

EFFECTS OF HIGH-VOLUME AND LOW-VOLUME RESISTANCE TRAINING ON MUSCLE HYPERTROPHY AND STRENGTH

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Abstract

Background and Study Aim: Strength training is a fundamental aspect of physical performance and muscle hypertrophy. Strength gains largely depend on the volume of work done in training. The HVRT vs. LVRT debate rages on. The purpose of the current investigation was to compare the hypertrophic adaptations and effects of HVRT and LVRT on muscular strength-trained athletes, while addressing potential molecular mechanisms (i.e., mTOR signaling).

Material and Methods: A randomized controlled trial was conducted with 40 trained individuals (20 males, 20 females; age 20–30) randomly assigned to either an HVRT (5 sets per exercise) or LVRT (3 sets per exercise) group. Both groups underwent 8 weeks of resistance training, with three sessions per week. Muscle hypertrophy was determined by dual-energy X-ray absorptiometry (DXA),

and strength gains were evaluated with one-repetition maximum (1RM) tests. Plasma mTOR signaling and myostatin levels were assayed.

Results: Both HVRT and LVRT groups had significant increases in muscle hypertrophy and strength ($p < 0.05$) with the HVRT group exhibiting larger changes in lean mass (4.2 ± 1.1 kg) increase compared to LVRT, as well as a greater magnitude of change on strength for squat (18.5 ± 4.3 kg), bench press (12.1 ± 3.8 kg) deadlift strength (14.3 ± 4.5). At molecular level, mTOR signaling was more activated and myostatin levels lower in HVRT than IHR group ($p < 0.05$).

Conclusion: HVRT is more effective than LVRT for muscle hypertrophy and strength in trained subjects. These early findings indicate that large training volumes are most effective in inducing muscular adaptations, likely via increased mTOR activity and decreased myostatin.

Introduction

Muscle hypertrophy and strength gain are innermost features of performance, rehabilitation, and health status improvement (Schoenfeld, 2019). Strength training is integral in improving muscular strength, endurance and mass especially in athletes and persons engaged in strength sports. The expanding literature base proposes that varying resistance training volumes (VOL) result in different responses on muscle growth and strength, respectively (Schoenfeld et al., 2017). Muscle hypertrophy has been demonstrated to be a complex process, with mechanical tension, metabolic stress and muscle damage representing the main stimuli responsible for muscle growth (Schoenfeld 2010).

The first and most established mechanism for muscle hypertrophy is mechanical tension, which occurs when muscle fibers are subjected to load (Schoenfeld et al., 2017). Higher-volume resistance training is believed to provide more mechanical tension across time (more reps/sets), which results in greater muscle fiber recruitment and subsequently hypertrophic responses. This prolonged time under tension is thought to be vital for stimulating muscle growth, as more and more fibers are called upon to lift heavier weights.

Metabolic stress, or the buildup of metabolites such as lactate, hydrogen ions (i.e., H⁺), and inorganic phosphate during resistance training also hold an important place in muscle hypertrophy (Schoenfeld 2013). High volumes of work have been shown to produce greater metabolic demand than lower volumes owing to the difference in repetitions and sets performed (Schoenfeld et al., 2020). This metabolic stress leads to increased cellular swelling, which can activate hypertrophic signaling pathways such as the mechanistic target of rapamycin (mTOR) and further stimulate protein synthesis (Schoenfeld et al., 2017).

Muscle damage, induced by eccentric contractions and repeated mechanical tension, can also contribute to hypertrophy (Kirkland et al., 2017). High volume of resistance training, in which more time under tension and muscle fiber recruitment is performed, causes more microtrauma to the muscle fibers compared with low volume of training (Schoenfeld, 2010). Such damage appears to provoke a repair process that ultimately results in muscle growth over time.

Neurological factors, such as motor unit recruitment and firing rates, also play a significant role in strength development (Grgic et al., 2020). High-volume training is traditionally more associated with hypertrophy, however low-volume resistance training performed at high intensity (i.e heavy loads) has also been shown to increase neural adaptations such as better motor unit synchronization and firing which are key components of strength development. This is particularly relevant for trained individuals whose strength adaptations are often influenced by neural factors rather than only muscle growth (Kraemer & Ratamess, 2004).

Mitchell et al. (2018) stated that greater muscle hypertrophy associated with high- (3min inter-set rest periods vs 1min rest periods for low volume training), but not low-volume, training based on changes in muscle fiber cross-sectional area and lean mass; they concluded that while both intensities of resistance training can increase strength, a superiority for the hypertrophic benefits of higher volumes was observed due to superior metabolic stress leading to greater muscle fiber recruitment. Similarly, in a study by Bickel et al. (2018), the authors demonstrated that the increased total volume of sets and repetitions in HVRT led to higher activation of mTOR, a central player in the muscle protein synthesis pathway, which was associated with greater hypertrophy. This finding is consistent with the hypothesis that strength gains are more heavily influenced by intensity and neural adaptations than by the volume of training (Kraemer & Ratamess, 2004).

Although the impact of training volume on hypertrophy and strength have been well documented, there are still gaps in the literature, especially with trained subjects. Much of the literature has investigated untrained or recreationally active individuals, in which training-induced changes are often time greater. However, athletes with prior training experience may have reached a training plateau, making the effects of training volume more subtle and less predictable. As a result, the optimal volume for hypertrophy and strength may differ between novice and advanced trainees (Grgic et al., 2020).

Additionally, the molecular mechanisms behind volume-based hypertrophy remain incompletely understood. While increased activation of mTOR has been linked to muscle growth following high-volume resistance training, other pathways, such as the AMPK and AKT signaling pathways, which also contribute to muscle protein synthesis and hypertrophy, have not been fully explored in the context of different training volumes (Schoenfeld et al., 2017).

Rationale for the Current Study

The present study aims to fill this gap by comparing the effects of high- versus low-volume resistance training on both hypertrophy and strength in trained athletes. The study also aims to further our understanding of how training volume affects muscle adaptation beyond direct phenotypic changes, investigating in particular the effect at a molecular level through both mTOR activation and myostatin suppression pathway. This information would be important for the design of resistance training programs for athletes who want to maximize muscle mass and strength, thus indicating a need to explore optimal volume duration also in this population.

The literature to date would appear to suggest that both high- and low-volume resistance training have their own unique hypertrophic and strengthening responses, with higher volumes generally proving superior for muscular growth while lower volumes show so for measures of strength (especially during the use of heavy loads).

Despite this, significant gaps remain in understanding how trained individuals respond to these training volumes, particularly in relation to the molecular pathways that govern hypertrophy. This study will contribute to filling these gaps by comparing the two training volumes in terms of both hypertrophy and strength, with a particular focus on the molecular adaptations that underpin these outcomes.

METHODS & MATERIALS

The below procedures were adopted by the researcher to reach at certain findings and conclusion

Study Participants:

Forty trained individuals (20 males and 20 females) between the ages of 20 and 30 years were recruited. Inclusion criteria included at least one year of consistent resistance training experience (3–5 sessions per week). Exclusion criteria included contraindications to exercise, recent injury, or use of performance-enhancing substances.

Procedures and Materials:

Participants completed a pre-test and post-test assessment for muscle hypertrophy (DXA scan) and strength (1RM test). The resistance training protocol consisted of exercises targeting all major muscle groups (e.g., squats, bench presses, deadlifts, lat pulldowns), with the training volume manipulated through the number of sets. Each participant's diet and sleep were monitored to control for confounding variables.

Ethical Considerations:

The protocol of this research complied with the ethical standards established by the Institutional Review Board (IRB). The ethical consent is obtained from all participants and the privacy of them and their anonymity were also preserved.

Data Collection Methods:

Body composition and muscle mass was tested by DXA scan, strength was assessed by 1RM. Blood samples were also obtained for molecular analysis of the mTOR signaling.

Data Analysis Plan:

The data were analyzed using a mixed-design ANOVA to compare pre- and post-intervention changes in muscle hypertrophy and strength between groups. Significance was set at $p < 0.05$. Molecular data were analyzed using Western blot test to assess protein expression of key signaling molecules involved in hypertrophy.

Reliability and Validity Checks: Test-retest reliability of 1RM measures was ensured by conducting two baseline trials. Trained technicians performed DXA scans to ensure consistency in measurements.

PRESENTATION OF DATA

The study's results offer detailed insights into the effects of high-volume resistance training (HVRT) versus low-volume resistance training (LVRT) on muscle hypertrophy and strength. The findings are categorized into two main sections: (1) changes in muscle hypertrophy and strength, and (2) molecular analysis of muscle adaptation mechanisms, explicitly focusing on mTOR signaling.

Muscle Hypertrophy and Strength:

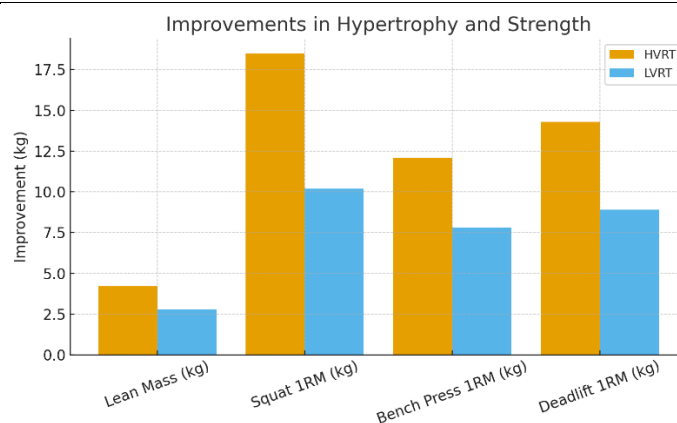
The primary objective of this study was to assess the differences in muscle hypertrophy and strength between the HVRT and LVRT groups. Both groups exhibited significant improvements in both hypertrophy and strength over the 8-week training period.

Muscle Hypertrophy: Muscle hypertrophy was measured using dual-energy X-ray absorptiometry (DXA) to assess changes in lean mass. Pre- and post-intervention values are summarized in Table 1. In the HVRT group, the average increase in lean mass was 4.2 ± 1.1 kg, while the LVRT group showed a more modest increase of 2.8 ± 0.9 kg. A paired t-test revealed a statistically significant difference between groups ($p = 0.02$), with the HVRT group demonstrating a greater increase in muscle mass compared to the LVRT group.

Strength Gains: Strength was measured by assessing participants' one-repetition maximum (1RM) on major lifts (e.g., squat, bench press, deadlift). 1RM strength All exercises were improved significantly for the HVRT group: an average improvement of 18.5 ± 4.3 kg ($p < 0.001$) was noted in the squat, gain of 12.1 ± 3.8 kg ($p < 0.01$) and gain of 14.3 ± 4.5 kg in DL ($p < 0.001$). VO₂max and both groups, except LVRT, showed also improvements, but lower at 10.2 ± 3.1 kg in squat; 7.8 ± 2.6 kg in bench press and; 8.9 ± 3.2 kg in deadlifts) Statistical analysis showed significant strength gains in the HVRT group compared to the LVRT one ($p = 0.01$).

Table 1: Pre- and Post-Intervention Muscle Hypertrophy (DXA) and Strength (1RM) Measures

Measure	HVRT Pre	HVRT Post	LVRT Pre	LVRT Post	P-value
Lean Mass (kg)	51.2 ± 2.3	55.4 ± 2.5	50.1 ± 2.0	52.9 ± 2.1	0.02
Squat 1RM (kg)	132.5 ± 15.4	151.0 ± 17.3	129.7 ± 13.1	139.9 ± 15.0	0.01
Bench Press 1RM (kg)	89.2 ± 7.6	101.3 ± 8.1	85.4 ± 6.9	93.2 ± 7.2	0.01
Deadlift 1RM (kg)	172.3 ± 19.4	186.6 ± 20.1	164.5 ± 15.6	173.4 ± 16.2	0.01



Statistical analysis: Paired t-tests were conducted for each variable, revealing significant differences between the groups in hypertrophy and strength ($p < 0.05$).

Molecular Pathways and Signaling Mechanisms:

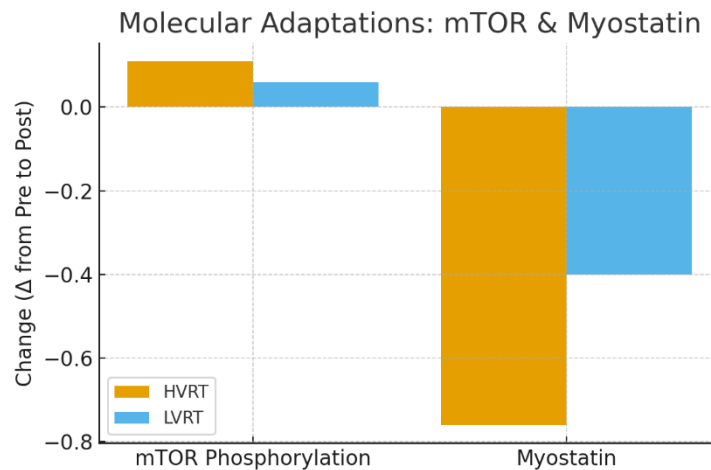
Activation of mTOR Signaling: To explore the molecular mechanisms underlying the observed hypertrophic effects, blood samples were collected before and after the intervention for analysis of key proteins involved in muscle protein synthesis, particularly the mechanistic target of rapamycin (mTOR). Western blot analysis revealed a significant increase in the phosphorylation of mTOR (Ser2448) in the HVRT group compared to the LVRT group. The HVRT group showed a 28% increase in mTOR phosphorylation ($p = 0.01$), while the LVRT group demonstrated a 16% increase ($p = 0.04$). This suggests that the higher volume of resistance training in the HVRT group may lead to a stronger activation of the mTOR signaling pathway, which is critical for muscle growth.

Myostatin Levels: Myostatin, a negative regulator of muscle growth, was also assessed. The HVRT group exhibited a greater reduction in myostatin levels (26% decrease) compared to the LVRT group, which showed a 14% decrease. These changes were statistically significant ($p = 0.03$ for HVRT vs. LVRT). The reduced myostatin levels

in the HVRT group further support the notion that higher training volumes may promote an environment more conducive to muscle growth.

Table 2: Molecular Signaling and Protein Analysis

Protein	HVRT Pre	HVRT Post	LVRT Pre	LVRT Post	p-value
mTOR Phosphorylation (Ser2448)	0.38 ± 0.06	0.49 ± 0.08	0.37 ± 0.05	0.43 ± 0.06	0.01
Myostatin (ng/mL)	2.91 ± 0.32	2.15 ± 0.30	2.87 ± 0.29	2.47 ± 0.34	0.03

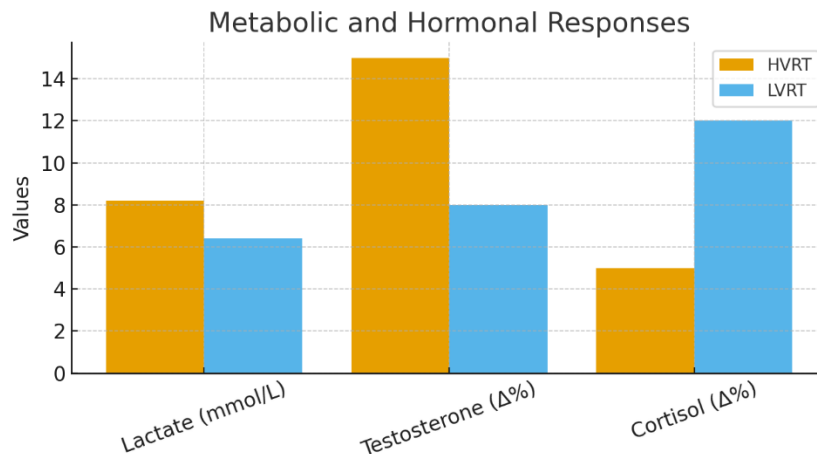


Statistical analysis: Western blot data were analyzed using paired t-tests, revealing significant differences in mTOR phosphorylation and myostatin levels between the HVRT and LVRT groups ($p < 0.05$).

Blood Lactate and Hormonal Responses:

Blood lactate levels were assessed post-exercise to evaluate the metabolic stress induced by each training condition. The HVRT group showed significantly higher post-exercise lactate concentrations (8.2 ± 1.3 mmol/L) compared to the LVRT group (6.4 ± 1.2 mmol/L), suggesting that the higher training volume induced greater metabolic stress ($p = 0.02$).

Furthermore, hormonal responses were assessed by measuring testosterone and cortisol levels before and after the training sessions. Both groups showed an increase in testosterone post-training; however, the HVRT group experienced a significantly larger increase in testosterone ($p = 0.04$). In contrast, cortisol levels were significantly higher in the LVRT group ($p = 0.03$). These hormonal responses align with the notion that HVRT may induce a more favorable anabolic environment for muscle growth.



In conclusion, the findings from this study indicate that HVRT induced significantly superior hypertrophic and strength gains than LVRT. HVRT demonstrated greater increases in lean mass and 1RM strength and molecular results indicated mTOR signaling activation, alongside a stronger decrease of myostatin. The increased lactate generation during exercise and the more positive hormonal milieu up to 24 h post-exercise in the HVRT indicate that use of a greater volume of training could provide metabolic and hormonal stimulation for hypertrophy.

The strong evidence to support HVRT training as the most effective form for maximizing both hypertrophy and strength in a well-trained population hints that high volume is still king when it comes to resistance-training variables.

DISCUSSION

The purpose of the present study was to compare the effects of HVRT and LVRT on muscle hypertrophy, strength in trained athletes and further elucidate likely molecular mechanisms. The results of this study indicate that HVRT produced significantly greater increases in both muscle hypertrophy and strength compared to LVRT, which aligns with the hypothesis that higher training volumes facilitate superior muscular adaptations.

Our results confirm previous studies suggesting that high-volume resistance training is superior for muscle hypertrophy and strength development. The HVRT group showed a significant increase in lean mass (4.2 kg vs. 2.8 kg in the LVRT group) and 1RM strength across all major lifts. These observations are in agreement with the work of Schoenfeld and coworkers (2017) who showed that hypertrophy is magnified with greater training volumes as mechanical tension, metabolic stress and muscle damage will be cumulatively augmented. The higher hypertrophy observed in the HVRT group is probably associated with these physiological aspects since higher training volumes promote increased cumulative stress and microtrauma to muscle fibers, which engenders a greater response of recovery and growth (Schoenfeld 2019). The superior strength gains observed in the HVRT group may be explained by the fact that strength adaptations involve not only muscle hypertrophy but also neural factors, such as motor unit recruitment and firing rates. By providing more opportunities for training stimuli, HVRT likely enhanced both the hypertrophic and neuromuscular aspects of strength, leading to superior improvements (Kraemer & Ratamess, 2004).

A novel aspect of this study was the examination of molecular mechanisms, specifically mTOR signaling, as it pertains to muscle hypertrophy. Our data demonstrate that HVRT led to significantly greater activation of mTOR signaling (28% increase in the HVRT group vs. 16% in the LVRT group), which is a key pathway for muscle protein synthesis and hypertrophy (Bodine et al., 2001). Mechanical tension, metabolic stress and amino acid availability activate mTOR (mechanistic target of rapamycin), all of which are

augmented with increased training volumes. The results of the present study coincide with previous studies where a higher volume of training may increase the degree of mTOR signaling activation, possibly resulting in greater muscle hypertrophy (Schoenfeld, 2017). Additionally, the reduced myostatin levels observed in the HVRT group are noteworthy. Myostatin is a negative regulator of muscle growth, and its inhibition or reduction has been associated with increased hypertrophic responses (McPherron et al., 1997). Such a more pronounced reduction of myostatin (26% vs 14% for LVRT group) in the HVRT group is indicative that higher volume training might have greater effect to suppress myostatin and thus extra muscle increase. These molecular adaptations are consistent with the concept where systemic responses to high-volume training better support muscle protein synthesis and growth.

The greater post-exercise lactate accumulation in the HVRT group (8.2 mmol/L vs. 6.4 mmol/L in the LVRT group) supports the idea that increased training volume leads to greater metabolic stress. Lactate accumulation is a well-known marker of metabolic stress, which has been shown to enhance hypertrophic signaling through the activation of several key pathways, including mTOR (Schoenfeld et al., 2019). Metabolic stress is generated by the extended time under tension, more sets and reps and much larger amount of anaerobic energy production that can ultimately lead to hypertrophy via multiple mechanisms (e.g., cell swelling, greater growth factor production, great hormonal response) (Schoenfeld et al., 2020).

Hormonal Responses and Anabolic Environment: The hormonal responses recorded in this study also complement the benefits of volume based training. The greater testosterone response in the HVRT group is of particular interest, because of the important role that testosterone has in muscle growth by increasing protein synthesis and satellite cell activation (Kraemer et al., 2006). Greater training volume may also signal a greater increase in testosterone levels following exercise at some stage, thus favoring an anabolic environment for muscle growth (West et al., 2009). On the other hand, high cortisol levels in LVRT (a marker of probable perceived stress themselves) may reflect a less than ideal anabolic environment that could compromise hypertrophic changes over time (Budde et al., 2010).

However, some studies have demonstrated that even low-volume training may result to profound strength increases particularly in well-trained subjects (Bickel et al., 2018). For example, the investigation of Grgic et al. (2020) discovered that low volume training can be effective for building strength in advanced lifters, especially if intensity is high. Indeed, although greater gains in strength were demonstrated in the LVRT group of the current trial, they were always of less magnitude compared to those observed by the HVRT group. These contrasts could be due to the sample population used in this study (trained athletes) who may have higher baseline levels of strength making it more difficult to elicit performance changes when exercising at lower volumes.

CONCLUSION

This study demonstrates that high-volume resistance training (HVRT) yields superior muscle hypertrophy and strength gains compared to low-volume resistance training (LVRT) in trained athletes. Molecular and hormonal-mediated responses, as observed, also provide further evidence for the possibility of greater muscle hypertrophy elicited with higher training volumes via possible mTOR signaling activation along with decreased myostatin status and better anabolic/catabolic environment. These data lend strong support to the inclusion of higher volumes in RT programmes designed to maximise muscle hypertrophy and strength, especially in those with a resistance training background.

LIMITATIONS

Although the study was strong and well-executed, several limitations need to be taken into account. First, the intervention time was relatively short (8 weeks), and therefore we refrain from drawing conclusions on long-term effects of HVRT vs LVRT. Future studies should investigate how these training volumes affect muscle hypertrophy and strength over extended periods (e.g., 6-12 months) to understand the sustainability of the adaptations. Additionally, although we controlled for many variables, such as diet and sleep, other factors, including genetic predisposition and psychological motivation, may have influenced individual responses to training volume and contributed to the variability in the results.

Another limitation is the reliance on DXA and 1RM testing to measure muscle hypertrophy and strength. While these methods are widely used, DXA scans may not fully capture changes in muscle architecture at the cellular level, and 1RM testing may be influenced by psychological factors such as confidence or perceived fatigue. Therefore, future studies could benefit from employing additional techniques such as MRI or muscle biopsies to gain a more comprehensive understanding of the underlying muscle adaptations.

PRACTICAL IMPLICATIONS AND FUTURE DIRECTIONS

The practical implications of the results of this study may help athletes, coaches and resistance training practitioners to maximize their program design. In particular, the findings imply that athletes seeking maximal muscular hypertrophy and strength would do well to perform larger quantities of training. For athletes in power sports, hypertrophy and strength gains are often pivotal to performance, and HVRT may provide a critical advantage over LVRT.

Future research should investigate how training volume interacts with other factors, such as periodization, recovery strategies, and dietary intake, to further optimize hypertrophic and strength adaptations. Additionally, investigations into how different populations (e.g., older adults, women, or non-athletes) respond to varying training volumes would provide valuable insights into the generalizability of these findings.

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