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Impact of Low-Load High-Volume Initial Sets vs. Traditional High-Load Low-Volume Bench Press Protocols on Functional and Structural Adaptations in Powerlifters

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Abstract: This study aimed to investigate the effectiveness of low-load high-volume (LL-HV) resistance training compared to traditional high-load low-volume (HL-LV) protocols in eliciting functional and structural adaptations in powerlifters. Twenty-six well-trained male powerlifters were randomly assigned to LL-HV and HL-LV groups and participated in a 12-week supervised training intervention. The LL-HV protocol involved an initial bench press set performed at 45–60% of one-repetition maximum (1RM), with very high repetitions, while the HL-LV group performed the initial set at 75–90% of 1RM, following matched total training volume for accessory exercises. Both groups trained twice weekly, with identical proximity to failure based on repetitions in reserve (RIR). Functional outcomes included changes in bench press 1RM and mean velocity (MV) measured at various submaximal loads, while structural adaptations were assessed through arm and chest circumferences. Statistical analyses were conducted using a two-factor mixed analysis of variance (ANOVA) to assess the effects of "time" and "training group" on these outcomes. Percent changes were comparable between groups for most variables, with significant improvements observed in the LL-HV group for MV at 80% of 1RM and arm circumference. These findings suggest that LL-HV, emphasizing high-repetition sets, offers an effective alternative to HL-LV protocols for enhancing performance and structural adaptations in powerlifters.

Keywords: strength training; training load; exercise volume; performance; physical exercise

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1. Introduction

The development and enhancement of physical capabilities, particularly strength, are fundamental to improving athletic performance [1–3]. Strength, defined as the ability to generate muscle tension to overcome resistance, has been posited as the primary physical quality underpinning other capabilities such as speed, endurance, and flexibility [1,4]. It directly impacts overall sports performance by improving balance, coordination, and bone health, all of which are essential for optimal athletic function [5,6].

Powerlifting exemplifies the critical role of maximal strength in athletic performance. This sport focuses exclusively on three principal lifts: squat, bench press, and deadlift. Competitors aim to lift the maximum possible weight in each lift, known as the one-repetition maximum (1RM). Total performance is evaluated by summing the 1RM scores across all three lifts and normalizing for body weight using standardized scoring systems, such as the Wilks coefficient [7] or the recently established International Powerlifting Federation Good Lift (IPF-GL) points [8].

Training methodologies in powerlifting are centered around either lifting heavier loads at the same speed or increasing the speed of movement for a given load. These principles are rooted in the well-established load–velocity and force–velocity relationships, which are critical for optimizing performance in this sport [9–11]. Research consistently shows a linear relationship between relative load and movement velocity across resistance exercises, enabling precise predictions and monitoring of training intensity [12,13]. However, individualized approaches are essential, as velocity profiles can vary between athletes due to differences in physiological characteristics and technical execution [14–17].

Previous studies have extensively examined the effects of varying loads and volumes on muscle strength, hypertrophy, and endurance [18–21]. Traditionally, improvements in maximal strength have been associated with training intensities close to 1RM, reflecting the specificity required for competitive powerlifting [1,21,22]. High-load low-volume (HL-LV) training has been conventionally linked to neural adaptations, including improved motor unit synchronization and increased firing frequency, as well as enhanced intramuscular coordination, making it a cornerstone of strength development [23,24]. These adaptations are particularly effective for tasks requiring maximal strength production, aligning with the specificity principle in strength sports [1]. However, emerging evidence suggests that low-load high-volume (LL-HV) approaches can also elicit significant strength gains, even in well-trained individuals [25,26]. Regarding muscle hypertrophy, recent research highlights the benefits of employing a broad range of loads, from high to low, provided the effort level approaches maximum [27]. This approach aligns with findings supporting LL-HV resistance training protocols, which have been correlated with increased ribosomal biogenesis, contributing to both hypertrophy and strength development [25].

In light of the growing interest in alternative training methods, particularly LL-HV protocols that emphasize maximal intended velocity of execution to optimize power production [28,29], this study aims to evaluate the effects of a 12-week LL-HV bench press protocol compared to a traditional HL-LV approach on key performance and structural outcomes in well-trained powerlifters. Specifically, we hypothesize that LL-HV training will yield improvements comparable to HL-LV across maximal absolute (1RM) and relative strength (Wilks coefficient and IPF-GL points), mean velocity (MV) across various submaximal loads, and anthropometric measures (arm and chest circumferences), thereby positioning it as a viable alternative for optimizing bench press performance, providing new insights into powerlifting training practices.

2. Materials and Methods

2.1. Experimental Approach to the Problem

This study followed a randomized interventional design to investigate the effects of an LL-HV bench press protocol compared to a traditional HL-LV bench press regimen on bench press performance and upper-body muscle size, assessed through arm and chest circumferences, in trained male powerlifters. Participants were randomly allocated either the LL-HV or HL-LV group using a computer-generated randomization sequence created via the Research Randomized website (www.randomizer.org; accessed on 23 January 2024). The allocation was concealed from the researchers through the use of sealed, opaque envelopes prepared by an independent assistant not involved in the study. Both groups followed a 12-week resistance training program with variations in load and repetition schemes specifically applied to the bench press exercise. The training volume and intensity for all other exercises were balanced between the groups. The dependent variables measured at baseline and after the intervention included bench press 1RM, Wilks coefficient, IPF-GL points, MV and at 80%, 85%, 90%, and 95% 1RM, and arm and chest circumference. Participants were advised to maintain consistent dietary habits throughout the study and refrain from chest-dominant or strenuous exercises for 48 h prior to both pre- and post-testing sessions. Furthermore, participants were explicitly advised not to engage in additional training of the pectoral muscles or similar muscle groups during the study period. Training sessions were supervised by certified coaches and experienced sports scientists.

2.2. Subjects

Twenty-six trained male subjects voluntarily participated in the study. Participants were randomly allocated to either the LL-HV group or the traditional HL-LV group (Figure 1), with baseline characteristics presented in Table 1. All participants had a minimum of two years of resistance training experience in the bench press exercise (5.0 ± 2.7 years), and at least one year of consistent weekly training using repetitions in reserve (RIR) to gauge effort. Exclusion criteria included: (a) any current injuries or orthopedic, neurological, or cardiovascular conditions that could impact study outcomes; (b) use of anabolic steroids or illegal drugs in the past decade; (c) participation in competitions during the study period; and (d) inconsistent training adherence.

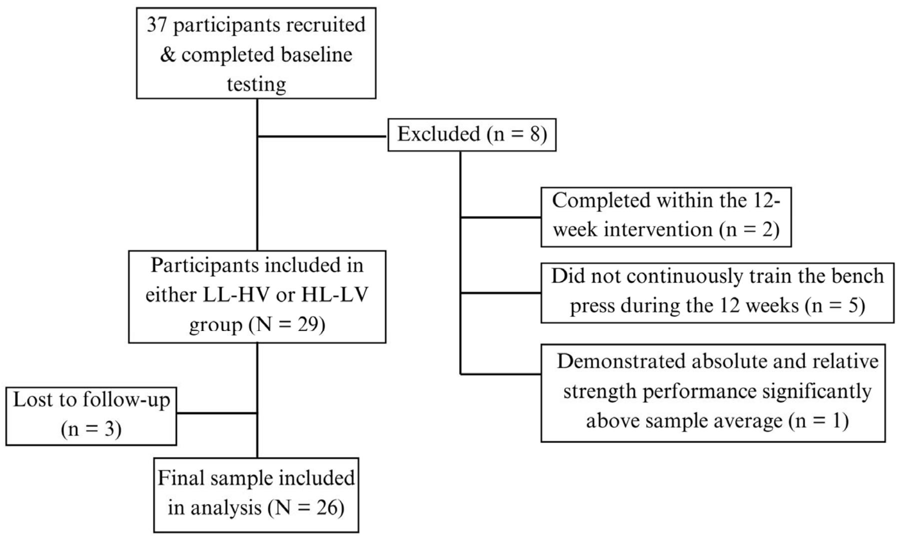

Figure 1. Participants flow diagram.

Table 1. Baseline demographic and physical characteristics of both training groups.

Characteristic	LL-HV (n = 13)	HL-LV (n = 13)	*p*-Value
	Mean ± SD	Mean ± SD	
Age (years)	23.2 ± 2.7	23.9 ± 3.7	0.273
Body mass (kg)	81.8 ± 9.2	80.8 ± 12.7	0.614
Height (cm)	175.3 ± 4.3	174.6 ± 3.9	0.677
Powerlifting experience (years)	4.9 ± 2.2	5.1 ± 3.1	0.402

SD, standard deviation; LL-HV, low-load high-volume group; HL-LV, high-load low-volume group; $p < 0.05$.

Participants were recruited from local powerlifting clubs and sports centers. All subjects provided written informed consent after being briefed on the study's procedures, risks, and benefits. The study protocol was approved by the Institutional Review Board of the University of Granada (491/CEIH/2018) and conformed to the ethical standards of the Declaration of Helsinki. The sample size was determined using G*Power 3.1 (Heinrich Heine, Düsseldorf, Germany), based on a two-tailed *t*-test for independent means. Assuming a medium effect size (d = 0.6) based on previous resistance training performance in previous research [30], significance level (α) of 0.05, and statistical power ($1-\beta$) of 0.80, with an equal allocation ratio between groups, the calculation indicated a need for 12 subjects per group, resulting in a total of 24 participants.

2.3. Procedures

2.3.1. Anthropometric Measurements

Body mass was measured with a calibrated scale (model 529, Electrodomésticos Jata S.A., Navarra, Spain). Arm circumference was recorded at the midpoint of the biceps brachii with the arm flexed, and chest circumference was measured at the midpoint of the pectoralis major using a measuring tape (Seca 201, Seca Deutschland, Hamburg, Germany). Circumference measurements were conducted in accordance with the guidelines established by the International Society for the Advancement of Kinanthropometry (ISAK) to ensure consistency and accuracy [31], under standardized conditions with participants in a fasted state.

While these measurements provide practical insights into muscle size in applied settings, they were included as secondary outcomes to complement the primary measures, such as maximal strength and MV, by offering additional context for structural adaptations. It is important to note that circumference measurements may be influenced by factors such as transient cell swelling. To mitigate these effects, all measurements were scheduled 48 h after the last training session, minimizing the impact of acute training-induced changes. Although circumference and muscle size measurements are not identical, they are often highly linked, serving as a more accessible and cost-effective method for detecting changes induced by resistance training [32].

2.3.2. Maximal Strength Testing

Participants performed a standardized 10 min warm-up before 1RM testing, which included shoulder, elbow, and wrist joint mobility exercises, dynamic stretching, and specific warm-up sets for the bench press exercise. Warm-up loads were incrementally increased from 50% to 70% of estimated 1RM, followed by single repetitions of 80%, 85%, 90%, 95%, and 100% of their 1RM. A rest period of 3 min was provided between each load to ensure adequate recovery. If participants successfully completed the 1RM attempt with capacity for further effort, additional attempts were made to determine the true 1RM. The 1RM test was conducted once during each phase of the study: at baseline (pre-intervention) and after the completion of the training intervention (post-intervention). This decision aligns with evidence from Grgic et al. [33], demonstrating the high reliability and stability of the 1RM test.

In addition to absolute strength measurements, the 1RM values were normalized using two established methods commonly employed in powerlifting to evaluate relative strength: the Wilks coefficient and IPF-CL points. Both metrics were included due to their relevance and widespread application within the sport, ensuring a comprehensive evaluation of the participant's relative strength.

The Wilks coefficient, a traditional metric in powerlifting, adjusts the total lifted weight according to body mass [7]. This coefficient is calculated using the following equations:

$$\text{Wilks points} = \text{Wilks coefficient} \cdot w$$

$$\text{Wilks coefficient} = 500/\left(a + b \cdot x + c \cdot x^2 + d \cdot x^3 + e \cdot x^4 + f \cdot x^5\right)$$

where w is the total weight lifted (kg); x is the athlete's body mass (kg), and a, b, c, d, e, f are gender-specific coefficients. The coefficients are derived from large-scale datasets and are recognized by powerlifting federations worldwide [7].

The IPF-GL points, a more recent metric, offer a refined assessment by accounting for differences between classic and equipped powerlifting disciplines [8]. It accounts for differences between body weight, gender, and lifting modality (classic or equipped). The formulas for calculating IPF-GL points are expressed as:

$$\text{IPF GL points} = \text{IPF GL coefficient} \cdot w$$

$$\text{IPF GL coefficient} = 100/\left(A – B \cdot e^{(-C \cdot x)}\right)$$

In these equations, w is the total weight lifted (kg); x is the athlete's body mass (kg); e is the base of the natural logarithm; and A, B, C are coefficients specific to gender and lifting modality [34]. The coefficients are based on statistical models validated by the IPF and are now widely used in competitive powerlifting [34].

2.3.3. Velocity Measurements

The MV was assessed using a linear position transducer attached to a free-weight barbell (Speed4Lifts v.1, SPEED4LIFTS, Madrid, Spain), during the same procedure as the 1RM evaluation. The MV was measured at intensities of 80%, 85%, 90%, and 95% of the estimated 1RM of the pre-test. This approach ensures consistency by using a standardized baseline load, as recalculating percentages based on post-intervention 1RM would introduce variability unrelated to the intended evaluation of relative improvements in movement velocity. As an increase in velocity at a consistent absolute load is widely acknowledged as an indicator of strength improvement [35–37], these percentages were determined during the same sets used to estimate the direct measurement of 1RM.

Data were transmitted wirelessly to a smartphone application for real-time load-velocity profiling. The Speed4Lifts device has been validated against devices such as the T-Force System (T-FORCE System, ERGOTECH Consulting SL, Murcia, Spain) and gold-standard Trio-Optitrack (V120, NaturalPoint, Inc., Corvallis, OR, USA) for accuracy in measuring barbell velocity during bench press exercises. In the bench press exercise performed on a Smith machine, the Speed4Lifts demonstrated high correlations in MV with the Trio-OptiTrack (r = 0.994), confirming its suitability for measuring lifting velocity due to its high precision, user-friendliness, and affordability [38].

2.3.4. Resistance Training Protocol

The 12-week training program consisted of two weekly sessions, each comprising four upper-body exercises commonly used in powerlifting to improve muscle strength and hypertrophy. Session 1 included the bench press (1 set at a specified intensity with RIR 4), flat dumbbell press (3 sets of 10 repetitions at RIR 1), incline dumbbell press (2 sets of 10 repetitions at RIR 1), and pulley crosses (2 sets of 15 repetitions at RIR 1). Session 2 included the bench press (1 set at a specified intensity with RIR 4), followed by three additional sets of bench press (3 sets of 10 repetitions at RIR 1), incline barbell press (2 sets of 10 repetitions at RIR 1), and dips (2 sets of 15 repetitions at RIR 1).

The main difference between the protocols was the load applied to the initial set of the bench press exercise. For the LL-HV group, the first set of Session 1 was performed at 45% of 1RM, and the first set of Session 2 was performed at 60% of 1RM. This alternating pattern, sustained throughout the program, aligns with previous research categorizing loads at or below 60% of 1RM as low-load training [21]. Conversely, the HL-LV group performed the first set of Session 1 at 75% of 1RM and the first set of Session 2 at 90% of 1RM, maintaining the same periodization pattern as LL-HV group. This structured plan ensured consistency in the training design while distinctly differentiating the loading strategies for the initial bench press sets, offering a clear comparison of low-load and high-load resistance training protocols.

Training sessions were conducted twice weekly, with at least a 72 h recovery period between sessions. This training frequency involved a total of 16 weekly sets primarily targeting the pectoral muscles, with 14 sets being identical between the groups and differing only in a single bench press set per session. This approach aligns with established guidelines for optimizing muscle strength and hypertrophy [27,39].

Participants exclusively performed the prescribed training protocol, focusing solely on the bench press and the accessory exercises detailed above. No additional exercises targeting other muscle groups were included to ensure that the observed adaptations were solely attributable to the implemented training protocols. Participants were instructed to refrain from any other physical activity that could influence the dependent variables, including additional training for either the upper or lower body. The experimental training protocol was adapted from the methodology developed by Jesús Varela-Goicoechea, European champion in the bench press at the 2017 Arnold's Europe Championships and the 2018 European Classic Bench Press Championships.

Before each session, participants completed a standardized warm-up comprising general and specific exercises. During this warm-up, the Speed4Lifts device was attached to the barbell to estimate 1RM indirectly. Participants performed incremental sets ranging from 50% to 80% of their pre-test 1RM, while the encoder measured barbell velocity and transmitted the data to a smartphone application (SPEED4LIFTS, Madrid, Spain) for real-time analysis. This method ensured precise load adjustments by minimizing discrepancies associated with programming solely based on pre-intervention 1RM values [40]. A 3 min rest period followed the warm-up, in alignment with established research evidence [41,42].

Participant's existing training regimens were reviewed before the program's commencement to ensure that upper-body training volumes were standardized across groups. The only difference between the groups was in the first set of the bench press exercise, aimed at assessing the effects of a low-load, high-repetition initial set. Both groups trained with the same level of exertion, determined by RIR, a validated method for determining set endpoints [43]. The HL-LV group executed all exercises at 75–90% of 1RM, whereas the LL-HV group performed all their first bench press sets at 45–70% of 1RM with subsequent sets matching the intensity and volume of the HL-LV group. Rest intervals of 2 min were maintained between sets and exercises.

Training sessions were consistently scheduled at the same times each week. All exercises were executed at maximal intended velocity avoiding pauses for recovery or rebounding. Bench press sets were performed according to the technical standards set by the International Powerlifting Federation (IPF), ensuring proper form and execution. An experienced researcher supervised each lift, offering assistance only for unracking and reracking the barbell (CrossBlack, Maniak Fitness, Málaga, Spain) and intervening solely in case of lift failure. The equipment used included a flat bench (Heavy Duty, Force USA, Sant Cugat del Vallès, Spain), bumper plates (MD Equipment Box SL, Madrid, Spain), and a rack (TopGrade, Maniak Fitness, Málaga, Spain).

2.4. Statistical Analyses

Data are presented as means and standard deviations (Mean ± SD). Statistical analyses were conducted using SPSS version 25.0 for Windows (IBM SPSS, Chicago, IL, USA). Statistical significance was set at $p < 0.05$, with a 95% confidence interval. The normality of the data distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances between groups was evaluated using Levene's test. All variables met the assumptions of normality ($p > 0.05$) and homogeneity of variances ($p > 0.05$), allowing the use of parametric test for data analysis. A two-factor mixed analysis of variance (ANOVA) test was employed to assess the effects of "time" (within-subject factor: pre- vs. post-intervention) and "training group" (between-subject factor: LL-HV vs. HL-LV) on bench press MV at various relative loads (80%, 85%, 90%, and 95% 1RM), maximal bench press absolute (1RM) and relative (body mass, and Wilks and IPF-GL points) strength, and anthropometric variables (arm and chest circumference). The magnitude of the changes was assessed using Hedges' g effect size (ES), along with 95% confidence intervals. ES was calculated using pre-test SD for within-group and pooled pre-test SD for between-group comparisons. ES magnitudes were classified as: trivial (<0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.20–2.00), and extremely large (>2.00) [44].

3. Results

Table 1 presents the baseline characteristics of the participants in the LL-HV and HL-LV groups. The *p*-values confirm the absence of significant differences in age, body mass, height, and powerlifting experience between the groups ($p > 0.05$). These findings validate the randomization process, ensuring that the groups were statistically similar at baseline and minimizing potential confounding factors.

Table 2 summarizes the changes in MV for 80%, 85%, 90%, and 95% of pre-intervention 1RM. For MV at 80% of 1RM, the interaction effect demonstrated significant effects ($F = 5.6$; $p = 0.033$), due to the greater values observed in the LL-HV group at post-intervention compared to pre-intervention. No significant interaction effects were observed for MV at other percentages of 1RM ($F \leq 3.3$; $p \geq 0.084$), suggesting that the changes over time were similar between groups. Figure 2 highlights the standardized differences for MV improvements across all submaximal loads, showing a notable advantage for the LL-HV group at 80% of 1RM.

For 1RM, no significant interaction effect was observed ($F = 3.5$; $p = 0.072$), suggesting similar maximal strength gains in both groups. Changes in Wilks coefficient and IPF-GL points also showed non-significant interaction effects ($F \leq 3.8$; $p \geq 0.063$), with comparable improvements in relative strength for both protocols. Minimal changes in body mass were observed, with no significant group differences ($F = 0.6$; $p = 0.455$). Those results revealed that the enhancements in performance levels were comparable for LL-HV and HL-LV (Table 3).

Table 4 presents changes in arm and chest circumferences. A significant interaction effect was found for arm circumference ($F = 4.7$; $p = 0.040$), favoring the LL-HV group. Although the interaction effect for chest circumference approached significance ($F = 3.9$; $p = 0.060$), the improvements were comparable between groups.

When evaluating the magnitude of differences between the groups, small effect sizes (ES = 0.20–0.56) were observed for most variables, favoring the LL-HV group for MV at 80% of 1RM and arm circumference. A trivial effect size (ES = 0.17) was noted for chest circumference (Figure 3), further supporting the comparable efficacy of both protocols.

Table 2. Comparison of changes in mean velocity at various loads between training groups over a 12-week resistance training period.

% 1RM	Group	Time	Mean ± SD (m/s)	Δ (%)	Hedges' g ES (95% CI)	ANOVA Time	ANOVA Group	ANOVA Interaction
80%	LL-HV	Pre	0.43 ± 0.09	16.2 *	0.80 (0.00, 1.59)	***F* = 6.4** ***p* = 0.019**	*F* = 1.1 *p* = 0.315	***F* = 5.6** ***p* = 0.033**
		Post	0.50 ± 0.08					
	HL-LV	Pre	0.43 ± 0.07	0.9	0.00 (−0.77, 0.77)			
		Post	0.43 ± 0.10					
85%	LL-HV	Pre	0.36 ± 0.09	18.9 *	0.80 (0.00, −1.59)	***F* = 10.7** ***p* = 0.003**	*F* = 0.1 *p* = 0.706	*F* = 1.3 *p* = 0.271
		Post	0.43 ± 0.08					
	HL-LV	Pre	0.36 ± 0.07	9.1	0.42 (−0.36, 1.20)			
		Post	0.40 ± 0.11					
90%	LL-HV	Pre	0.29 ± 0.08	30.1 *	0.13 (−0.64, 0.90)	***F* = 13.7** ***p* = 0.001**	*F* = 0.4 *p* = 0.508	*F* = 3.3 *p* = 0.084
		Post	0.38 ± 0.07					
	HL-LV	Pre	0.30 ± 0.07	10.1	0.34 (−0.44, 1.11)			
		Post	0.33 ± 0.10					
95%	LL-HV	Pre	0.25 ± 0.09	26.2 *	0.73 (−0.07, 1.52)	***F* = 5.6** ***p* = 0.026**	*F* = 4.0 *p* = 0.057	*F* = 1.8 *p* = 0.189
		Post	0.31 ± 0.07					
	HL-LV	Pre	0.22 ± 0.04	8.1	0.25 (−0.52, 1.03)			
		Post	0.24 ± 0.10					

1RM, one-repetition maximum; LL-HV, low-load high-volume group; HL-LV, high-load low-volume training group. Asterisks (*) mark indicates statistically significant differences ($p < 0.05$) between pre- and post-intervention values within the same group. Bolded *p*-values represent statistically significant effects derived from the ANOVA analysis.

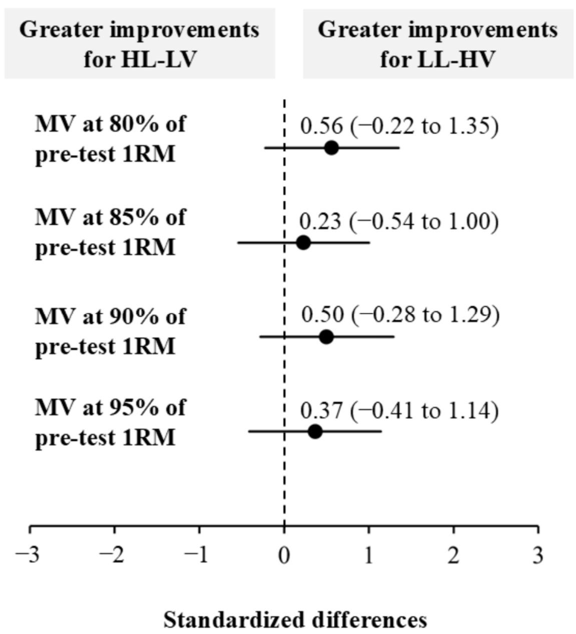

Figure 2. Standardized mean differences (Hedges' g) with 95% confidence intervals for mean velocity (MV) at all submaximal loads measured. Positive values indicate greater improvements for low-load high-volume (LL-HV), while negative values indicate greater improvements for high-load low-volume (HL-LV).

Table 3. Comparison of changes in maximal absolute and relative strength variables between training groups over a 12-week resistance training period.

Variable	Group	Time	Mean ± SD	Δ (%)	Hedges' g ES (95% CI)	ANOVA Time	ANOVA Group	ANOVA Interaction
Body mass (kg)	LL-HV	Pre	81.8 ± 9.2	1.3	0.11			
		Post	82.9 ± 9.5		(−0.88, 0.66)	$F = 1.0$	$F = 0.1$	$F = 0.6$
	HL-LV	Pre	80.8 ± 12.7	0.1	0.01	$p = 0.330$	$p = 0.745$	$p = 0.455$
		Post	80.9 ± 13.6		(−0.78, 0.76)			
1RM (kg)	LL-HV	Pre	106.3 ± 19.6	8.4	0.42			
		Post	114.8 ± 19.2		(−0.35, 1.20)	**$F = 10.8$**	$F = 0.2$	$F = 3.5$
	HL-LV	Pre	106.2 ± 19.1	2.2	0.10	**$p = 0.003$**	$p = 0.683$	$p = 0.072$
		Post	108.5 ± 23.6		(−0.67, 0.87)			
Wilks points	LL-HV	Pre	72.1 ± 12.1	7.2	0.41			
		Post	77.2 ± 11.7		(−0.36, 1.19)	**$F = 13.2$**	$F = 0.1$	$F = 3.5$
	HL-LV	Pre	73.2 ± 11.4	2.2	0.12	**$p < 0.001$**	$p = 0.889$	$p = 0.075$
		Post	74.8 ± 13.9		(−0.65, 0.89)			
IPF-GL points	LL-HV	Pre	14.8 ± 2.5	8.4	0.49			
		Post	16.1 ± 2.6		(−0.29, 1.27)	**$F = 11.0$**	$F = 0.1$	$F = 3.8$
	HL-LV	Pre	15.0 ± 2.4	2.2	0.10	**$p = 0.003$**	$p = 0.752$	$p = 0.063$
		Post	15.3 ± 3.1		(−0.66, 0.87)			

1RM, one-repetition maximum; LL-HV, low-load, high-volume group; HL-LV, high-load low-volume group; CW, coefficient wilks, IPF-GL, International Powerlifting Federation—Good Lifts. Bolded *p*-values represent statistically significant effects ($p < 0.05$) derived from the ANOVA analysis.

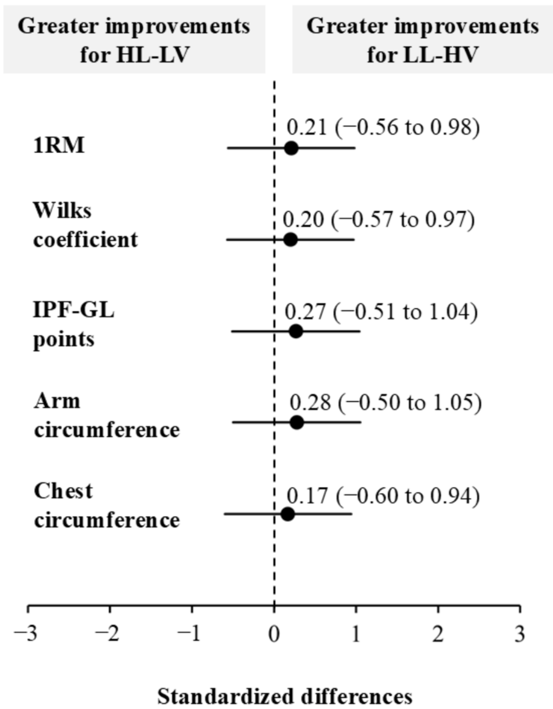

Figure 3. Standardized mean differences (Hedges' g) with 95% confidence intervals for the changes in one-repetition maximum (1RM), Wilks coefficient, IPF-GL points, arm circumference, and chest circumference. Positive values indicate greater improvements for low-load high-volume (LL-HV), while negative values indicate greater improvements for high-load low-volume (HL-LV).

Table 4. Comparison of changes in arm and chest circumference between training groups over a 12-week resistance training period.

Variable	Group	Time	Mean ± SD	Δ (%)	Hedges' g ES (95% CI)	ANOVA		
						Time	Group	Interaction
Arm circumference (cm)	LL-HV	Pre	38.0 ± 2.8	3.2 *	0.42	**F = 4.2**	F = 1.3	**F = 4.7**
		Post	39.2 ± 2.7		(−0.35, 1.20)	**p = 0.050**	p = 0.268	**p = 0.040**
	HL-LV	Pre	37.3 ± 3.2	−0.1	−0.01			
		Post	37.3 ± 3.2		(−0.78, 0.76)			
Chest circumference (cm)	LL-HV	Pre	105.2 ± 6.5	2.3	0.35	**F = 14.4**	F = 0.5	F = 3.9
		Post	107.5 ± 6.2		(−0.42, 1.13)	**p = 0.001**	p = 0.504	p = 0.060
	HL-LV	Pre	104.3 ± 6.8	0.7	0.13			
		Post	105.0 ± 6.7		(−0.64, 0.90)			

LL-HV, low-load, high-volume group; HL-LV, high-load low-volume group; Asterisks (*) mark indicates statistically significant differences ($p < 0.05$) between pre- and post-intervention values within the same group. Bolded p-values represent statistically significant effects derived from the ANOVA analysis.

4. Discussion

This study aimed to investigate the effects of a 12-week LL-HV resistance training compared to the traditional HL-LV approach focusing on the bench press on maximal strength, mechanical performance at submaximal loads, and arm and chest circumferences in powerlifters. Our main findings reveal that LL-HV resistance training is comparable to HL-LV in promoting functional and structural adaptations in well-trained powerlifters, with specific advantages observed in certain performance metrics.

Both training methodologies significantly improved MV across various submaximal intensities, but the LL-HV group demonstrated distinct advantages at MV at 80% of 1RM, while the HL-LV group did not display comparable changes at this intensity. These results align with the load-velocity relationship, suggesting that LL-HV may better enhance velocity at submaximal loads due to the high-repetition nature of this protocol [45].

In terms of maximal strength, both groups achieved substantial improvements in 1RM, contrasting with findings from some previous studies. For instance, Jenkins et al. [24] observed that HL-LV training led to significantly greater gains in knee extension 1RM and voluntary isometric contraction (MVIC) in untrained men, while Lasevicius et al. [19] found greater strength improvements in both 1RM leg press and elbow flexion with HL-LV protocols in young, untrained men. Conversely, Steele et al. [46] reported no significant differences between HL-LV and LL-HV groups in untrained adolescents over a 9-week period for bench press 1RM, and Yeom et al. [26] found comparable increases in maximal muscle strength and skeletal muscle mass with both protocols among elite weightlifters after an eight-week intervention. This discrepancy can be attributed to the advanced training expertise of our participants, who had over a year of experience employing autoregulation techniques, specifically RIR, in their training programs. These practices likely enhanced their ability to dynamically adjust effort and intensity, ensuring consistent engagement across all repetitions and maximizing adaptations even when utilizing lower loads. These findings are consistent with prior research, including the work of Ormsbee et al. [47], which demonstrated that autoregulation through RIR facilitates the optimization of training load and volume while preserving neuromuscular efficiency in experienced lifters. The capacity to maintain consistent effort with their respective loads may have benefited both groups, potentially explaining the absence of significant differences in most outcomes related to maximal strength and MV between the two training protocols.

Intentional velocity further emerged as a critical factor influencing strength gains. Participants in both groups were instructed to perform all repetitions with maximal intended velocity, regardless of load, a methodological approach supported by González-Badillo et al. [35], who demonstrated that maintaining maximal intentional velocity during training enhances strength gains. This focus on intentional velocity likely explains the comparable strength gains observed in the LL-HV group relative to the HL-LV group, contrasting with previous studies where participants were often not instructed to lift with maximal intent. Without such instructions, lighter loads may elicit less effortful engagement, potentially limiting adaptations, whereas heavy loads naturally require maximal effort regardless of guidance. Therefore, the observed differences among studies may not solely arise from variations in load but also from whether participants were explicitly directed to lift with maximal intent. These findings underscore the importance of combining intentional velocity with precise effort regulation to achieve optimal strength outcomes, highlighting the adaptability of trained powerlifters to diverse training stimuli.

Relative strength, assessed using the Wilks coefficient and IPF-GL points, showed a trend toward improvement in the LL-HV group, though these differences were not statistically significant compared to the HL-LV protocol. It is important to note that these changes in relative strength indices are primarily attributable to increases in 1RM, as body mass remained practically constant throughout the intervention. This indicates that the improvements in relative strength are a direct reflection of the absolute strength gains achieved via LL-HV training. Together with the observed enhancements in 1RM, these findings suggest that LL-HV training can be as effective as, or potentially more effective than traditional HL-LV training methods in strength sports such as powerlifting, by improving performance metrics relative to body weight without necessitating changes in body mass.

Structural outcomes were also positively influenced by LL-HV training. The LL-HV group exhibited significant increases in arm circumference, with a trending increase in chest circumference compared to the HL-LV group. We acknowledge the limitations of using thigh circumference as a proxy for muscle hypertrophy, as it does not provide a direct measure of muscle thickness or volume. However, its inclusion as a secondary variable was intended to support and complement the primary outcomes of maximal strength and MV, providing a broader perspective on the structural adaptations elicited by the protocols. The results of circumference measurements align with the improvements observed in 1RM and MV, reinforcing the overall effectiveness of both training approaches. These findings align with studies showing that higher training volumes, particularly when incorporating diverse loading schemes, can promote muscle hypertrophy in trained athletes [48]. The broader range of repetitions (approximately 15 to 50) and relative loads (45% and approximately 70% 1RM) in the LL-HV protocol may have provided a more varied stimulus conducive to muscle growth. Previous research has explored the effects of training protocols based on a constant load percentage zone (8–12 repetitions) versus protocols that vary the load percentage across a broader range (2–30 repetitions) [21,49]. Our findings support the idea that optimizing structural adaptations can be achieved by employing a broad range of loads, provided the effort level approaches maximum intensity [27]. Supporting this, Yeom et al. [26] demonstrated that LL-HV training not only influences muscle strength and damage but also indicates that varying training stimuli among trained weightlifting athletes, can yield beneficial outcomes. Notably, the LL-HV group demonstrated reduced markers of muscle damage, such as creatine kinase (CK) and lactate dehydrogenase (LDH), highlighting an additional benefit of minimizing recovery time and fatigue. These findings suggest that diversifying the training stimulus with a wide range of repetitions, as executed in the LL-HV protocol of our study, may mitigate injury risk, enhance adaptation in well-trained athletes, and balance performance gains with reduced physiological strain by decreasing mechanical stress on muscles and joints.

Despite these robust findings, several limitations must be acknowledged. The study's duration, while consistent with the previous literature [49], may not fully capture long-term adaptations and potential variations in individual responses to LL-HV training. Furthermore, although the sample size was adequate for statistical analysis, it may not fully represent the broader population of resistance-trained individuals. Future research should explore the effects of extended training durations and include more diverse populations to validate and extend these findings. Additionally, while circumference measurements provide practical and applicable insights into structural adaptations, they are limited in their ability to directly assess muscle thickness or volume and may be influenced by factors such as transient cell swelling. Moreover, the study did not employ advanced imaging or assessment techniques, such as bioimpedance analysis or dual-energy X-ray absorptiometry (DEXA), which could have provided more detailed insights into changes in intra- and extracellular water content at the level of the upper limbs. Nevertheless, it is important to note that we implemented measures to minimize potential confounding factors in circumference assessments, as detailed previously. These precautions ensured that the data collected provided a reliable representation of structural adaptations within the practical constraints of applied sports settings. By designating circumference measurements as a secondary variable and explicitly acknowledging their limitations, we aimed to ensure transparency and provide a balanced interpretation of the findings. Another limitation is the lack of direct dietary monitoring, as participants were only instructed to maintain their dietary habits throughout the intervention. Although this approach ensures ecological validity by reflecting real-world training conditions, variations in macronutrient intake, total energy consumption, and supplementation practices could have influenced strength and structural adaptations. Future studies should consider incorporating controlled dietary assessments, such as food diaries or dietary recalls, to better account for potential nutritional confounders. Furthermore, individual differences in motivation during training could have played a role in performance outcomes. While all training sessions were supervised to ensure adherence to the prescribed protocols, effort exertion was monitored through RIR, and participants (who were experienced powerlifters accustomed to structured training programs) were likely to maintain consistent effort levels. Nevertheless, intrinsic motivation and psychological factors remain influential variables in neuromuscular adaptations. Despite this limitation, the supervised nature of the sessions and the inclusion of well-trained participants likely helped minimize variability in effort exertion.

The practical implications of this study highlight the versatility and effectiveness of LL-HV resistance training as a viable strategy for enhancing bench press performance and promoting structural adaptations, particularly in trained powerlifters. This protocol demonstrated certain advantages, such as improved MV at 80% of 1RM and significant increases in arm circumference, the overall lack of significant between-group differences suggests that both LL-HV and HL-LV protocols are effective within this population. These findings reinforce the adaptability of trained powerlifters to diverse training stimuli, offering strength and conditioning professionals a flexible framework for program design. Given that LL-HV training leads to notable gains in both maximal and relative strength, it provides a viable alternative or complement to HL-LV training methods. Coaches might consider integrating LL-HV phases into training regimens to optimize athletic performance across various sports by improving both strength-to-body-weight ratios and overall performance metrics, which are particularly critical for competitive powerlifters. In practice, incorporating LL-HV training phases can help achieve a balanced development of power output and maximal strength. This approach offers a promising alternative to traditional HL-LV training, potentially reducing injury risks associated with high loads and providing a varied stimulus for functional and structural adaptations.

5. Conclusions

LL-HV resistance training represents a practical and effective alternative to traditional HL-LV protocols, yielding comparable functional and structural adaptations in powerlifters. Notable advantages, including enhanced mean velocity at submaximal loads and increased arm circumference, highlight its potential to diversify training strategies while reducing injury risks. These findings provide valuable insights for optimizing strength training programs, offering greater flexibility and efficacy in designing tailored approaches for athletes.

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