

Effect of high intensity in every set on strength gains in novice lifters: a randomized controlled trial

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Abstract

Background and Study Aim Effective program design is essential for maximizing adaptation by balancing strength gains, minimizing stress, and enhancing recovery. However, it remains unclear whether training at high intensity in every set is necessary for optimal strength gains. This study compares the effects of two distinct 6-week resistance training programs on maximum strength in novice lifters.

Material and Methods Twenty participants were recruited and randomly assigned to either the traditional strength program (TSP) or the combined strength program (CSP), both periodized to increase the number of sets every 2 weeks over a total of 6 weeks. A two-way ANOVA was used to analyze maximum isometric strength, maximum dynamic strength, and strength ratio differences between groups and over time.

Results The results showed significant increases in maximum isometric knee extension and elbow flexion strength for both the TSP (CI 95% = 55.87-99.92 N and CI 95% = 10.93-26.86 N, respectively) and the CSP (CI 95% = 43.32-111.42 N and CI 95% = 8.54-28.96 N, respectively). Similarly, maximum dynamic knee extension and elbow flexion strength also improved significantly in both programs (knee extension: TSP CI 95% = 8.16-17.24 kg and CSP CI 95% = 9.10-28.32 kg; elbow flexion: TSP CI 95% = 6.74-11.26 kg and CSP CI 95% = 3.05-10.70 kg). Additionally, strength ratios increased significantly in both the TSP (knee extension CI 95% = 0.87-1.36 N/kg and elbow flexion CI 95% = 0.15-0.42 N/kg) and the CSP (knee extension CI 95% = 0.68-1.59 N/kg and elbow flexion CI 95% = 0.14-0.39 N/kg) from baseline.

Conclusions Both training programs led to significant increases in maximum strength metrics. Novice practitioners did not need to train at high intensity in every set to achieve substantial strength gains. This was particularly evident during the early weeks of training, when recovery and adaptation are critical.

Keywords: isometric strength, dynamic strength, strength ratio, knee extension, preacher curl

Introduction

From the resistance training literature, it is well-documented that high-intensity resistance training is beneficial for increasing muscle strength among practitioners. According to guidelines from the American College of Sports Medicine, an intensity of approximately 70% or more of one-repetition maximum (1RM) is generally recommended for practitioners aiming to achieve significant strength gains [1]. This guideline is well-supported by a substantial body of evidence from previous studies, which consistently demonstrate that training at this intensity is effective in enhancing maximum strength [2, 3, 4].

Mechanistically, high-intensity resistance training facilitates a range of physiological adaptations that contribute to improvements in muscle strength. For instance, such training promotes increased maximal motor unit recruitment, referring to the activation of a greater number of motor units within a muscle [5]. This increased recruitment is crucial for generating

higher force levels by enhancing the utilization of fast-twitch muscle fibers, which are primarily responsible for maximum strength and explosive power [6]. Additionally, improvements in motor unit synchronization and firing rate — both of which refer to the efficiency and frequency at which motor units are activated — play a significant role in increasing muscle strength [7]. Furthermore, muscle hypertrophy, or the increase in muscle size, is another important factor contributing to greater muscle strength [8]. This phenomenon is commonly observed in response to high-intensity training, as the mechanical tension placed on muscles leads to structural adaptations [9]. From a practical perspective, these findings suggest that training at or above 70% 1RM is particularly well-suited for individuals seeking to maximize their strength gains, as it triggers the necessary physiological adaptations to achieve this goal.

However, consistently training at high intensity presents challenges, as it can lead to the accumulation of stress on musculotendinous units and contribute to fatigue due to the high levels of perceived effort required. To mitigate these issues,

alternative techniques, such as low-intensity resistance training with blood flow restriction (BFR), have been suggested as beneficial, as they allow for reduced external load during training [10]. This approach may facilitate faster recovery by causing less muscle damage [11] and reducing fatigue while still promoting substantial strength gains [12].

However, a recent meta-analysis demonstrated that while low-intensity resistance training with BFR significantly increases muscle strength, its strength gains remain suboptimal compared to traditional high-intensity resistance training [13]. For example, in one study, participants experienced a 31.2% increase in 1RM knee extension following traditional high-intensity training at 80% 1RM, compared to only a 19.1% increase from low-intensity BFR training at 20% 1RM [14]. Numerous studies further support the superiority of high-intensity resistance training for muscle strength gains [15, 16, 17].

From a practical perspective, an optimal resistance training program should not only maximize strength gains but also minimize stress and enhance recovery. While recent meta-analyses suggest that lifting light loads with BFR alone may be less effective for strength gains, it could still offer recovery benefits. Novice lifters, in particular, may benefit from a combined approach that reduces the need for consistently high-intensity training, allowing for easier recovery without compromising progress. It remains unclear whether combining high-intensity training with low-intensity BFR can produce strength gains comparable to high-intensity training alone, especially when the total number of sets is controlled. Therefore, this study aims to compare the effects of two different 6-week resistance training programs on maximum strength in novice lifters.

Materials and Methods

Participants

Before implementing the exercise intervention, this study used a priori power analysis. The analysis employed G*Power version 3.1.9.7 software with the following parameters: Effect size = 0.75, α = 0.05, and Power = 0.80, considering a 20% dropout rate. The total number of participants was set at 20. These input parameters were based on a previous study, which used a similar experimental design to investigate muscle strength changes in two groups [18].

Twenty healthy young males (age = 21.1 ± 0.4 years, height = 1.74 ± 0.5 m, weight = 69.1 ± 11 kg) were recruited for this study. All participants met specific inclusion criteria. They were under 22 years of age, had no resistance training experience, and had no functional limitations that could affect training. Additionally, none had a history of using

pharmacological substances, ergogenic drugs, performance supplements, or anabolic steroids that could influence muscle strength. A thorough health screening was conducted by a physician, and informed consent was obtained from all participants. To prevent bias, participants were randomly assigned to either traditional strength program (TSP) (n=10) or combined strength program (CSP) (n=10).

Research Design

This study aimed to compare changes in maximum strength metrics influenced by two different resistance training programs. An experimental design was used, comparing two groups with standardized controls for training volume, exercise order, execution pattern, repetition tempo, and rest intervals. Eligibility criteria required participants to have no prior structured resistance training experience to minimize bias related to experience. All resistance training sessions were supervised by a specialist in a controlled laboratory environment.

Baseline assessments included measurements of maximum voluntary isometric strength using an isokinetic dynamometer (ISOFORCE, Germany). Maximum dynamic strength was assessed via 1RM knee extension and 1RM preacher curl, using standard training machines (Body-solid, USA). The study was conducted in accordance with the Declaration of Helsinki, and informed consent was obtained from all participants. Ethical approval was granted by the institutional review board of Burapha University (Reference No. G-HS046/2566(C1)).

Resistance training programs

In the traditional strength program (TSP), participants engaged in one training session per week, held on Monday, throughout the 6-week program. This duration was selected based on a classic study indicating that substantial strength adaptations, especially in novice lifters, could occur relatively quickly within this time frame [19]. Participants performed 3 sets of knee extensions on a machine (Body-Solid, USA) and 3 sets of preacher curls on a machine (Body-Solid, USA) during the first two weeks. The training intensity was set at 70% 1RM for every set. Repetitions were executed to failure in both exercises to ensure maximal motor unit recruitment.

Each repetition followed a fixed tempo of 2 seconds for both the concentric and eccentric phases, with a 60-second rest interval between sets. Participants were instructed to maintain a full range of motion throughout each repetition, and each set was terminated upon concentric failure. A 4-minute rest interval was given between exercises, with knee extensors being trained first. By the third and fourth weeks, the set volume was doubled to six sets for both exercises. In the fifth and sixth weeks, the volume increased to eight sets per exercise.

In the combined strength program (CSP),

participants also trained one session per week. During the first two weeks, they performed two sets at high intensity (70% 1RM) and one set at low intensity (30% 1RM) with BFR for both knee extension and preacher curl exercises. The BFR was achieved using elastic wraps (Grizzly Fitness, Canada) fastened proximally on the upper arms and legs. The elastic wraps were approximately 7.5 cm wide and 120 cm long.

To standardize the BFR protocol, a clinical pneumatic cuff (H+CUFF, USA) was applied to the upper legs and arms. The pressure was gradually increased until a vascular Doppler could no longer detect blood flow, confirming complete occlusion. The pressure was then reduced to 40% of the occlusion pressure, allowing participants to acclimate through alternating periods of pressure on and off. Participants were subsequently provided with elastic wraps and instructed to apply them at a perceived pressure similar to 40% of the occlusion pressure.

As highlighted by a previous study, individuals can be trained to sense the target BFR pressure through repeated inflations and deflations at 40% arterial occlusion pressure, resulting in improved accuracy in estimating the target pressure [20]. The high-intensity sets were performed first, followed by the low-intensity sets. The elastic wrap was tightened only before the low-intensity sets began. After finishing each BFR set, the wraps were released immediately. The total duration of blood flow restriction was kept under 10 minutes, as recommended by a previous study [21].

In the third and fourth weeks, the training

volume increased to three sets of each intensity. By the fifth and sixth weeks, participants performed four sets of each intensity for both exercises. All other training variables remained consistent across both groups. A summary of the training programs is provided in Table 1.

Maximum isometric strength test

For maximal isometric strength testing, participants completed a standardized warm-up, followed by a 3-minute rest. Testing began with the isometric knee extension strength assessment, conducted on a seated bench with secure fixation using strap belts. Participants sat upright on the bench with approximately 90 degrees of hip flexion and about 60 degrees of knee flexion (full knee extension = 0 degrees). This knee angle was chosen based on a previous study, which reported that participants could generate the most force at this angle compared to shorter or longer angles [22].

Participants were instructed to exert maximal force against an immovable resistance pad as hard and fast as possible for three 5-second repetitions, with a 15-second rest interval between attempts. After the knee extension test, participants were given a 1-hour rest to allow for fatigue recovery. Elbow flexion strength testing followed a similar protocol. Participants lay supine, with strap belts securing their torso on the bench, and their elbows fixed at a 90-degree angle. This angle was selected based on a study that identified it as the strongest elbow flexion angle during isometric testing [23].

Participants performed maximal elbow flexion for three 5-second repetitions, with a 15-second rest between attempts. Accurate measurements were

Table 1. Training programs

Week	Traditional strength program	Combined strength program
Week 1-2	a. Knee extension 3 sets 70% 1RM	a. Knee extension 2 sets 70% 1RM
	b. Preacher curl 3 sets 70% 1RM	b. Knee extension 1 sets 30% 1RM + BFR c. Preacher curl 2 sets 70% 1RM d. Preacher curl 1 sets 30% 1RM + BFR
Week 3-4	a. Knee extension 6 sets 70% 1RM	a. Knee extension 3 sets 70% 1RM
	b. Preacher curl 6 sets 70% 1RM	b. Knee extension 3 sets 30% 1RM + BFR c. Preacher curl 3 sets 70% 1RM d. Preacher curl 3 sets 30% 1RM + BFR
Week 5-6	a. Knee extension 8 sets 70% 1RM	a. Knee extension 4 sets 70% 1RM
	b. Preacher curl 8 sets 70% 1RM	b. Knee extension 4 sets 30% 1RM + BFR c. Preacher curl 4 sets 70% 1RM d. Preacher curl 4 sets 30% 1RM + BFR

Note. Equipment - Knee extension machine (Body-Solid, USA); Preacher curl machine (Body-Solid, USA); Number of repetitions - To failure; Tempo (Concentric: Eccentric phase) - 2seconds each; Range of motion - Full range of motion; Rest interval between sets - 60 seconds; Rest interval between exercises - 4 minutes; Exercise order: a>b or a>b>c>d; Abbreviation: TSP - Traditional strength program; CSP - Combined strength program; BFR - Blood flow restriction; 1RM - 1 repetition maximum.

ensured using a gold-standard isokinetic machine (ISOFORCE, Germany).

Strength ratio calculation

The strength ratios for both knee extension and elbow flexion were calculated by dividing the maximum isometric strength for each movement by the participant’s bodyweight, following the method used in a previous study [24]. This ratio provided a normalized measure of strength relative to body mass, allowing for more accurate comparisons across participants of varying sizes.

Maximum dynamic strength test

Maximum dynamic strength was assessed using knee extension and preacher curl machines (Body-Solid, USA) by determining the heaviest load a participant could lift for one repetition with a full range of motion. After a standardized warm-up consisting of 3 sets of 10 repetitions with progressively heavier, self-selected loads for each exercise, participants began the one-repetition maximum (1RM) attempts. These attempts started with a load heavy enough to allow for 3-5 repetitions, and the weight was gradually increased until the participant failed to lift the load for one perfect repetition. Each attempt consisted of one repetition, with at least 3 minutes of passive recovery between attempts. Participants were strongly encouraged to exert maximum effort during each trial. The 1RM for knee extension was tested first, followed by the 1RM for the preacher curl after a one-hour rest.

Statistical Analysis

The statistical analysis was conducted to investigate the effects of two different training protocols on muscle strength and perceived effort. The Shapiro-Wilk test was used to assess the distribution of the data. Descriptive statistics were calculated to summarize the baseline characteristics of both groups. A one-way ANOVA was employed to compare baseline variables between the two groups. Levene’s test was used to assess the homogeneity of variances. A two-way repeated measures ANOVA was conducted to compare the effects between groups (TSP vs. CSP) and time points (Pre vs. Post). Changes in each muscle strength metric and 95% Confidence Intervals (CI95%) were also calculated. Effect size was calculated using the formula: mean change /

pooled SD, with interpretation based on Hopkins’ recommendations: 0.00–0.19: Trivial; 0.20–0.59: Small; 0.60–1.19: Moderate; 1.20–1.99: Large; ≥ 2.00 : Very large [25]. Statistical analyses were performed using IBM SPSS Statistics version 20, with the significance level set at $\alpha = 0.05$.

Results

The baseline characteristics of the participants are shown in Table 2. Of the 20 participants, 2 dropped out, 1 due to loss of interest and 1 due to an unexpected injury, resulting in 8 participants in the CSP group and 10 in the TSP group. Statistical analysis revealed no significant differences in participant characteristics between the two groups at baseline ($p > 0.05$).

The changes in muscle strength from pre- to post-intervention are presented in Table 3. Both the traditional strength program (TSP) and the combined strength program (CSP) groups showed significant improvements in all measured parameters ($p < 0.05$). The effect sizes (ES) indicate strong improvements across most measures for both groups.

Significant main effects of time were observed for all strength metrics (all $p < 0.01$). Firstly, substantial increases in isometric knee extension strength were recorded, with $\Delta 32.3\%$ (ES = Large) in the CSP group and $\Delta 34\%$ (ES = Large) in the TSP group. Similarly, significant increases in isometric elbow flexion strength were observed, with $\Delta 38.5\%$ (ES = Large) in the CSP group and $\Delta 43.1\%$ (ES = Large) in the TSP group (Figure 1).

Moreover, 1RM strength significantly increased in both the TSP and CSP groups. In knee extension, the increases were $\Delta 19.7\%$ (ES = Moderate) for TSP and $\Delta 26.8\%$ (ES = Moderate) for CSP. For elbow flexion, the increases were $\Delta 28.6\%$ (ES = Moderate) for TSP and $\Delta 17.8\%$ (ES = Small) for CSP (Figure 2).

Similarly, both knee extension and elbow flexion strength ratios significantly increased in both groups. For TSP, the increases were $\Delta 32.7\%$ (ES = Large) for knee extension and $\Delta 44.6\%$ (ES = Large) for elbow flexion. For CSP, the increases were $\Delta 31.7\%$ (ES = Moderate) for knee extension and $\Delta 40\%$ (ES = Large) for elbow flexion (Figure 3).

However, no significant main effects of group or interaction were observed for any strength metrics (all $p > 0.05$) (Table 3).

Table 2. Participants characteristics at baseline

Variable	Traditional strength program (n=10)	Combined strength program (n=8)	F	p-value
Age (years)	21.25±0.7	21±0	1.27	0.28
Height (cm)	173.1±5.5	174.6±5.3	0.01	0.93
Body mass (kg)	68.5±11.4	69.5±11.9	0.48	0.50

Note. Data were presented as mean ± standard deviation

Table 3. Changes in muscle strength from Pre to Post

Measurement	Traditional strength program (n=10)				Combined strength program (n=8)				Effect p		
	Pre	Post	Change (CI95%)	ES	Pre	Post	Change (CI95%)	ES	Group	Time	Interaction
Isometric KE (N)	229.10 ±57.51	307.00 ±67.65 *	77.90 (55.87;99.92)	1.24	239.88 ±62.91	317.25 ±59.40 *	77.37 (43.32;111.42)	1.26	.71	.00	.98
Isometric EF (N)	43.90 ±12.54	62.80 ±5.47 *	18.90 (10.93;26.86)	1.95	48.63 ±10.29	67.37 ±13.24 *	18.75 (8.54;28.96)	1.64	.29	.00	.98
1RM KE (kg)	64.41 ±9.02	77.11 ±13.01 *	12.70 (8.16;17.24)	1.13	69.74 ±18.13	88.45 ±27.00 *	18.71 (9.10;28.32)	0.81	.31	.00	.18
1RM EF (kg)	31.50 ±11.07	40.50 ±9.85 *	9.00 (6.74;11.26)	0.86	38.75 ±13.82	45.63 ±13.21 *	6.88 (3.05;10.70)	0.51	.28	.00	.26
KE strength ratio (N/kg)	3.39 ±0.90	4.50 ±0.93 *	1.11 (0.87;1.36)	1.22	3.57 ±1.02	4.70 ±1.00 *	1.13 (0.68;1.59)	1.12	.68	.00	.93
EF strength ratio (N/kg)	0.65 ±0.21	0.94 ±0.17 *	0.28 (0.15;0.42)	1.49	0.73 ±0.21	1.00 ±0.17 *	0.27 (0.14;0.39)	1.42	.40	.00	.87

Note. Data were presented as mean ± standard deviation. 1RM - 1 repetition maximum; KE - Knee extension; EF - Elbow flexion; ES - effect size. * - p < 0.05

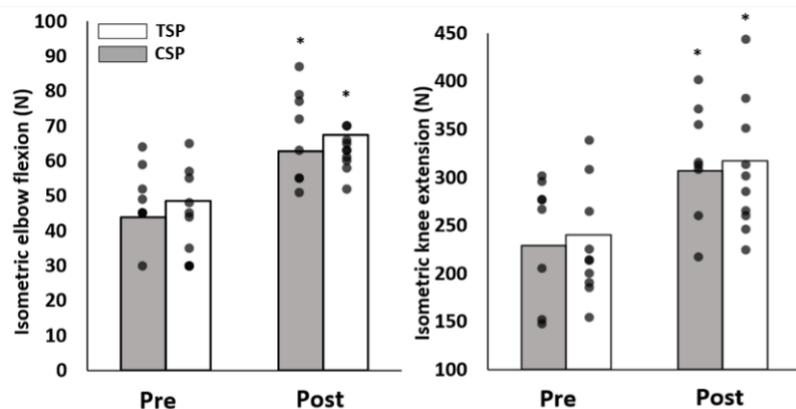


Figure 1. Change in isometric elbow flexion and isometric knee extension from Pre to Post. Individual analyses were illustrated in black dots. * - indicates p < 0.05 to Pre.

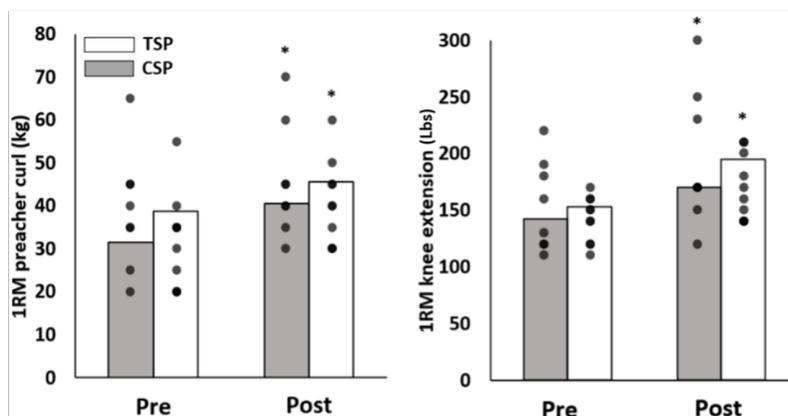


Figure 2. Change in 1RM preacher curl and 1RM knee extension from Pre to Post. Individual analyses were illustrated in black dots. * - indicates p < 0.05 to Pre.

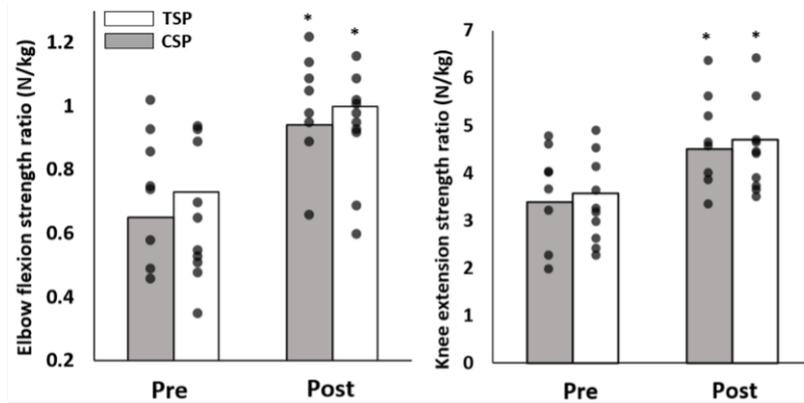


Figure 3. Change in elbow flexion strength ratio and knee extension strength ratio from Pre to Post. Individual analyses were illustrated in black dots. * - indicates $p < 0.05$ to Pre

Discussion

This study compared the effects of two different 6-week resistance training programs, CSP and TSP, on maximum strength gains. The primary findings revealed that CSP resulted in strength gains comparable to those achieved with TSP across all strength metrics. To the author's knowledge, this is the first study to demonstrate that achieving maximum strength gains does not necessarily require maintaining high intensity across every set throughout the entire training program, especially for novice lifters during the early weeks of training. These findings have significant implications for the design of training programs. The substantial improvements in all strength metrics were likely attributable to neural adaptations occurring in the early stages [19]. It was hypothesized that these neural adaptations played a crucial role in the observed strength gains, particularly in novice lifters. To better understand these neural adaptations, future studies could benefit from using electromyography (EMG) or electroencephalography (EEG) to investigate the underlying neural mechanisms associated with this program.

In comparison, our findings are consistent with several previous studies that demonstrated high-intensity resistance training alone can significantly increase maximal strength. For instance, Clark and colleagues found that knee extension training at 80% 1RM increased 1RM knee extension by 13% in 4 weeks [26]. Similarly, another study reported a 16.8% increase in isometric knee extension strength after 12 weeks of training at 80% 1RM [27]. Additionally, Libardi and colleagues observed a 38.1% increase in 1RM leg press following 70-80% 1RM resistance training [28]. Our study extends this literature by showing that after 6 weeks of high-intensity training, both maximum isometric and dynamic strength, as well as strength ratios, improved in both upper and lower body musculature.

Moreover, in the combined group (CSP), participants performed high-intensity sets for only half of their training volume, with the remaining

half consisting of low-intensity sets with BFR. This innovative approach demonstrated that novice lifters did not need to use high-intensity sets throughout their entire training program. Previous research supports this strategy, showing that low-intensity resistance training with BFR can minimize muscle damage [11] and enhance recovery [12]. This aligns with Scott's suggestion that incorporating low-intensity training with BFR might help manage musculotendinous stress, promoting recovery and allowing for more frequent training sessions [10]. Our study's findings reinforce this idea, suggesting that integrating high-intensity sets only part of the time can be effective for novice lifters. To further explore this approach, future research should examine the impact of increasing training frequency within this combined training regimen to determine if more frequent application could yield additional benefits.

Additionally, we addressed the limitations of BFR training on muscle strength, as reported in earlier meta-analyses. It was found that while low-intensity resistance training with BFR can increase muscle strength to some extent, the gains are still inferior to those achieved with high-intensity resistance training alone [13]. For instance, Martin-Hernandez and colleagues showed that low-intensity 20% 1RM knee extension training with BFR increased 1RM knee extension and isokinetic knee extension by 6.3-7% and 2.6-4.67%, respectively. However, high-intensity training at 85% 1RM resulted in much larger increases of 18.3% and 6.5%, respectively [17]. Similarly, Ozaki and colleagues demonstrated that low-intensity bench press with BFR increased 1RM by 8.7%, while training at 75% 1RM led to a twofold greater increase of 17.7% [29].

Furthermore, several studies highlighted that strength gains were clearly suboptimal when low-intensity resistance training was performed without BFR. For example, when comparing programs using 8-12 RM and 20-25 RM, it was found that 1RM improvements in bench press and leg press were considerably lower in the higher-repetition range

(8% vs 14.1% for bench press and 29.4% vs 41.9% for leg press) [30].

We proposed that incorporating a few high-intensity sets into a low-intensity resistance training program with BFR could enhance maximal strength gains to levels comparable to those achieved through high-intensity training alone. This approach addressed the issue of suboptimal strength gains associated with low-intensity training [13]. Previous studies supported this rationale, showing that high-intensity sets performed to failure result in greater neural adaptations compared to low-intensity training to failure [31]. Additionally, Schoenfeld and colleagues noted that low-intensity training to failure might not fully engage the entire motor unit pool, particularly the stronger fast-twitch fibers, which are typically recruited later in the process [32]. This insufficient activation of fast-twitch fibers could compromise muscle strength adaptations. By including high-intensity sets, lifters could ensure the recruitment of these fibers, likely contributing to the comparable strength gains observed in our study. However, as mentioned earlier, it may not have been necessary to employ high-intensity efforts in every set to achieve maximal adaptations. The approach used in this study, incorporating high-intensity sets for only half of the total volume, may have been sufficient for optimizing strength gains in novice lifters.

This study was not without limitations. While its strength lay in confirming muscle strength improvements through various testing methods, which enhanced the validity of our findings, there are areas requiring further investigation. Firstly, this study was conducted with novice lifters, and the results might not be directly applicable to more experienced individuals. Future research should examine this protocol with trained participants to verify its effectiveness across different experience levels. Additionally, exploring other muscle groups would be beneficial to determine if similar benefits can be observed.

Conclusions

This study demonstrated that achieving maximum strength gains does not require high-intensity training in every set. Both TSP and CSP, which included high-intensity sets for only half of the training volume, produced comparable improvements in strength metrics over 6 weeks. The effectiveness of CSP underscores the potential for optimizing strength gains with a more varied approach to intensity. Moreover, this approach can offer benefits in terms of reduced fatigue and enhanced recovery, making it particularly suitable for novice lifters. Future research should explore the long-term effects of this training strategy and its applicability to more experienced athletes and other muscle groups.

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