Scientific Reports

https://doi.org/10.1038/s41598-026-40612-5

Article in Press

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Received: 30 January 2025

Accepted: 13 February 2026

Published online: 24 February 2026

Cite this article as: Pancar Z., Ilhan M.T., Darendeli M.K. *et al.* Effects of deload periods in resistance training on muscle hypertrophy and strength endurance in untrained young men using a randomized within subject design. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-40612-5

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scientific reports

Effects of Deload Periods in Resistance Training on Muscle Hypertrophy and Strength Endurance in Untrained Young Men Using a Randomized Within Subject Design

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Abstract

This study aimed to investigate the effects of deload periods implemented through reductions in weekly set volume and training frequency at the midpoint and endpoint of an 8-week resistance training (RT) program on muscle hypertrophy and strength-endurance in untrained individuals. 19 untrained young men participated in the study using a within-subject design. Each participant's legs and arms were randomly assigned to the continuous and deload training conditions. In the continuous condition, unilateral leg extension and biceps curl exercises were performed twice per week for 8 weeks (6–8 sets per exercise, 8–12RM). In the deload condition, a similar training program was followed; however, during weeks 4 and 8, the exercises were performed only once per week with 2 sets per exercise. Muscle thickness was measured with ultrasound, while strength-endurance was assessed with 10-repetition maximum (10RM) testing, pre- and post-intervention. Both conditions produced similar, statistically significant increases in quadriceps/biceps muscle thickness and 10RM (single exception: lateral 30%—deload, $p = 0.073$). No time × condition interactions were detected for muscle thickness or strength-endurance ($p = 0.239$–0.955); between-condition effects were small ($\eta p^2 = 0.001$–0.076), and all Δ 95% confidence intervals included zero. In conclusion, reducing training volume and frequency at the midpoint and endpoint of an 8-week resistance training program does not appear to hinder adaptations in muscle hypertrophy and strength-endurance in untrained young men.

Keywords: Resistance training; Muscle hypertrophy; strength-endurance; deload; training volume

Introduction

Building and maintaining skeletal muscle mass and strength across the lifespan is a well-known aspect of a healthy lifestyle (1, 2, 3). Resistance training (RT) is the primary intervention strategy used to increase muscle mass and strength (4). Optimizing RT-induced adaptations may require the appropriate manipulation of key training variables, including the number of sets (5), load (6), weekly frequency (7), and proximity to failure (8). However, deload periods are commonly used in practice within RT programs to prevent potential performance declines and support recovery (9, 10, 11, 12). Deloading is sometimes considered in similar terms to tapering, yet these two strategies serve different purposes. Tapering typically refers to a period of reduced training volume in the days or weeks leading up to a competition, with the goal of achieving peaking (13, 14). In contrast, the primary aim of deloading periods is not to induce peaking, but rather to enhance readiness for the subsequent training cycle (12). Moreover, deloading periods are implemented not before competition, but at various points within the overall training cycle (12, 15, 16).

Deloading is generally implemented every 4–6 weeks for a duration of approximately 7 days, (12). During a deload period, common approaches include reducing training volume, decreasing training intensity, using a combination of both strategies, or even implementing complete training cessation (9, 11, 12). However, it remains under-researched despite being commonly used (10, 11, 12). Ogasawara et al. (2011, 2013) conducted two studies comparing continuous resistance training and periodic training that included a 3-week deload period (complete training cessation) on upper-body muscle size and strength in untrained young men (17, 18). Their findings showed that both training approaches were similarly effective in improving muscle size and strength. However, these studies have certain limitations. The deload duration (3 weeks) was longer than what is typically used in practice (5–7 days), and both the training protocols and outcome assessments were limited to the bench press and upper-body muscles, which reduces the generalizability of the findings (17, 18). In another study conducted by Coleman et al. (2024), the group that followed a 9-week continuous RT program and the group that implemented a one-week deload period at the midpoint showed similar improvements in lower-body hypertrophy and local muscular endurance; however, lower-body strength increased more in the continuous training group (19). In this study, only lower-body muscular adaptations were assessed; therefore, no inferences can be made regarding the effects of deloading on upper-body muscles. As in previous studies (17, 18), the findings are specific to a deload protocol involving complete cessation of RT (19).

Although these studies suggest that deload periods involving short-term training cessation do not negatively affect long-term muscle hypertrophy (17, 18, 19), the literature also reports that even a 7–10 day detraining period may lead to reductions in muscle thickness (20), decreases in the cross-sectional area of muscle fibers (21), and shortening of muscle fascicle length (22). Hortobágyi et al. reported that a 14-day detraining period in power athletes did not alter the size of slow-twitch fibers in the vastus lateralis or maximal concentric and isometric strength levels, but led to significant decreases in fast-twitch fiber size and maximal eccentric strength (23). Therefore, implementing a deload period involving a reduction in training volume and/or intensity, rather than complete training cessation, may support the recovery of physiological systems supporting performance, potentially mitigating detraining effects and even enhancing adaptations (24). However, evidence on this topic remains limited (19). Vann et al. (2021) examined the effects of one week of active (i.e., reduction in training volume) and passive recovery (i.e., complete cessation from training) on muscle hypertrophy and molecular markers following six weeks of RT (16). Their findings indicated that both recovery methods resulted in similar outcomes. However, a subsequent training cycle was not included in the study. In addition to short-term recovery strategies, Bickel et al. (2011) reported that following 16 weeks of resistance training muscle mass and strength could be maintained and/or improved with a markedly reduced training volume (i.e., reduced to one-third or one-ninth) (25). Similarly, these findings are also supported by the study conducted by Tavares et al. (2017) (26). However, because the studies did not include a group that maintained the initial training volume or applied a temporary reduction followed by reloading (i.e., a deload model), no direct conclusions can be drawn regarding the effects of deload periods. Nevertheless, it can be speculated that during deload periods, rather than completely ceasing training, an approach involving a reduction in training volume may help to prevent potential declines in muscular adaptations; however, this hypothesis has not been tested.

Given the conflicting findings of studies examining the effects of deload strategies on muscular adaptations, as well as the paucity of evidence regarding the effects of different deload approaches (10, 12, 19,) the aim of this study was to investigate the effects of deload periods, implemented at the midpoint and endpoint of an 8-week RT program, involving reductions in weekly set volume (by approximately 66–75% per exercise) and frequency (from two to one day per week) on muscle hypertrophy and strength-endurance in untrained individuals. To this end, we employed a within-subject study design. Although this design may present potential limitations for assessing strength outcomes due to cross-education and neural adaptations (27), it is considered a powerful approach for comparing muscle hypertrophy resulting from two different interventions (28). Moreover, it may be more advantageous than traditional parallel-group designs, as it allows for better control of environmental and behavioral confounding factors such as diet, sleep, and training history (29). We hypothesized that the deload and continuous training conditions would result in similar muscle hypertrophy and strength-endurance outcomes.

Methods

Study Design

This study employed a within-subject design. This design was specifically chosen because it controls for genetic and lifestyle factors, thus providing increased precision of effect estimation (28). The rationale for selecting this design has been described in detail in a previous publication (30). The study lasted a total of 11 weeks, including 1 week of familiarization training, 1 week of pre-testing, 8 weeks of training intervention, and 1 week of post-testing (**Figure 1**). Following the pre-testing, the participants' legs and arms were randomly assigned to the training conditions (continuous and deload). For example, if a participant's right leg was assigned to the continuous training condition, the left leg was assigned to the deload training condition. Random allocation was performed using a computer-generated permuted block randomization sequence (block size = 4) to ensure balanced distribution of limbs across conditions. The allocation sequence was concealed from both participants and researchers until assignment. An independent researcher generated the sequence using a computerized tool, and a separate researcher, blinded to the allocation, performed the assignments. Outcome assessors and statisticians were also blinded to group allocation. However, due to the nature of the intervention, participants could not be blinded.

In the continuous training condition, unilateral leg extension and unilateral dumbbell biceps curl exercises were performed twice per week for 8 weeks (6–8 sets per week per exercise, 8–12 RM), with each set continued until technical failure. In the deload training condition, the same resistance training program was followed throughout the intervention period, except during weeks 4 and 8. During these two weeks, the limbs assigned to the deload condition performed the exercises once per week, with two sets per exercise. Therefore, over the 8-week intervention period, the deload protocol involved approximately 18% lower total set volume per muscle group compared to the continuous protocol (deload: 46 sets, continuous: 56 sets). Before and after the training intervention, muscle thickness of the biceps brachii and the middle and lateral regions of the quadriceps femoris was assessed using B-mode ultrasound imaging, while strength-endurance was evaluated via 10RM tests in the respective trained exercises. The testing and training sessions were supervised by at least two researchers. This study was approved by the Gaziantep University Health and Sports Sciences Ethics Committee (Protocol Code: 2024/03) and conducted in accordance with the Declaration of Helsinki. This study was registered on ClinicalTrials.gov Identifier: NCT06825052 on (**13/02/2025**). The raw data supporting the findings of this study will be made available by the authors upon reasonable request, in line with transparency standards. In addition, the data will be deposited in an open-access repository (Open Science Framework, OSF) to promote reproducibility. The registration details can be accessed via the following link: 12/01/2025 (https://osf.io/6cgpt/?view_ only =7a55420f9c0843838b7da349ba26195f]).

The predefined research questions, corresponding hypotheses, sample size justification, and analysis plans are presented in **Supplementary Table S1.**

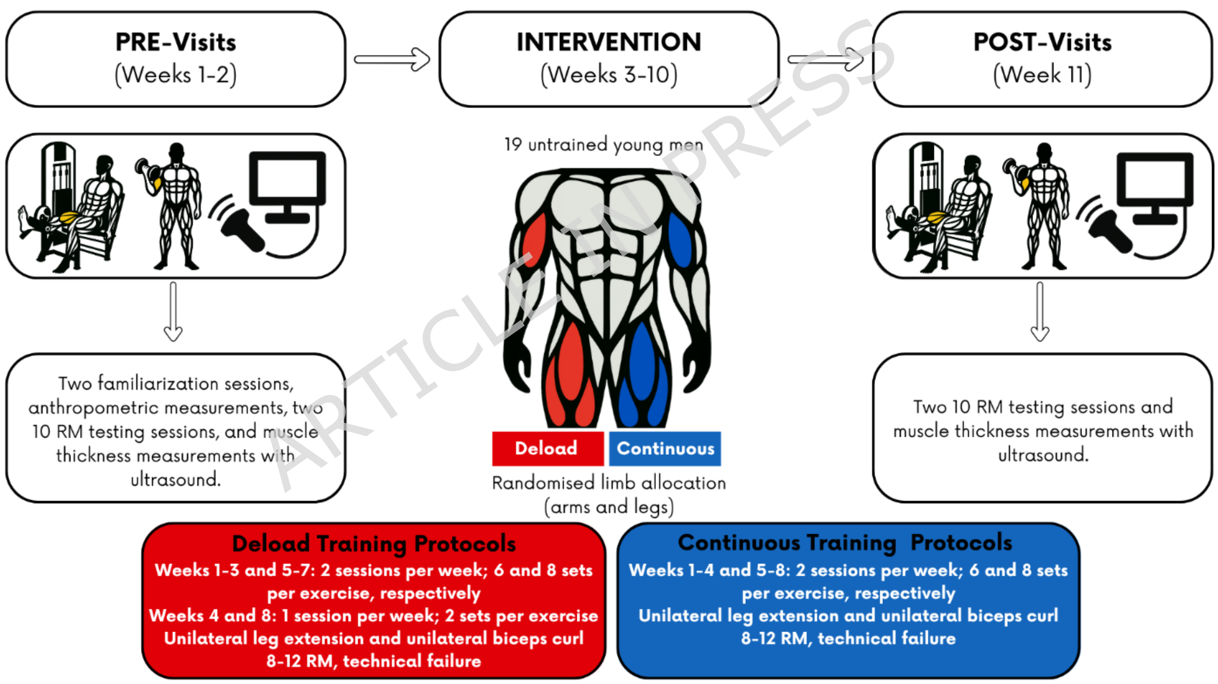


Figure 1. Schematic overview of study design and resistance training protocols (created by the authors). RM; repetition maximum.

Participants

The sample size for this study was determined a priori to achieve a statistical power of 0.8 and an α level of 0.05, with an estimated minimum of 15 participants required. Directly comparable studies with the same design are limited in the literature; therefore, we relied on effect sizes reported in systematic reviews and meta-analyses on resistance training-induced muscle hypertrophy (SMD ≈ 0.34–0.63) and selected Cohen's d = 0.55 as a conservative estimate (5, 31, 32). The calculation was based on a within-subject (dependent) design, in which each participant's limbs were allocated to two different training conditions. This moderate effect size, commonly reported for hypertrophy-related outcomes, was adopted to ensure adequate statistical power even if the true effects were smaller. Importantly, the actual effect sizes observed in our study were generally greater than 0.55, suggesting that the a priori assumption was reasonable (33). To be eligible for inclusion in the study, volunteers had to meet the following inclusion criteria: (a) men, 18–35 years old; (b) no participation in a structured resistance training program in the previous 6 months; (c) free from cardiorespiratory, orthopedic, or musculoskeletal disorders that could impede exercise practice; (d) negative responses to all items on the Physical Activity Readiness Questionnaire (PAR-Q); and (e) no use of anabolic steroids or illegal substances known to enhance muscle size. As a result, we recruited 20 volunteers from a university population to participate in this study. However, one participant dropped out due to an injury unrelated to the study. Therefore, the final sample size was 19 participants (age = 21.79 ± 1.69; height = 170.84 ± 8.95 cm; weight = 63.21 ± 9.99; BMI (kg/m^2) = 21.62 ± 2.46). To avoid potential dietary confounding of results, participants were instructed to maintain their habitual dietary intake and to refrain from using creatine products throughout the study period, as this supplement has been shown to enhance muscle development when combined with resistance training (34). Written informed consent was obtained from all participants after a detailed explanation of the study procedures was given.

Resistance Training Procedures

During the resistance training intervention, unilateral leg extension and unilateral dumbbell biceps curl exercises were performed. All exercises were conducted within a target range of 8–12 repetitions until technical failure, defined as the inability to complete an additional concentric repetition while maintaining proper technique. Training loads were adjusted from set to set within each session to ensure that the prescribed repetition range was maintained and technical failure was achieved. If more than 12 repetitions were completed in a set, the load was increased by approximately 10% in the following set. Conversely, if fewer than 8 repetitions were completed in a set, the load was decreased by approximately 10%. The repetition cadence was standardized, with the concentric phase lasting approximately 1 s and the eccentric phase approximately 2 s, supported by a metronome to ensure consistency. The rest interval between sets and exercises was set to 120 s. Additionally, a 30 s rest period was provided between limbs. Limb training order was alternated each week, meaning that in Weeks 1, 3, 5, and 7, exercise sessions started with the continuous limb, whereas in Weeks 2, 4, 6, and 8, sessions began with the deload limb.

Measurements and data collection

Anthropometry

Participants were instructed to refrain from eating for at least 8 hours prior to the anthropometric measurements, to avoid alcohol consumption in the 24 hours preceding testing, and to abstain from strenuous physical activity. They were also instructed to minimize fluid intake and to empty their bladder before the assessment. Height was measured using a stadiometer (SECA, Germany) with an accuracy of 0.1 cm, and body weight was measured using an electronic scale (SECA, Germany) with an accuracy of 0.1 kg. Body mass index (kg/m²) was calculated using the height and body weight values.

Dynamic muscle strength-endurance

Dynamic muscle strength-endurance was assessed using 10 RM testing for the unilateral leg extension and unilateral dumbbell biceps curl exercises, respectively. The 10RM loads were determined for both limbs using a counterbalanced order. Testing procedures were conducted in accordance with the guidelines established by the National Strength and Conditioning Association (35). In brief, participants performed a five-repetition warm-up set at approximately 50% of their estimated 10RM, followed by one or two sets of 2–3 repetitions using a load corresponding to approximately 60–80% of their estimated 10RM, with one-minute rest intervals between sets. Participants then performed a set of 10 repetitions with a heavier load. If successful, participants attempted a heavier load for 10 repetitions, continuing this process until they were unable to complete all 10 repetitions. During the 10 RM test, each participant was allowed a maximum of five attempts per exercise, with five-minute rest intervals between attempts. Each repetition was performed with a 1-second eccentric and a 1-second concentric phase, without pauses between contractions, with the tempo controlled by a metronome. A rest interval of at least 10 minutes was provided between the exercises. Standardized exercise techniques were employed to ensure proper execution, and verbal encouragement was provided throughout the tests. To ensure reliability, 10RM re-testing was conducted 48 to 72 hours later. The highest load lifted during both testing sessions was accepted as the 10RM load and used for the strength-endurance analysis. Post-intervention testing was conducted using the same procedures as the pre-intervention assessments.

Muscle Thickness Measurements

Data were collected as previously described (36). Measurements of longitudinal and transverse modes of muscle thickness were obtained at baseline and post-training using ultrasound imaging.

Ultrasound is a valid, reliable and low-cost method used to assess changes in muscle thickness (37). All tests were performed using a B-mode ultrasound imaging unit (Siemens Acuson S2000; Siemens, Erlangen, Germany). A water-soluble transmission gel (Aquasonic 100 Ultrasound Transmission gel; Parker Laboratories Inc., Fairfield, NJ, USA) was applied to each area to be measured and a 4-12 MHz linear array ultrasound probe was placed at the tissue interface without pressing against the skin. Once the image was of sufficient quality, it was recorded on a hard disk and the extent of muscle thickness was obtained by measuring the distance from the subcutaneous adipose tissue-muscle interface to the aponeurosis or muscle-bone interface. The calculation package of the machine was used for the values obtained for each measurement. Measurements were taken from both limbs and from three different muscle groups: (1) elbow flexors, (2) mid-thigh (a composite of the rectus femoris and vastus intermedius) and (3) lateral-thigh (a composite of the vastus lateralis and vastus intermedius). The anatomical locations were marked with a pencil before image acquisition to ensure consistency of measurements. For the anterior upper arm, measurements were taken at 60% of the distance between the lateral epicondyle and acromion process; mid-thigh and lateral-thigh measurements were obtained at 30%, 50% and 70% between the lateral condyle of the femur and the greater trochanter. Quadriceps measurements were performed with the participants lying on their backs with their legs extended (**Figure 2**). Biceps brachii measurements were performed with the subjects' arms relaxed and elbows extended (**Figure 3**). Muscle thickness measurements were performed at least 48 hours after the training session, considering research showing that acute increases in muscle thickness from resistance training return to baseline within 48 hours (38) and that muscle damage is minimal after repeated exposure to the same exercise stimulus over time (39, 40). To further ensure the accuracy of the measurements, 3 images were taken from each site and their average was used in the analysis. All measurements at baseline and after training were performed by the same experienced technician blinded to the resistance training protocol.

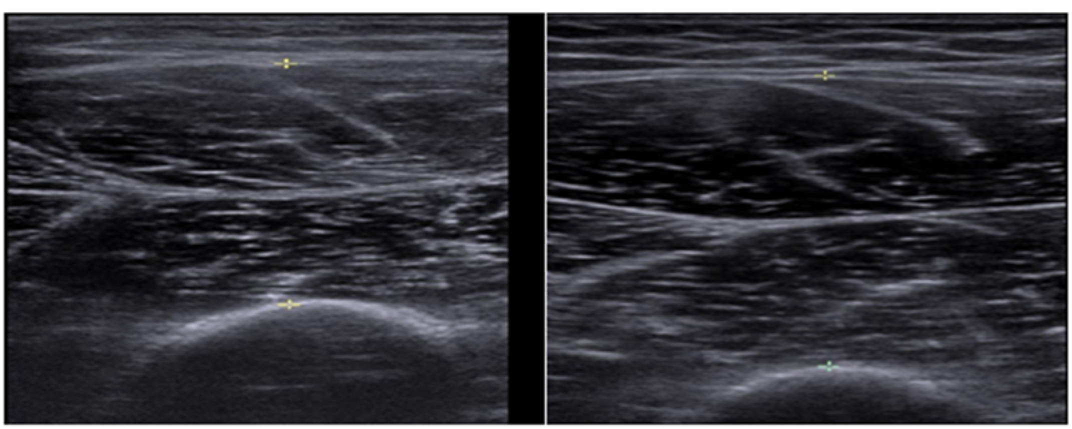


Image 3. Sample Case Quadriceps Pre-test **Image 3.** Sample Case Quadriceps Post-test

Figure 2. Pre and post-test examples of quadriceps thickness measurements.

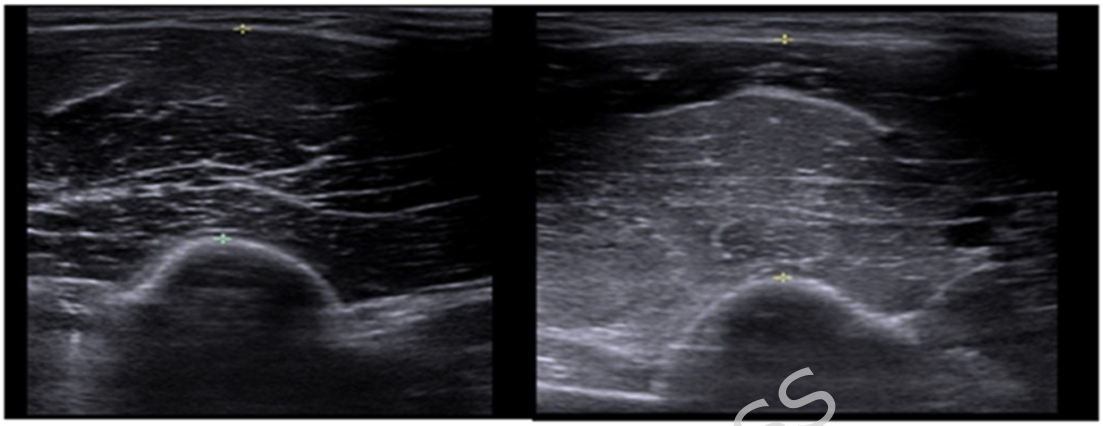


Image 1. Sample Case Biceps Pre-test **Image 2.** Sample Case Biceps Post-test

Figure 3. Pre and post-test examples of biceps thickness measurements.

Statistical Analysis

The data are reported as means ± standard deviations (SD). Normality was assessed using the Shapiro-Wilk test. For datasets that did not meet normality, skewness and kurtosis values within ±2 were considered acceptable to proceed with parametric tests (41). A two-way repeated-measures ANOVA with a 2 × 2 design (time × trial) was performed, adopting a 95% confidence interval. Post hoc pairwise comparisons were conducted using the Bonferroni correction where appropriate. Effect sizes were calculated using partial eta squared (ηp^2), with thresholds of 0.01 (small), 0.06 (medium), and 0.14 (large) interpreted accordingly (42).

In line with the preregistration protocol, complementary Bayesian paired-samples t-tests were conducted to quantify the strength of evidence for differences within conditions. Directional hypotheses (post > pre) were specified, and Bayes factors (BF_{10}) were interpreted according to Raftery's classification (43). Classical frequentist paired-samples t-tests were also reported to support comparisons within trials. Bayesian tests used the default JZS prior—a Cauchy prior on the standardized effect size δ centered at 0 with scale $r = 0.707$ (44), together with a Jeffreys prior on the variance (45). All analyses were carried out using Jamovi (version 2.5.6.0). Statistical significance was set at $p < 0.05$ for all frequentist tests.

Results

Table 1. Change-Score (Δ) Analysis Across Conditions

Variable	Δ Deload (95% CI)	Δ Continuous (95% CI)	Δ Difference (95% CI)	p (Paired Δ)	Time x Trial		
					F	p	ηp²
Lateral Quad 30% (mm)	+1.99 [−0.76, 4.74]	+2.27 [0.06, 4.48]	−0.28 [−2.61, 2.05]	0.803	0.035	0.853	0.002
Lateral Quad 50% (mm)	+3.18 [1.91, 4.45]	+3.94 [2.60, 5.28]	−0.76 [−2.20, 0.68]	0.282	0.563	0.463	0.030
Lateral Quad 70% (mm)	+4.12 [2.11, 6.13]	+4.20 [2.48, 5.92]	−0.08 [−2.12, 1.96]	0.937	0.003	0.955	0.001
Mid Quad 30% (mm)	+4.16 [2.97, 5.36]	+5.09 [3.71, 6.47]	−0.93 [−2.34, 0.48]	0.183	1.104	0.307	0.058
Mid Quad 50% (mm)	+5.67 [4.18, 7.15]	+6.74 [5.06, 8.43]	−1.08 [−2.75, 0.59]	0.191	1.093	0.310	0.057
Mid Quad 70% (mm)	+4.46 [3.38, 5.54]	+5.61 [4.11, 7.11]	−1.15 [−2.63, 0.33]	0.119	1.483	0.239	0.076
Upper Arm 60% (mm)	+6.03 [4.48, 7.58]	+6.33 [4.69, 7.96]	−0.30 [−1.88, 1.29]	0.698	0.077	0.784	0.004
10RM Leg (kg)	+17.63 [12.66, 22.61]	+16.84 [11.75, 21.94]	+0.79 [−0.66, 2.24]	0.268	1.306	0.268	0.068
10RM Arm (kg)	+3.55 [2.47, 4.64]	+3.42 [2.42, 4.42]	+0.13 [−0.14, 0.41]	0.331	0.073	0.790	0.004

Muscle thickness

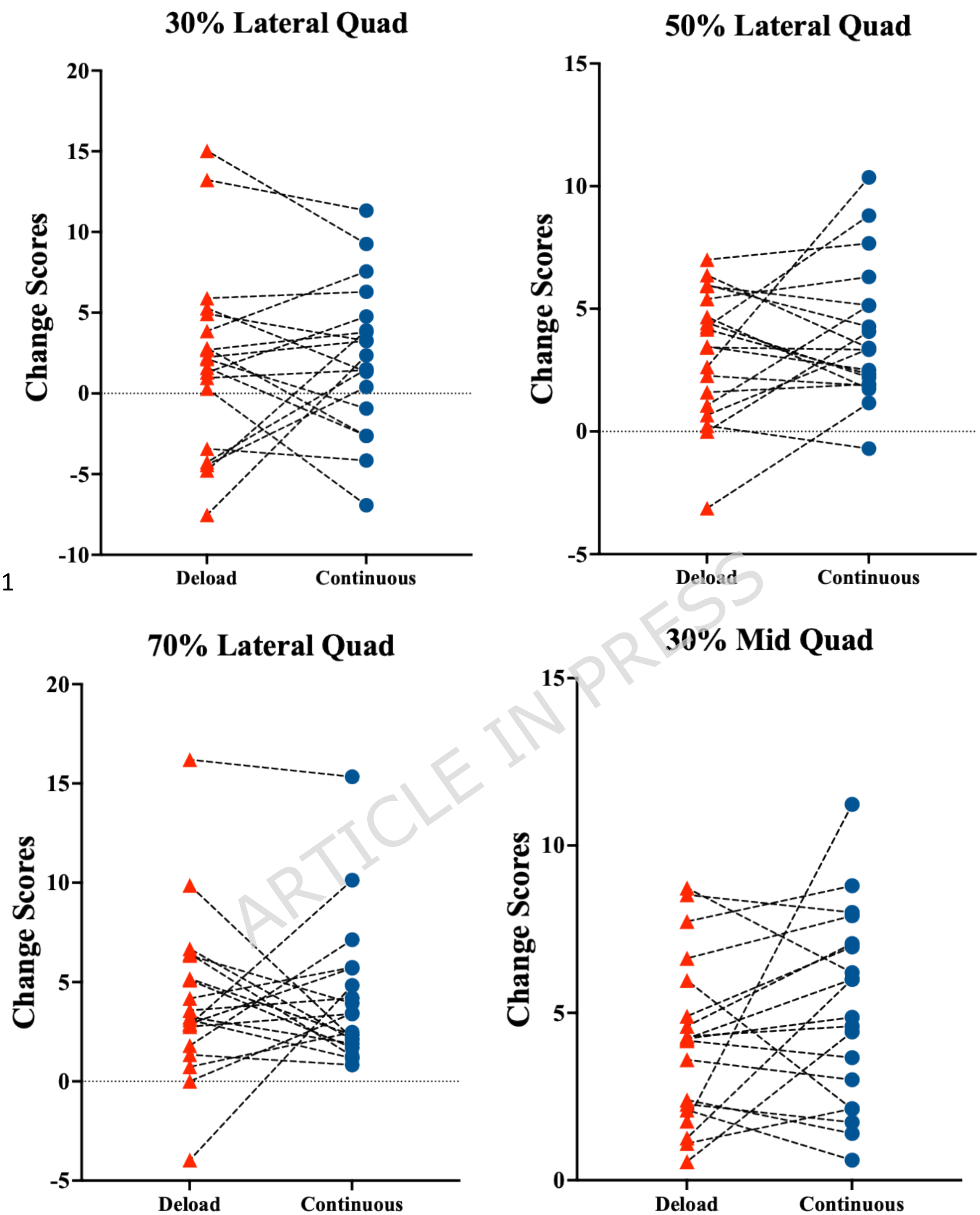
Across all measurement sites, both conditions improved from pre to post, and paired change-score comparisons did not indicate a between-condition advantage. For the lateral quadriceps at 30%, the change in the deload condition (Δ deload) was +1.99 mm [95% CI: −0.76, 4.74], whereas the change in the continuous condition (Δ continuous) was +2.27 mm [0.06, 4.48]. The paired change-score difference (Δ deload − Δ continuous) was −0.28 mm [−2.61, 2.05], p=0.803. The time × condition interaction effect was not statistically significant ($F(1,18)=0.035$, $p=0.853$, $\eta p^2=0.002$). At the lateral 50%, Δ deload was +3.18 mm [1.91, 4.45] and Δ continuous was +3.94 mm [2.60, 5.28]; the paired difference was −0.76 mm [−2.20, 0.68], p=0.282. Changes over time did not differ between conditions, as indicated by a non-significant time × condition interaction effect ($F(1,18)=0.563$, $p=0.463$, $\eta p^2=0.030$). At lateral 70%, Δ deload was +4.12 mm [2.11, 6.13] and Δ continuous was +4.20 mm [2.48, 5.92]; the paired difference was −0.08 mm [−2.12, 1.96], $p=0.937$. There was no evidence of a time × condition interaction effect ($F(1,18)=0.003$, $p=0.955$, $\eta p^2=0.001$).

A similar pattern emerged for the mid-thigh. At mid 30%, Δ deload was +4.16 mm [2.97, 5.36] and Δ continuous was +5.09 mm [3.71, 6.47]; the paired difference was −0.93 mm [−2.34, 0.48], $p=0.183$. The time × condition interaction effect was not statistically significant ($F(1,18)=1.104$, $p=0.307$, $\eta p^2=0.058$). At mid 50%, Δ deload was +5.67 mm [4.18, 7.15] and Δ continuous was +6.74 mm [5.06, 8.43]; the paired difference was −1.08 mm [−2.75, 0.59], $p=0.191$. Insufficient evidence was found for a time × condition interaction effect ($F(1,18)=1.093$, $p=0.310$, $\eta p^2=0.057$).

At mid 70%, Δ deload was +4.46 mm [3.38, 5.54] and Δ continuous was +5.61 mm [4.11, 7.11]; the paired difference was −1.15 mm [−2.63, 0.33], $p=0.119$. The time × condition interaction effect was non-significant and negligible in magnitude ($F(1,18)=1.483$, $p=0.239$, $\eta p^2=0.076$). For the anterior upper arm (60%), Δ deload was +6.03 mm [4.48, 7.58], whereas Δ continuous was +6.33 mm [4.69, 7.96]; the paired difference was −0.30 mm [−1.88, 1.29], $p=0.698$. No significant time × condition interaction effect was observed ($F(1,18)=0.077$, $p=0.784$, $\eta p^2=0.004$). Collectively, all (Δ deload − Δ continuous) 95% CIs included zero, and no time × condition interaction effect reached significance, indicating comparable hypertrophic responses between deload and continuous training across the 8-week period (see Table 1; Figure 4).

Strength-endurance (10RM)

For the unilateral leg extension, Δ deload was +17.63 kg [12.66, 22.61] and Δ continuous was +16.84 kg [11.75, 21.94]; the paired difference (Δ deload − Δ continuous) was +0.79 kg [−0.66, 2.24], $p=0.268$. The time × condition interaction effect was not statistically significant ($F(1,18)=1.306$, $p=0.268$, $\eta p^2=0.068$). For the unilateral biceps curl, Δ deload was +3.55 kg [2.47, 4.64] and Δ continuous was +3.42 kg [2.42, 4.42]; the paired difference was +0.13 kg [−0.14, 0.41], $p=0.331$. Consistent with the paired Δ comparison, the time × condition interaction effect was also non-significant ($F(1,18)=0.073$, $p=0.790$, $\eta p^2=0.004$). Overall, these Δ-based comparisons do not support a between-condition advantage for strength-endurance (see Table 1; Figure 4).


30% Lateral Quad
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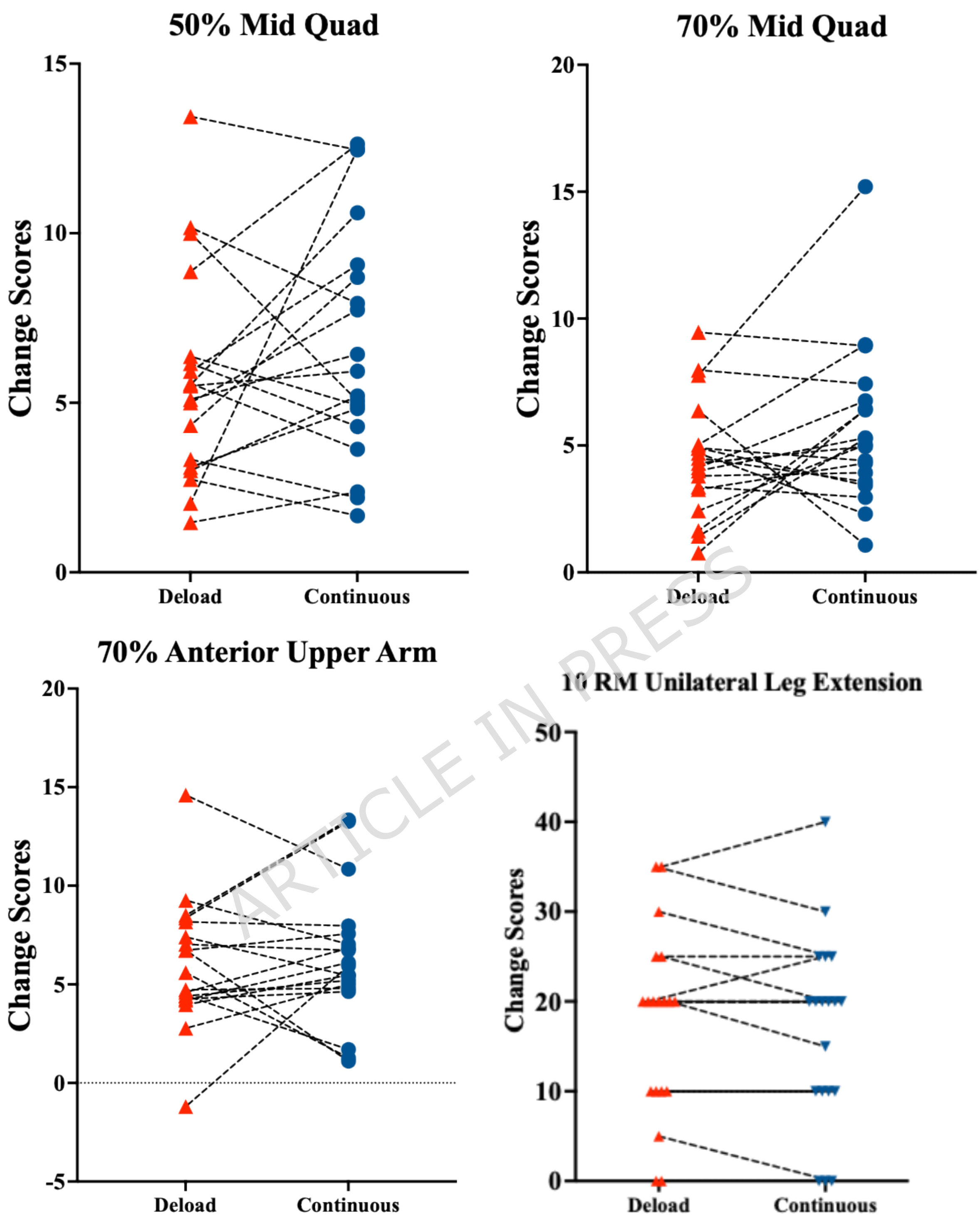
50% Mid Quad
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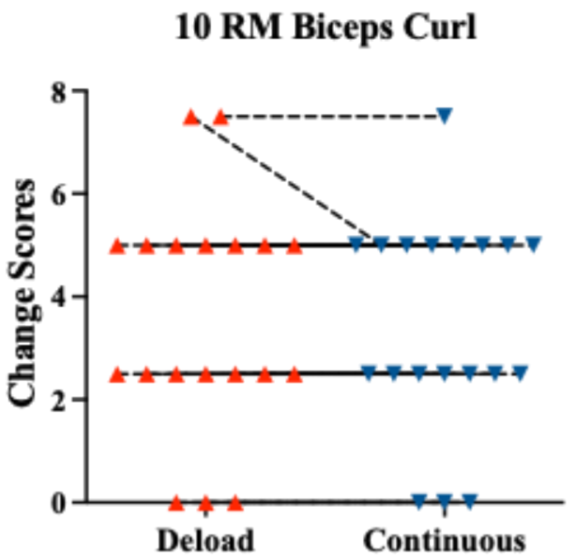

Figure 4. Individual change scores (Δ) by condition. (Y-axis shows Δ = post − pre; units: mm (MTH), kg (10RM); positive = increase)

Table 2. Within-Condition Pre–Post Changes (Complementary Bayesian & Frequentist Paired Tests)

Muscle Region (Site)	Condition	t(df)	p	Cohen's d	95% CI for d	BF_{10}	Interpretation
30% Lateral Quadriceps	Deload	–1.52 (18)	0.073	–0.349	[–0.808, 0.119]	1.163	Anecdotal
	Continuous	–2.16 (18)	0.022	–0.496	[–0.967, –0.012]	3.015	Moderate
50% Lateral Quadriceps	Deload	–5.28 (18)	< 0.001	–1.211	[–1.798, –0.604]	1019.008	Extreme
	Continuous	–6.19 (18)	< 0.001	–1.421	[–2.055, –0.767]	5647.607	Extreme
70% Lateral Quadriceps	Deload	–4.32 (18)	< 0.001	–0.990	[–1.534, –0.429]	158.901	Extreme
	Continuous	–5.12 (18)	< 0.001	–1.175	[–1.755, –0.576]	756.925	Extreme
30% Mid Quadriceps	Deload	–7.32 (18)	< 0.001	–1.679	[–2.376, –0.964]	41649.011	Extreme
	Continuous	–7.74 (18)	< 0.001	–1.776	[–2.497, –1.036]	84942.072	Extreme
50% Mid Quadriceps	Deload	–7.99 (18)	< 0.001	–1.835	[–2.571, –1.080]	129160.113	Extreme

	Continuous	–8.40 (18)	< 0.001	–1.926	[–2.686, 1.148]	– 245380.603	Extreme
70% Mid Quadriceps	Deload	–8.65 (18)	< 0.001	–1.984	[–2.759, 1.190]	– 365855.199	Extreme
	Continuous	–7.85 (18)	< 0.001	–1.802	[–2.529, 1.055]	– 101965.008	Extreme
70% Anterior Upper Arm	Deload	–8.16 (18)	< 0.001	–1.872	[–2.618, 1.108]	– 168458.272	Extreme
	Continuous	–8.13 (18)	< 0.001	–1.865	[–2.609, 1.103]	– 160562.214	Extreme
Leg Strength* (10 RM)	Deload	–7.44 (18)	< 0.001	–1.708	[–2.411, 0.985]	– 51418.511	Extreme
	Continuous	–6.95 (18)	< 0.001	–1.594	[–2.269, 0.899]	– 21789.768	Extreme
Arm Strength* (10 RM)	Deload	–6.87 (18)	< 0.001	–1.576	[–2.247, 0.886]	– 19069.323	Extreme
	Continuous	–7.18 (18)	< 0.001	–1.647	[–2.336, 0.940]	– 32735.051	Extreme

Directional hypothesis specified as Measure 1 – Measure 2 < 0 (implying post > pre, expected increases). BF_{10} refers to the Bayes factor in favor of the directional alternative. Interpretations based on Raftery (1995). *Strength-endurance

As summarized in **Table 2**, the Bayesian paired-samples t-tests (using the default JZS prior—a Cauchy prior on the standardized effect size δ centered at 0 with scale r = 0.707, together with a Jeffreys prior on the variance—and specifying a one-sided alternative, pre − post < 0 [i.e., post > pre]) supported the directional hypothesis of increased muscle thickness and strength following resistance training. For the 30% lateral quadriceps site, anecdotal to moderate evidence was observed in favor of increases, whereas all other measurement sites showed extreme evidence supporting the alternative hypothesis (BF_{10} > 1000 in most cases per Raftery's evidence categories). Corresponding Cohen's d values were consistently large, ranging from –0.349 to –1.984 for muscle thickness and from –1.576 to –1.708 for strength measures, with 95% confidence intervals generally excluding zero except for the 30% lateral quadriceps deload condition. These findings reinforce the conclusion that both deload and continuous protocols elicited increases in muscular hypertrophy and strength, with generally stronger effects observed in mid-quadriceps regions and for 10RM performance in both arms and legs. The directional Bayes factors (BF_{10}) consistently supported the hypothesized increases (post > pre), aligning with the anticipated training adaptations (Note: These within-condition tests establish pre–post increases but do not adjudicate between-condition differences; those are addressed by the Δ-based analyses.)

Discussion

To the best of our knowledge, this is the first study to examine the effects of deload periods implemented through reductions in weekly set volume and training frequency during an 8-week

RT program on muscle hypertrophy and strength-endurance in untrained individuals. Our findings showed that both the deload and continuous protocols resulted in similar increases in these outcomes. However, due to the absence of a time-matched, non-exercise control group, these results should be interpreted with caution, as we cannot rule out potential influences unrelated to the training interventions.

Muscle thickness increased in both training conditions throughout the intervention, with similar improvements found across all measurement sites. The findings are supported by previous studies that have examined the effects of deload periods on muscle size (17, 18, 19). Ogasawara et al. (2011, 2013) conducted two studies comparing the effects of continuous and periodic resistance training on muscular adaptations in untrained young men, using a RT program consisting of the bench press exercise performed for 3 sets of 10 repetitions at 75% of 1RM (17, 18). In the first study (17), they reported similar increases in muscle size after 15 weeks of continuous RT compared to a periodic RT program consisting of 6 weeks of training, 3 weeks of complete training cessation, and 6 weeks of training again. In the second study (18), no differences in muscle size were reported between 24 weeks of continuous resistance training and a periodic resistance training program consisting of three 6-week training periods, each separated by 3 weeks of complete training cessation. However, the deload durations used (e.g., 3 weeks) are considerably longer than those typically applied in RT practice (12). Additionally, the protocols were limited to the bench press exercise and assessed only upper-body muscles, restricting the generalizability of the findings to the lower body and other muscle groups. These limitations of the two studies conducted by Ogasawara et al. (2011, 2013) may limit the ecological validity of the findings (17, 18). In contrast, our study fills an important gap in the literature on untrained men by implementing a deload duration commonly used in practice (5-7 days), involving reductions in training volume and frequency, and including lower-body muscle thickness assessments. A recent study also compared a continuous 9-week RT program with an identical program incorporating a one-week midpoint deload in trained individuals, reporting similar lower-body muscle size gains in both groups (19). However, methodological differences in the study by Coleman et al. (2024), such as complete training cessation as the deload strategy, use of trained participants, and a high-volume protocol (20 sets/week/muscle group), make direct comparisons with our findings difficult (19). Nonetheless, based on the limited evidence available (17, 18, 19), when the goal of a relatively short-term RT program is to maximize muscle hypertrophy, both protocols may be effective. Still, further research is needed to determine how different deload strategies influence adaptations in higher-volume, higher-frequency, or longer-duration RT programs.

Following the training intervention, similar increases in strength-endurance, as assessed by 10 RM, were observed in both training protocols. In the studies conducted by Ogasawara et al. (2011, 2013), periodic training that included deload periods implemented as complete training cessation (i.e., 3 weeks) was shown to produce similar increases in upper-body strength compared to continuous training in untrained individuals (17, 18). Notably, in these studies, a 1RM test was administered every three weeks throughout the intervention, which may itself have contributed to a training effect (46). However, Coleman et al. (2024) showed that the group that continued training without interruption for 9 weeks demonstrated greater improvements in lower-body dynamic and isometric strength compared to the group that implemented a deload period by completely ceasing training at the midpoint of the 9-week RT program (19). Although the methodological differences we previously outlined make it difficult to draw firm conclusions, all existing research investigating the effects of deload periods on strength has employed RT programs primarily designed to maximize muscle hypertrophy (e.g., 8–12 RM) (17, 18, 19). In the present study, strength was assessed using the 10RM test, which therefore provided a measure of strength-endurance. Therefore, the similarity between the training and testing methods is thought to have possibly facilitated the transfer from training to testing. To more clearly reveal the effects of deload on strength, future studies should be structured using protocols specifically aimed at maximizing strength gains (i.e., low-volume, high-load). Moreover, there are no studies to date that have examined the effects of deload strategies involving short-term reductions in training volume and/or frequency, as opposed to complete training cessation, on muscular adaptations. Nevertheless, longer-term reductions in training volume have also been investigated with respect to the maintenance of muscle adaptations (25, 26). In the study by Bickel et al. (2011), following 16 weeks of lower-body resistance training (27 weekly sets), participants were randomly assigned to maintenance groups (3 sets per week or 9 sets per week) or to a detraining group (25). Over the subsequent 32 weeks, 3 sets per week preserved muscle mass in young adults, whereas 9 sets resulted in additional hypertrophy, and both maintenance protocols continued to increase maximal strength (25). In another study by Tavares et al. (2017), untrained males completed 8 weeks of strength training followed by 8 weeks in either reduced training groups (once or twice per week, with volume-load reduced by ~50–57%) or a detraining group (26). The reduced training groups maintained previously gained strength and quadriceps muscle size, whereas the detraining group experienced significant decreases (26). These findings indicate that reduced training volumes can play an important role in maintaining and/or improving previously gained adaptations. However, because these studies did not include a group that maintained the initial training volume or applied a temporary reduction followed by reloading (i.e., a deload model), no direct conclusions can be drawn regarding the effects of deload periods. Therefore, the present study aimed to address this gap by investigating the effects of deload periods implemented via temporary reductions in training volume and frequency.

Although there are no definitive conclusions on the topic, some studies have anecdotally reported that participants felt lethargic, lazy, or sluggish (i.e., out of practice) following short-term training cessation (19, 23). Together with this, considering the potential negative effects of short-term detraining (19, 23), implementing a deload involving a reduction in training volume and/or intensity rather than complete cessation may be a more reasonable approach. While the findings of our study indicate that both training protocols led to similar increases in muscle hypertrophy and strength-endurance, it is important to highlight that training in the deload protocol was performed with approximately 18% less set volume (46 vs. 56 sets per muscle group over 8 weeks, deload vs. continuous, respectively). Considering that only 10 to 30% of adults engage in RT (47) and that one of the major barriers to participation in such exercise is time limitation (48), these results highlight the potential time-efficiency of such an approach. Therefore, future research should not only examine the effects of deload periods on muscular adaptations but also explore their impact on training adherence, motivation, and psychological factors, which may provide a more comprehensive understanding of the role and practical value of deloading.

Our study has limitations that should be considered when interpreting the findings. First, our sample consisted of untrained young men. Therefore, the findings cannot necessarily be generalized to other populations such as adolescents, older adults, and trained individuals. Second, we used a within-subject design. Although this design allows for control of environmental and behavioral confounding factors (29), it may present a potential limitation for assessing strength outcomes due to cross-education and neural adaptations (27). Although the magnitude of the cross-education effect varies, it is typically around 7% (49). However, recent evidence suggests that the cross-education effect is minimal or negligible when both limbs are exposed to high-load resistance training (50). Third, the lack of a time-matched non-exercise control group may limit the ability to quantify the degree of measurement error over time (51). This limitation reduces the extent to which the observed changes can be confidently attributed solely to the intervention. Future research is encouraged to incorporate a time-matched, non-exercise control group to better distinguish the true effects of the intervention from potential confounding influences, such as measurement familiarity, natural variability, or time-related factors. Fourth, the study duration was limited to 8 weeks. Therefore, it is not possible to draw direct inferences about the effects of deload periods on muscle hypertrophy and strength-endurance over longer training periods. Fifth, the RT program in this study included only two exercises, including unilateral leg extension and unilateral dumbbell biceps curl. Therefore, our findings are limited in their ability to infer how deload periods would affect muscular adaptations in a RT program that includes more exercises targeting different muscle groups. Sixth, an additional muscle thickness assessment was not performed during the pre-intervention period. Although three consecutive measurements were taken from each anatomical site and all assessments were conducted by an experienced technician blinded to the RT protocol, an additional muscle thickness evaluation could have further improved measurement reliability.

Nevertheless, the procedure we employed for muscle thickness assessment is widely used in the RT literature (36, 52). Finally, the findings are specific to a pre-planned deload strategy involving reductions in training volume and frequency. Therefore, we cannot draw direct inferences about the effects of various deload strategies, including those that involve reduced training intensity, complete cessation of training, or are autoregulated, on muscular adaptations. Future studies should address these limitations to better understand the effects of different deload strategies on muscular adaptations.

Conclusions

The findings of this study suggest that deload periods implemented as reductions in training volume and frequency at the midpoint and endpoint of an 8-week RT program using a within-subject design may lead to similar increases in muscle hypertrophy and strength-endurance compared to continuous training in untrained individuals. This indicates that both training protocols may be effective strategies for enhancing these adaptations in early-phase RT. However, these findings should be interpreted considering the limitations of the study, such as the short intervention duration, the relatively low training volume, and the lack of a time-matched control group.

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Acknowledgements

The funders have/had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.
This study acknowledges the fund support from Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2026R424), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Data Availability

The raw data and materials associated with this study will be publicly available upon acceptance of the Stage 2 manuscript. The statistical analyses and results are already presented in tables and figures within the manuscript. Additionally, the raw data will be deposited in an open-access repository (Open Science Framework - OSF) to ensure transparency and reproducibility. The registration details are available at the following link (Date of registration: 12/01/2025): https://osf.io/6cgpt/?view_only =7a55420f9c08 43838b7da349ba26195f.
For additional inquiries regarding the data, please contact the corresponding author: (z_pancar@hotmail.com).

Author contributions

ZP, MTİ, EK, contributed to the study concept and study design. BK, MAİ, performed the statistical analysis and data interpretation. AMT, MSU, BK were responsible for the quality control of the data. MKD, MSU, ZP, AB and NHA performed the literature research and data extraction. NHA, SBA, AB, and ZP were responsible for the revision and academic proofreading of the manuscript. NHS, SBA, ZP and AB were responsible for project administration. All authors contributed to the writing of the manuscript and approved the final manuscript.

Competing interests

The authors declare no competing interests.