REVIEW ARTICLE

Revisiting the relationship between resistance training dose and strength gains: what is the real role of volume?

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Resistance training (RT) volume is considered a critical variable to induce neuromuscular adaptations (i.e., increased muscular strength). However, emerging findings have allowed us to revisit the role of volume in strength gains.
Objectives: In the present study, we seek to present these emerging findings to discuss the role of RT volume in one-repetition maximum (1RM), isometric, and isokinetic strength gains. In addition, we propose alternative ways to test whether or not volume plays a determining role in strength adaptation.
Design & methods: We reviewed the literature on RT volume and strength. In addition, we examined the RT literature to provide alternative ways to investigate the effect of volume on changes in strength.
Results/conclusions: From the recent findings, we argue that an increase in strength can be achieved through a refined interaction between skill enhancement, regular use of high loads, and neuromuscular fatigue management; these points can be obtained from different RT volumes. From an inquiring point of view, we suggest that future investigations that aim to verify the effects of volume on muscular strength may consider the inclusion of high load sessions (80-100% of 1RM), periodically (e.g., every three or four weeks), in both low and high-volume groups, as well as considering the inclusion of different strength measures (e.g., isokinetic and isometric). We believe that this will help to clarify the nature of the relationship between RT volume and strength adaptations.
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Key words: neuromuscular adaptations ■ resistance training ■ isometric strength ■ isokinetic strength

INTRODUCTION

Muscular strength is recognized as one of the most important physical attributes of overall health status and athletic performance.[1-3] The effectiveness of resistance training (RT) to improve muscular strength is well-established.[1,4,5] In order to increase muscular strength gains through RT, strength coaches can manipulate several training parameters (i.e., rest interval, repetition tempo, intensity, and volume).[1] Among these RT prescription parameters, training intensity (i.e., % of one-repetition maximum [1RM]) plays a key role in long-term muscular strength gains. This premise relies on the so-called "specific adaptations to imposed demands" principle.[6,7] Furthermore, it has been suggested that RT volume is another essential prescription parameter purported to improve muscular strength.[1,8,9]

The most common parameters used to quantify RT volume are the number of sets performed and/or the volume-load (load lifted multiplied by the number of repetitions).[10-12] In this context, different studies—including systematic reviews with meta-analysis—have suggested a positive dose-response relationship between training volume and the increase in muscular strength.[8,9] For example, it was demonstrated that

performing higher RT volume (> 5 sets/week per exercise) was more effective than low volume (≤ 5 sets/week per exercise) to increase 1RM strength.[8] However, in that study, the dose-response relationship was not confirmed.[13] Furthermore, emerging findings did not observe differences in 1RM gains between low, moderate, and high RT volume.[14-16]

Additionally, it should be acknowledged that the method used to assess muscular strength may provide controversial findings concerning the effects of RT volume on strength gains. Although the 1RM test is often used to measure muscular strength, it has been suggested that assessing differences between pre- to post-training interventions on 1RM assessment might not represent the broad spectrum of muscular strength adaptations attained through RT.[6,17] Thus, the assessment of muscular strength in different pattern (e.g., isometric and isokinetic) has been encouraged.[6,17]

Previous studies on RT volume raised some questions about its role and muscular strength adaptations when non-specific muscular strength tests were performed.[18-20] Therefore, the aims of the present study were: a) critically review the role of RT volume on muscular strength adaptations (1RM, isokinetic, and isometric measures), in light of the evidence support-

ing the dose-response relationship and emerging findings, and b) to provide alternative ways to investigate the nature of the relationship between volume and strength adaptations in future studies. The findings might assist strength coaches in designing optimal RT programs aimed at developing long-term muscular strength.

Support for the dose-response relationship between volume and 1RM strength gains

Several meta-analyses indicate that, to some extent, the higher the RT volume, the more pronounced the strength gains.[8,9,13] For example, in the Krieger[9] meta-analytic study, the authors concluded that multiple sets promote greater muscular strength improvements than single-set RT programs. More precisely, Krieger[9] showed that for muscular strength gains, two and three sets per exercise were more effective than one set. However, four to six sets did not provide additional gains compared to lower volumes (≤ 3 sets). Furthermore, it seems that a greater number of sets does not necessarily translate into higher neural adaptations[13,19,21]. These findings suggest that the enhancement in muscular strength is related to learning effects (i.e., skill improvement) due to repeated exposure to the specific resistance exercise.[22,23]. Furthermore, when more than three sets are performed, it seems that these neural learning adaptation effects might be attenuated (this hypothesis is detailed in section 3), raising some questions about their dose-response relationship.

In another meta-analysis, Borde et al.[13] investigated the effects of RT volume on strength when considering only studies with older adults. In that study, no dose-response relationship was observed between RT volume and strength gains when performing meta-regression analyses. Likewise, Peterson et al.[24] did not identify any significant relationships between RT volume and muscular strength gains in older adults. Recently, Ralston et al.[8] analyzed the effects of the weekly-sets volume on 1RM strength gains in adult men and found that performing more than five sets per week (moderate volume) induced significant, although trivial (effect size = 0.18), additional gains compared to low RT volume. In that meta-analysis, beyond the trivial advantage of performing five or more sets per week, the authors draw attention to the possibility that the greater effectiveness of moderate-high volume protocols may not have been solely related to exercise volume but could have been driven by the greater exposure to exercise with characteristics similar to the 1RM test. This statement is supported by the lack of difference in strength gains between different RT sets-volumes, when strength was measured in a non-specific way (e.g., isometric and isokinetic strength).[19,20,25] Furthermore, emerging findings show similar gains in muscular strength in response to low, moderate, and high-volume protocols.[14-16,26]

Emerging findings and argumentation

The number of studies investigating RT volume in muscular adaptations has been growing in several populations and in various training ages.[27,28] These studies enable strength and conditioning scientists and coaches to improve their under-standing of the dose-response relationship, or the lack of, between RT volume and muscular strength adaptations. Recently, it has been indicated that strength gains may not differ amongst RT volumes (e.g., one vs. three vs. five sets), suggesting that optimal strength increases could occur in alternative ways rather than through the increase in RT volume.[15,29] Previous studies on RT volume in older women[14], resistance-trained men[16], and powerlifters[15] showed similar results amongst different RT volumes. Overall, this current body of knowledge might be used to guide strength coaches to manage their decisions from an evidence-based approach to improve the effectiveness of their RT prescription. Given the scenario described above, we detail and discuss the results of studies investigating the effect of volume (number of sets and volume-load) on strength adaptations.

1. Number of sets and 1RM strength

The number of sets is the most common parameter to quantify RT volume.[28] In this context, some studies have observed similar 1RM strength gains with low, moderate, and high set volumes (e.g., 1, 3, and 5 sets, respectively).[14-16,26] For instance, similar improvements in muscular strength were found following 12-weeks of RT in older women performing one (upper-limb = 37.1%, lower-limb = 16.3%) or three sets (upper-limb = 27.4%, lower-limb = 21.7%) per exercise (volume-load = 40.9 vs. 105.8 ton, respectively).[14] Resistance-trained adults, a population that would theoretically benefit more from a larger training volume, demonstrated similar muscular strength gains when training with one (upper-limb = 9.3%, lower-limb = 18.9%), three (upper-limb = 5.7%, lower-limb = 13.6%), and five sets (upper-limb = 6.8%, lower-limb = 19.6%).[16] More recently, Androulakis-Korakakis et al.[15] demonstrated, in a pilot study, that performing single-set, single-rep, RPE-based training may be an effective strategy for some beginner-intermediate powerlifters to increase maximum strength similarly to high-volume periodized training.[15] Therefore, similar muscular strength gains in different populations and training ages suggest that the RT volume may not determine the magnitude of strength adaptations.

In scientific investigations, maximum muscular strength is usually measured through the 1RM test. An increasing number of studies point out that, perhaps, improvements in 1RM test performance resemble a skill, which is enhanced when the training characteristics, such as muscle action, velocity, range of motion, and external load (%RM) are similar to those used in the test.[22,23,25] For example, Dankel et al.[23] evaluated the effect of 21 consecutive sessions of the 1RM familiarization test compared to traditional training on strength gains, through an intra-subject design study. The results showed that the arm that performed only the 1RM test in all sessions increased the load lifted similarly when compared to the arm that performed three sets at 70% 1RM throughout the experiment (1.9 kg vs. 2.2 kg, respectively). Likewise, Mattocks et al.[25] observed that the 1RM test practice promoted similar strength gains to a multiple sets scheme of 8-12RM.

Previous studies using low RT volume but repeated expo-

sure to the 1RM test during RT programs support the hypothesis of a learning effect on 1RM gains rather than a dose-response relationship between them.[5,30,31] In a comprehensive study by Bickel et al.[31], young and older adults performed an RT program divided into two phases with the following characteristics: in the first phase, the subjects trained three times a week, over 16 weeks. The sessions were composed of three sets in the knee extension, leg press, and squat; in the second phase, which extended from weeks 17 to 48, the subjects were randomly divided into three groups: (1) detraining, reducing the volume to (2) one-third and (3) one-ninth of the volume performed in the first phase. The 1RM test was performed for the knee extension every four weeks for 32 weeks, and after this, in weeks 40 and 48. Interestingly, after the end of phase two, the 1RM performance in the groups that reduced to one-third and one-ninth of the initial volume was significantly greater than the baseline and week 16; suggesting that the regular practice of exercise with characteristics similar or identical to the 1RM test seems to be sufficient to increase performance, even when training with low RT volume (i.e., 1/3 or 1/9 of initial RT volume). Together, these findings indicate that increased 1RM strength can be better explained by skill improvement—through increased neural drive of agonist muscles, adaptations of motor neuron properties, and reduced co-activation of antagonists.[32,33] In this regard, high loads ($\geq$ 70% 1RM) and not greater RT volume[7,34,35] might optimize strength adaptations.

2. Volume-load and 1RM strength

The volume-load, obtained by multiplying the number of repetitions and load, is another way to quantify the RT volume.[1] Concerning this metric and its effects on the increase in strength, the dose-response relationship appears to be even more trivial. First, the volume-load is influenced by the relative intensity (i.e., %RM). For example, a high number of repetitions with low-load ($\leq$ 60% 1RM) can result in a high volume-load. However, it generally induces similar or smaller increases in strength compared to other protocols, including a low number of repetitions and high-load (> 60% 1RM), resulting in a lower volume-load.[28,36] Second, even in studies with equalized relative intensity, greater volume-load—due to a greater number of repetitions—does not induce additional muscle strength gains, regardless of the sample characteristics (i.e., physically active, strength-trained, or athlete subjects).[37-39]

An increasing body of knowledge using the velocity-based training (VBT) approach (i.e., including different velocity loss thresholds to determine set volume) has accumulated evidence to support the statement that RT volume-load does not play a determinant role in muscular strength adaptation. For instance, Pareja-Blanco et al.[40] observed that performing twice as many repetitions (~143.6 vs. ~305.3) —and consequently higher volume-load—with equated relative intensity (70-85% 1RM) did not promote additional gains in lower limb maximum strength (1RM). In another study, Dorrell et al.[39] compared the effects of the prescription using the VBT paradigm versus the traditional percentage-based approach. The

VBT group interrupted the sets when the subjects presented a 20% reduction in mean concentric velocity, while the percentage-based group performed the previously determined number of repetitions. After six weeks of RT, the VBT group demonstrated more significant gains in maximum strength in the bench press, and only this group increased maximum strength in the deadlift exercise. Interestingly, the VBT group significantly performed a lower total volume-load than the percentage-based group.[39] Similarly, Sánchez-Moreno et al.[41] reported that interrupting the pull-up exercise when reaching a 25% reduction (~50% in the number of maximum repetitions) in velocity increased the maximum strength, while performing the exercise up to a 50% (~85% in the number of maximum repetitions) velocity reduction did not promote significant increases. Together, these studies suggest that maximum dynamic strength development is obtained regardless of the volume-load. Moreover, this adaptation, at least in part, might be associated with the management of fatigue.[42]

3. If the volume is not a determinant, how can we explain previous dose-response findings?

Overall, these emerging findings suggest that high-volume does not seem to be *necessary* to promote greater gains in maximum strength. However, there is still a question to be answered: What would explain the results of previous studies—including meta-analyses—which suggest a dose-response relationship? A plausible explanation for the advantage observed for high-volume groups may be the motor task improvement—that occurs, in part, through neural adaptations such as increased neural drive to the agonists and reduced presynaptic inhibition.[32-34] Participants who perform high-volume are more frequently exposed to exercise than the low RT volume group, which could contribute, in part, to improving performance in the strength test at the end of the study. This hypothesis corroborates a recent review by Spitz et al.[22]. In this review, the authors included studies that compared high and low loads to illustrate the effect of exercise on improving performance in the strength test. Spitz et al.[22] observed that participants increased maximum strength when frequently exposed to the practice of the 1RM test (e.g., every four weeks), even when training with low loads ($\leq$ 40% 1RM).

Returning to the RT volume, if the relative intensity (%RM) remains the same, the subjects who perform more sets are exposed more often to the practice of a particular exercise, and this difference can favor improvement in performance in the 1RM test. On the other hand, if the subjects in the low RT volume group are exposed periodically to the execution of a motor task with characteristics similar to the 1RM test—with similar muscle action, velocity, range of motion, and %RM—, it is possible to assume that the differences between low and high volume in improving the 1RM are mitigated. However, this hypothesis warrants further investigation. If confirmed, this assumption opens up other research questions, such as; is there an optimal RT frequency of sets and sessions with similar characteristics to the 1RM test? What is the optimal dose of high load sets to promote optimal

1RM strength? Despite lacking direct evidence, this hypothesis (i.e., effects of the number of times/sets that individuals are exposed to exercise) is supported indirectly by the similarity between the effects of low and high RT volume on strength changes when strength is measured in a non-specific way, as discussed in the next section.

The role of volume on isometric and isokinetic strength

Importantly, we need to describe what pattern of muscular strength we are evaluating since this phenomenon can be analyzed differently.[17,43] Specifically, muscular strength, defined as the muscle ability to generate force against external resistance, is a multifactorial ability measured using several methods (e.g., voluntary, isotonic, isometric). The development of this construct depends on the combination of different morphological (e.g., muscle architecture) and neural factors (e.g., increased central motor drive, elevated motoneuron excitability, reduced presynaptic inhibition, and adaptations in properties of the motor neurons).[32,33,44] Concerning the influence of RT volume on muscular strength, the divergence between findings in the scientific literature has intensified discussions about the existence of a relationship between RT volume and muscular strength gains measured in a non-specific way.[19,25,45-47]

Investigations conducted by different research groups have pointed out that the volume has a low impact on the magnitude of isometric and isokinetic strength changes.[19,25,47] For example, Radaelli et al.[19] investigated the effect of RT volume manipulation (one vs. three sets) in older women and observed a higher increase in the 1RM performance of the knee extension for the three set group compared to the one set group after 20-weeks of RT; however, there were no differences in isometric strength gains between groups. Similarly, Mitchell et al.[47], when comparing one set at 80% 1RM vs. three sets at 80% 1RM vs. three sets at 30% 1RM, verified an effect for training intensity but not for volume in the 1RM test. Moreover, when evaluating different strength patterns, such as the rate of force development, maximal voluntary contraction force, and knee extension maximal power output, the magnitude of the adaptations was smaller for low intensities, and no difference was observed between different RT volumes.

In another investigation, Radaelli et al.[18] observed that the strength adaptations were similar in both the 1RM test and isometric strength when training with one and three sets in older women. In a more comprehensive investigation, the researchers evaluated, in addition to isotonic strength (i.e., 1RM), the isometric and isokinetic torque of adult men.[25] The experiment consisted of one group that performed the 1RM test and another group that performed four sets (~8RM-12RM) for eight weeks.[25] Interestingly, both groups presented similar increases in 1RM, isometric, and isokinetic torque.[25] Taken together, these findings illustrate that when measured in a non-specific way, the possible advantages in strength gains from performing a greater volume are attenuated or absent; nonetheless, these findings are not universal.[46]

The lack of differences in non-specific strength gains when performing different RT volumes might be related to similar neural adaptations in response to low and high RT volume.[19,21,25] For example, Marshall et al.[21] did not observe differences in quadriceps electromyography activation and isometric strength between one, four, and eight sets in resistance-trained males after 10-weeks of RT. Likewise, Radaelli et al.[19] did not observe differences in the muscular activation of the quadriceps and biceps brachii and isometric strength in response to 20-weeks of one and three sets in older women. This indicates that the similarity of isometric and isokinetic strength adaptations between low and high RT volume may, in part, be due to similarities in neural adaptations in the agonist muscles, at least concerning peripheral adjustments (e.g., surface electromyography); despite this, we have not ruled out possible effects of volume on changes in the motor cortex and supraspinal levels.

Additionally, the greater repeated exposure might improve the skill/performance in the 1RM test through adjustments at the central and peripheral levels specific to the pattern of muscle action, repetition tempo, range of motion, and muscle groups.[1,48] This is important because there is a dissimilarity of neural activity patterns between isotonic, isokinetic, and isometric tasks—such as unique spatial and spectro-temporal electrocortical signatures, recruitment of the components of the muscular groups[48-51]. Together with the limited dose-response relationship between RT volume and the magnitude of neural adaptations, this aspect might partially explain why higher isotonic RT volumes do not culminate in greater non-specific strength adaptations (e.g., isometric and isokinetic).

PERSPECTIVES

From the arguments presented above, we propose that if the goal is to increase maximum strength (i.e., 1RM), this target can be achieved through a refined interaction between improved skill, periodic use of high load, and management of neuromuscular fatigue. In practical terms, these three points can be achieved with low to moderate RT volume programs, as long as the exercise is performed with high effort. Importantly, we do not dismiss the RT volume as playing a significant role in strength adaptations; although this role appears to be less than previously thought, higher RT volume remains an effective alternative to optimize strength gains in subjects who cannot tolerate training with high loads. Furthermore, concerning the different measurement patterns of strength (e.g., isokinetic and isometric), the RT volume does not seem to affect the magnitude of the changes.

From an inquiring point of view, we suggest that future investigations aim to verify the effects of volume on muscular strength increase, considering the inclusion of high load sessions (80-100% of 1RM), periodically (e.g., every three or four weeks), in both low and high-volume groups. This will enable verification of whether higher volume has additional effects on the 1RM strength gains. In addition, we emphasize the need for studies that apply different training volumes and evaluate different patterns of muscular strength to capture a better image of kinetic adaptations in response to different doses of RT. Otherwise, the extrapolations are restricted, in

the case of 1RM, to a single strength measure. Thus, investigations that evaluate different parts of the strength spectrum will have an even greater appeal since the answers to the question "does high volume correspond to greater strength adaptations?" are of interest to diverse populations, regardless of chronological age or training status.

Compliance with Ethical Standards

Conflicts of interest   Witalo Kassiano, Bruna Daniella de Vasconcelos Costa, Dalton de Lima-Júnior, Petrus Gantois, Fabiano de Souza Fonseca, and Leonardo de Sousa Fortes declare that they have no conflicts of interest that are relevant to the content of this article.

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