.45,46,47

Regarding the quality of the studies, the median quality score was 7 points (95 % confidence interval 6.5–7.5) on the PEDro scale. Thirteen studies were of excellent quality (score 6 or higher), three of good quality (score 5), while one study was defined as a poor-quality study (score 3) (see Table 1). Accordingly, thirteen studies were defined as studies with low risk of bias (score 6 or above), while four were defined as studies with high risk of bias (score below 6).

3.2. Main analyses

3.2.1. Maximal muscle strength

Eleven of the included studies examined the effects of VRT versus TRT on maximal muscle strength in the lower body. The analysis showed no significant differences between the two training modalities (p = 0.46; I² = 29 %, χ² = 15.55, df = 11, Fig. 1A). For the upper body, eleven studies were included, and this analysis also showed no significant difference between VRT and TRT effects on muscle strength (p = 0.14; I² = 0 %, χ² = 3.96, df = 13, Fig. 1B).

3.2.2. Muscle power

Seven studies were included in the analysis for comparing the effects of VRT versus TRT on lower body muscle power. The results showed no significant differences between the two training modalities (p = 0.16; I² = 10 %, χ² = 6.66, df = 6, Fig. 2A). Regarding upper body muscle power, four studies were included (six interventions) and the analysis revealed no significant differences between VRT and TRT effects on muscle power (p = 0.81; I² = 0 %, χ² = 2.48, df = 5, Fig. 2B).

3.3. Sub-group analyses

3.3.1. Subject-related moderating variables

The influence of sex on VRT/TRT effects on maximal muscle strength and muscle power is displayed in Table 2. Univariate sub-group analyses revealed that sex did not significantly moderate the effects of VRT versus TRT on maximal muscle strength (p > 0.05). Subgroup analyses were not applicable for muscle power.

3.3.2. Training-related programming parameters

Effects of training-related programming parameters for VRT/TRT effects on maximal muscle strength and muscle power are displayed in Table 3. Univariate sub-group analyses revealed that training period (number of weeks) and number of repetitions per set significantly moderated the effects of VRT versus TRT on maximal lower body strength (p = 0.03–0.04). Significant and small-sized effects on maximal lower body strength were observed in favor of TRT for 8–12 repetitions per set (SMD = −0.33, p = 0.03), but not for <8 repetitions per set (p = 0.20). For training period, no significant effects were found for the comparison of VRT versus TRT (p = 0.08–0.25). Further, total number of sessions,
The aim of the present study was to compare the effects of VRT versus TRT on maximal muscle strength and muscle power in the lower and upper body in healthy adults. The main analyses revealed no significant differences between the two training modalities for all outcome variables. Independent sub-group analyses showed that TRT was superior to VRT for increasing maximal strength in the lower body when a greater number of repetitions per set were performed. Overall, the quality of the included studies was acceptable, with 94% of the studies rated as good quality or above (PEDro score of ≥5 points) and 76% of the studies defined as having low risks of bias. Still, differences between the studies regarding programming parameters (training duration, frequency, volume, intensity and intended training velocity) should be kept in mind when interpreting the findings.

### 4. Discussion

The lack of differences between VRT and TRT effects on maximal muscle strength and muscle power is in accordance with previous meta-analyses. Importantly, these meta-analyses have focused on comparing TRT with elastic bands–VRT only, omitting other forms of variable resistance. Furthermore, only one of the previous meta-analyses focused on healthy adults, excluding elderly and/or different groups of patients. De Oliveira et al. included seven interventions measuring muscle strength (MVC) in the lower and upper body in...
addition to the trunk. The authors reported no differences between elastic- and other forms of training \(p = 0.59\), mean difference 0.11\) and, thereby, support our findings. Importantly, no previous review or meta-analysis has examined the effects of VRT on muscle power. In general, when comparing VRT and TRT, muscle power seems less emphasized compared to maximal muscle strength. As a result, the number of interventions examining muscle power is smaller than for maximal muscle strength. Therefore, we were not able to perform all sub-group analyses using muscle power as the outcome.

The rationale for using variable resistance has been maximizing the force output throughout the whole joint range of motion and thereby increasing the training stimuli for the muscles.\(^5\)\(^,\)\(^6\) However, since the load varies throughout the movement, increasing the load in one part of the motion (e.g., by adding elastic bands to a barbell) will reduce the load in the other. For example, when attaching elastic bands to the barbell and floor in the squat exercise, the load will be higher in the upper parts of the movement when the bands are stretched. However, in the lower parts of the movement when the elastic bands are close to their resting length, the total load will be close to equal to the constant load. Therefore, it can be speculated that the two modalities provide relatively equal stimuli, especially if the loads are matched in the middle of the trajectory. Consequently, when summarizing the stimuli over the complete range of motion similar strength gains can be expected.\(^4\)\(^1\) Especially when measuring maximal dynamic strength, as most of the studies included in the present meta-analysis, it is likely that the average stimuli throughout the movement are most important and not the stimuli in the different parts of the range of motion.

An increase in maximal muscle strength can increase muscle power.\(^4\)\(^9\) Hence, the lack of difference in maximal muscle strength gains between the modalities could also explain the lack of differences in the effects on muscle power between VRT and TRT. Measuring power output during dynamic movements is important.\(^5\)\(^0\) However, to optimally obtain these adaptions, the intended velocity during training should be maximal. For example, Behm and Sale\(^5\)\(^1\) compared ballistic isometric and dynamic contractions and demonstrated that the intention to perform ballistic contractions in general was more important.

### Table 2

Subgroup analyses for sex.

| Subgroup | Studies (N) | Participants (N) | Estimated effect size mean (95% CI) | Within group p | Between group p | Witching group \(I^2\) (%) | Effect descriptor |
|----------|-------------|------------------|----------------------------------|----------------|----------------|--------------------------|------------------|
| **Maximal muscle strength** | | | | | | | |
| Lower body | | | | | | | |
| Sex Male | 6 | 160 | −0.12 (−0.62−0.39) | 0.65 | 59 | Trivial |
| Female | 4 | 113 | −0.23 (−0.63−0.17) | 0.26 | 0 | Small |
| Mixed | 2 | 64 | 0.18 (−0.31−0.67) | 0.47 | 0 | Trivial |
| Upper body | | | | | | | |
| Sex Male | 8 | 154 | −0.18 (−0.50−0.15) | 0.30 | 0 | Trivial |
| Female | 4 | 103 | −0.31 (−0.74−0.12) | 0.16 | 0 | Small |
| Mixed | 3 | 64 | 0.00 (−0.49−0.49) | 0.99 | 0 | Trivial |
| **Muscle power** | | | | | | | |
| Lower and upper body | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

CI = confidence interval, N = number, RM = repetition maximum, N/A = not applicable.
### Table 3

Subgroup analyses, training-related moderating variables.

| Sub-group | Studies (N) | Participants (N) | Estimated effect size mean (95% CI) | Within group p | Between group p | Witching group | Effect descriptor |
|-----------|-------------|------------------|------------------------------------|----------------|-----------------|----------------|------------------|
| **Maximal muscle strength** | | | | | | | |
| **Lower body** | | | | | | | |
| Training period | 8 weeks | 4 | 125 | 0.21 (-0.15–0.56) | 0.25 | 0.04 | Small |
| | ≥8 weeks | 8 | 212 | -0.28 (-0.60–0.03) | 0.08 | 0.18 | Small |
| Total number of sessions | 16 sessions | 3 | 81 | 0.21 (-0.33–0.74) | 0.45 | 0.27 | Small |
| | 16–23 sessions | 3 | 97 | 0.07 (-0.33–0.47) | 0.73 | 0 | Trivial |
| | >23 sessions | 6 | 159 | -0.36 (-0.77–0.05) | 0.08 | 0.33 | Small |
| Number of sets per session | ≤4 sets | 5 | 117 | -0.05 (-0.67–0.58) | 0.88 | 0.61 | Trivial |
| | >5–8 sets | 4 | 137 | 0.03 (-0.31–0.37) | 0.85 | 0 | Trivial |
| | >8 sets | 1 | N/A | N/A | N/A | N/A | N/A |
| Number of repetitions per set | ≤8 repetitions | 5 | 157 | 0.20 (-0.11–0.52) | 0.20 | 0.03 | Small |
| | >8–12 repetitions | 6 | 160 | -0.43 (-0.78–0.07) | 0.02 | 0 | Trivial |
| | >12 repetitions | 0 | N/A | N/A | N/A | N/A | N/A |
| Training intensity | ≤60% of 1-RM | 0 | N/A | N/A | N/A | N/A | N/A |
| | ≥60% of 1-RM | 9 | 240 | -0.18 (-0.54–0.19) | 0.35 | 0.45 | Small |
| | Mixed | 3 | 97 | 0.07 (-0.33–0.47) | 0.74 | 0 | Trivial |
| Intended training velocity | Maximal | 2 | 57 | 0.07 (-0.44–0.59) | 0.78 | 0.78 | Trivial |
| | Controlled | 4 | 90 | -0.07 (-0.89–0.76) | 0.87 | 0 | Trivial |
| **Upper body** | | | | | | | |
| Training period | 8 weeks | 5 | 116 | 0.00 (-0.38–0.37) | 0.98 | 0.25 | Small |
| | ≥8 weeks | 9 | 205 | -0.28 (-0.57–0.01) | 0.06 | 0 | Small |
| Total number of sessions | 16 sessions | 4 | 72 | -0.07 (-0.55–0.41) | 0.78 | 0.25 | Small |
| | 16–23 sessions | 4 | 109 | 0.01 (-0.36–0.39) | 0.94 | 0 | Trivial |
| | >23 sessions | 6 | 140 | -0.41 (-0.78–0.05) | 0.03 | 0 | Small |
| Number of sets per session | ≤4 sets | 2 | 44 | 0.00 (-0.59–0.59) | 1.00 | 0.71 | Trivial |
| | >5–8 sets | 8 | 174 | -0.16 (-0.46–0.15) | 0.32 | 0 | Trivial |
| | >8 sets | 1 | N/A | N/A | N/A | N/A | N/A |
| Number of repetitions per set | ≤8 repetitions | 8 | 166 | -0.07 (-0.38–0.25) | 0.68 | 0.44 | Small |
| | >8–12 repetitions | 4 | 107 | -0.40 (-0.83–0.02) | 0.06 | 0 | Small |
| | >12 repetitions | 0 | N/A | N/A | N/A | N/A | N/A |
| Training intensity | ≤60% of 1-RM | 2 | 36 | -0.28 (-0.98–0.42) | 0.43 | 0.82 | Small |
| | ≥60% of 1-RM | 8 | 207 | -0.20 (-0.49–0.08) | 0.17 | 0 | Small |
| | Mixed | 4 | 78 | -0.05 (-0.52–0.41) | 0.82 | 0 | Trivial |
| Intended training velocity | Maximal | 5 | 86 | -0.15 (-0.60–0.30) | 0.53 | 0.94 | Small |
| | Controlled | 3 | 60 | -0.27 (-0.79–0.24) | 0.30 | 0 | Small |
| **Muscle power** | | | | | | | |
| **Lower body** | | | | | | | |
| Training period | 8 weeks | 4 | 125 | 0.12 (-0.24–0.47) | 0.52 | 0.48 | Small |
| | ≥8 weeks | 3 | 82 | 0.43 (-0.35–1.20) | 0.28 | 0.76 | Small |
| Total number of sessions | 16 sessions | 3 | 81 | 0.14 (-0.3–0.58) | 0.54 | 0 | Trivial |
| | 16–23 sessions | 3 | 94 | 0.27 (-0.46–1.00) | 0.47 | 0.65 | Small |
| | >23 sessions | 1 | N/A | N/A | N/A | 0.17 | N/A |
| Number of sets per session | ≤4 sets | 4 | 93 | 0.45 (-0.03–0.93) | 0.07 | 21 | Small |
| | >5–8 sets | 3 | 114 | 0.03 (-0.34–0.40) | 0.88 | 0 | Trivial |
| | >8 sets | 0 | N/A | N/A | N/A | N/A | N/A |
| Number of repetitions per set | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Training intensity | ≤60% of 1-RM | 1 | N/A | N/A | N/A | N/A | N/A |
| | ≥60% of 1-RM | 3 | 90 | 0.01 (-0.41–0.42) | 0.98 | 0.46 | Small |
| | Mixed | 3 | 97 | 0.22 (-0.18–0.63) | 0.27 | 0 | Small |
| Intended training velocity | Maximal | 3 | 77 | 0.50 (-0.14–1.14) | 0.12 | 0.20 | Small |
| | Controlled | 2 | 46 | -0.07 (-0.66–0.52) | 0.82 | 0 | Trivial |
| **Upper body** | | | | | | | |
| Training period | 8 weeks | 3 | 52 | 0.25 (-0.33–0.83) | 0.40 | 0.34 | Small |
| | ≥8 weeks | 3 | 50 | -0.15 (-0.73–0.43) | 0.61 | 0 | Trivial |
than the specificity of the movement (isometric vs. dynamic contrac-
tions). This fact may be even more important when comparing VRT
and TRT since it has been shown that VRT has a shorter deceleration
time compared with TRT15 and therefore has a potential for increased
displacements). This fact may be even more important when comparing VRT
sen et al.,36 the participants were instructed to perform each repetition
This may have affected the results. For example, in the study of Ander-
power used either a controlled velocity (i.e., the participants were not
allowed to lift as fast as they could) or not reported the velocity at all.
The only statistical difference between different sub-groups was ob-
erved for number of repetitions per set for maximal lower body muscle
strength. Importantly, the observed effects were trivial to small, and no other statistical differences were reached.
The finding might be a result of training specificity since maximal muscle
strength was examined using similar approaches as during TRT (e.g., constant resistance with free weights) in all of the included interventions.32 A higher training volume gives more time to practice, which may favor the training modality most similar to the testing condi-
tion. Consequently, it would be interesting to examine if the results will
favor VRT if the testing condition of maximal muscle strength complied
more closely with VRT exercises, e.g., 1-RM using variable resistance.
Of note, there were no sex-specific differences for the effects of VRT
and TRT on maximal muscle strength or muscle power. Previous re-
search indicated that VRT may not be optimal when a great amount of
force is required to optimally stimulate the muscles.13 In general, men
appear to be stronger for most of the muscle groups by 1.5 to 2 times
when compared with women.23 Therefore, it could be speculated that
VRT effects may be lower in men compared with women. However
and importantly, in the study of Iversen et al.,13 VRT consisted of vari-
able resistance only (i.e., only elastic bands) without combined constant
resistance, whereas most of the included studies in this meta-analysis
used combined constant and variable resistance. Consequently, in the
studies combining variable and constant resistance, it can be argued
that the proportion of the variable resistance is rather low (i.e., the
amount of constant resistance is significant in both VRT and TRT). This
would produce less difference between VRT and TRT stimuli which
could explain the similar training effects in the included studies.
For the remaining sub-group analyses, there were also no significant
differences between the groups. This supports the main findings that
the effects of VRT and TRT on maximal muscle strength and muscle power
appear to be very similar and that these effects are irrespective of individual
or training related moderator variables. Of importance, the lack of using
maximal intended velocity in several of the studies may have affected
the muscle power-findings also in the sub-group analyses.

4.3. Limitations

There are some limitations that must be acknowledged. TRT was in-
cluded as a comparator to VRT, while no passive control group was in-
cluded. Importantly, the effectiveness of VRT has already been
demonstrated.10 Therefore, the aim of this study was to compare the effi-
cacy of VRT versus TRT. Furthermore, variable resistance is a general term
which encompasses a large heterogeneity of approaches. For example, the
total resistance may consist of variable resistance only (e.g., using only
elastic bands)54 or of a combination of constant and variable resistance
(e.g., combining free weights and elastic bands).36 In most of the studies
combining variable and constant resistance, the amount of the load com-
ing from variable resistance was not controlled or reported. Accordingly,
differences in the methodology between the included studies may under-
mine the accuracy of the inter-study comparison and contributed to some
of the heterogeneity in the present analysis (I² = 0%–79%). Importantly,
I² exceeded 75% in only one of the analyses, which is rated as
considerable.32 Finally, dividing the continuous data into dichotomous
variables for the subgroup analyses may lead to residual confounding
and reduce statistical power.55 For example, treating volume and load
as independent factors may be problematic when comparing VRT and
TRT. More precisely, the resistance in VRT varies throughout the move-
ment. If the resistances during VRT and TRT are matched for one specific
position of the movement, the total load will be higher (if matched in the
bottom position) or lower (if matched in the top position) compared with
TRT. This would also affect the total volume lifted. To account for this, it
seems reasonable to combine the two factors in one measure, e.g., volume load (load × repetitions).

5. Conclusion

This is the first meta-analysis to compare the effects of VRT versus
TRT on maximal muscle strength and muscle power in healthy adult in-
dividuals. Our results suggest that similar strength and power gains can
be expected from the two training modalities. Practical implications. Our
findings suggesting similar effects of VRT and TRT allows coaches,
recreational trained individuals, and others engaged in resistance training to consider VRT as an alternative to TRT which can be included into long-term periodized resistance training. Further, selection of one modality should rather be based on preference than effects. VRT may have some practical advantages, for example is elastic bands being more portable than TRT. Consequently, VRT (elastic bands) may be a good alternative when travelling.

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CRediT authorship contribution statement
VA conceived the original idea and wrote the manuscript, conducted the search strategy, scored the included papers, and extracted the data from the included studies. OP analyzed the data, made the figures, and provided critical feedback, comments and input. NS scored the included papers and provided critical feedback and input. KTC scored included papers and provided critical feedback, comments and input. TES screened for potential papers, provided critical feedback and commented on the manuscript. GP, RT and HP provided comments, and input. AHS supervised feedback, and commented on the manuscript. GP, RT and HP provided critical feedback and input. All authors read and approved the final manuscript.

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Declaration of interest statement
The authors declare no conflict of interest.

Confirmation of ethical compliance
The study was conducted in accordance with the established ethical standards and the national legislation.

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