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Gaining more from doing less? The effects of a one-week deload period during supervised resistance training on muscular adaptations

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ABSTRACT

Based on emerging evidence that brief periods of cessation from resistance training (RT) may re-sensitize muscle to anabolic stimuli, we aimed to investigate the effects of a 1-week detraining interval at the midpoint of a 9-week RT program on muscular adaptations in resistance-trained individuals. Thirty-nine young men and women were randomly assigned to 1 of 2 experimental, parallel groups: An experimental group that abstained from RT for 1 week at the midpoint of a 9-week, high-volume RT program (DELOAD) or a traditional training group that performed the same RT program continuously over the study period (TRAD). The lower body routines were directly supervised by the research staff while upper body training was carried out in an unsupervised fashion. Outcomes included assessments of muscle thickness along proximal, mid and distal regions of the middle and lateral quadriceps femoris as well as the mid-region of the triceps surae, lower body isometric and dynamic strength, local muscular endurance of the quadriceps, and lower body muscle power. Results indicated similar between-group increases in lower body muscle size, local endurance, and power. Alternatively, TRAD showed greater improvements in both isometric and dynamic lower body strength compared to DELOAD. In conclusion, our findings suggest that a 1-week detraining period at the midpoint of a 9-week RT program appears to negatively influence measures of lower body muscle strength but has no effect on lower body hypertrophy, power or local muscular endurance.

Keywords: detraining; hypertrophy; strength; muscle endurance; re-sensitization

INTRODUCTION

A compelling body of evidence indicates that resistance training (RT) can promote appreciable increases in muscle size and strength [1]. However, it has been suggested that continuous bouts of intense RT are concomitantly associated with the accumulation of fatigue [2]. Deloads, herein defined as short periods (~1 week) of reduced training volume, load and/or intensity of effort, are a common strategy used to attenuate the accumulated physiological and psychological fatigue brought about by intense RT and thus conceivably reduce the potential for nonfunctional overreaching [3]. Deloads are also used to potentiate performance in subsequent training cycles or athletic competition [3 4]. While there is no universal paradigm by which deloads are employed in practice, detraining, or a complete cessation from RT, is a commonly used strategy [5].

Although current research analyzing the effects of detraining is limited, several studies have demonstrated mechanistic and pragmatic benefits when deloads are implemented into a training program [5 6 7]. Mechanistically, increases in serum testosterone and decreases in serum cortisol have been demonstrated following periods of detraining [8], which may potentiate muscular adaptations in following training cycles [9]. In addition, deloads may attenuate the reduction in anabolic signaling protein phosphorylation typically seen with continuous bouts of RT [10] as well as upregulate genes associated with muscle hypertrophy [11], facilitating a “re-sensitization” of muscle to hypertrophic stimuli. Pragmatically, it has been demonstrated that the short-term reduction in volume load associated with deloads results in increased muscle size as well as increased performance in the barbell back squat and bench press [12 13]. The diminished rate of muscular adaptations typically seen in the latter phases of RT programs may also be negated with the implementation of deloads [14].

Although the findings presented above are intriguing, current research on the effects of detraining does not reflect the typical practices of those in the lifting community. For instance, the length of detraining periods in the literature are typically much longer than what is commonly employed in real-world settings [14 7]. Moreover, there is no empirical evidence analyzing the direct potentiating effects of deloads on subsequent training cycles in resistance-trained individuals. Given the paucity of research on the topic, the purpose of this study was to investigate the effects of a brief period of detraining at the midpoint of a 9-week RT program on muscular adaptations in resistance-trained individuals. We hypothesized that detraining would result in superior muscular adaptations by reducing accumulated fatigue and re-sensitizing muscle to anabolic stimuli.

METHOD

Participants

We recruited 50 male and female volunteers from a university population. This sample size was justified by *a priori* precision analysis for the minimum detectable change at the 68% level ($MDC_{68\%}$; i.e., 1 standard deviation [SD], which is conservative in that it requires a larger sample to produce a narrow interval) for mid-thigh hypertrophy (i.e., $SEM \times \sqrt{2} = 2.93\ mm$), such that the compatibility interval (CI) of the between-group effect would be approximately ± $MDC_{68\%}$. Based on data from previous research [15], along with their sampling distributions, Monte Carlo simulation was used to generate 90% CI widths for 5000 random samples of each sample size. To ensure a conservative estimate, as literature values may not be extrapolatable, the sum of each simulated sample size's 90% CI's mean and SD was used, and the smallest sample that exceeded $MDC_{68\%}$ was chosen; that is, 18 participants per group (1:1 allocation ratio). Additional participants were recruited to account for the possibility of dropout.

To qualify for inclusion in the study, the participants were required to be: (a) between the ages of 18-40 years; (b) free from existing cardiorespiratory or musculoskeletal disorders; (c) self-reported as free from consumption of anabolic steroids or any other illegal agents known to increase muscle size currently and for the previous year; and, (d) considered as resistance-trained, defined as consistently lifting weights at least 3 times per week (on most weeks) with at least 1 weekly session for the lower body muscles for at least 1 year. Participants were asked to refrain from the use of creatine products throughout the course of the study period, as this supplement has been shown to enhance muscle-building when combined with RT [16].

Participants were randomly assigned to 1 of 2 experimental, parallel groups: An experimental group that detrained (i.e., no RT) for 1 week at the midpoint of a 9-week RT program (DELOAD: n = 25) or a traditional training group that performed the same RT program continuously over the study period (TRAD: n = 25). Randomization into groups was carried out using block randomization, with 2 participants per block, via online software (www.randomizer.org.). Approval for the study was obtained from the college Institutional Review Board. Written informed consent was obtained from all participants prior to beginning the study. The methods for this study were preregistered prior to recruitment (https://osf.io/bztka).

Resistance Training Procedures

The RT program was structured as an upper body/lower body split routine, with each body region protocol performed twice weekly. As previously described [17], the lower body protocol was directly supervised by the research team on a one-on-one basis to monitor the proper performance of the respective routines and ensure participant safety. Exercises consisted of the Smith squat, leg extension, straight-leg toe press, and seated calf raise. Participants performed 5 sets of 8-12 repetition maximum (RM) for each exercise with 2 minutes rest between sets. To help standardize the intensity of effort of the training protocols, we verbally encouraged participants to perform all sets to the point of volitional failure, herein defined as the inability to perform another concentric repetition while maintaining proper form. The cadence of repetitions was carried out in a controlled fashion, with a concentric action of approximately 1 second and an eccentric action of approximately 2 seconds as monitored by the research staff. Loads were progressively adjusted from set to set within each session as well as across the duration of the study period to maintain the target repetition range. Participants were given an upper body RT program to follow on alternate training days (without supervision by the researchers) and were instructed to refrain from performing any additional lower body RT for the duration of the study. To enhance accountability, participants kept a training log of their upper body routines and emailed the log to the lead researcher on a weekly basis. An overview of the training program is presented in supplementary file S1.

Prior to initiating the training program, participants underwent 10RM testing to determine individual initial loads for each lower body exercise. The RM testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association [18]. Thereafter, training for both routines consisted of 2 weekly sessions performed on non-consecutive days for 9 weeks. The DELOAD group took a 1-week break from training after the fourth week while the TRAD group trained consistently throughout the study period.

Dietary Adherence

To avoid potential dietary confounding of results, participants were advised to maintain their customary nutritional regimen. Dietary adherence was assessed by self-reported 5-day food records (including at least 1 weekend day) using MyFitnessPal.com (http://www.myfitnesspal.com), which has good relative validity for tracking energy and macronutrient intake [19]. Nutritional data was collected twice during the study: 1 week before the first training session (i.e., baseline) and during the final week of the training protocol. Participants were instructed on how to properly record all food items and their respective portion sizes consumed for the designated period of interest. Each item of food was individually entered into the program, and the program provided relevant information as to total energy consumption, as well as the amount of energy derived from proteins, fats, and carbohydrates for each time-period analyzed.

Measurements

The following measurements were conducted pre- and post-study in separate testing sessions. Participants reported to the lab having refrained from any strenuous exercise for at least 48 hours prior to baseline testing and at least 48 hours prior to testing at the conclusion of the study. Anthropometric and muscle thickness (MT) assessments were performed first in the session, followed by measures of muscle strength. Each strength assessment was separated by a 10-minute recovery interval to ensure restoration of resources.

Anthropometry: To reduce the potential for confounding from lifestyle factors, participants were told to refrain from eating or drinking for 8 hours prior to testing, eliminate alcohol consumption for 24 hours, and void their bladder immediately before anthropometric testing. Participants' heights were measured using a stadiometer and assessments of body mass and percent body fat and segmental lower limb lean mass were obtained by multifrequency bioelectrical impedance analysis (Model 770, InBody Corporation, Seoul, South Korea) as per the instructions of the manufacturer.

Muscle Thickness: As previously described [17], ultrasound imaging was used to obtain measurements of MT. A trained ultrasound technician performed all testing using a B-mode ultrasound imaging unit (Model E1, SonoScape, Corporation, Shenzhen, China). The technician applied a water-soluble transmission gel (Aquasonic 100 Ultrasound Transmission gel, Parker Laboratories Inc., Fairfield, NJ) to each measurement site, and a 4-12 MHz linear array ultrasound probe was placed perpendicular to the tissue interface without depressing the skin. When the quality of the image was deemed to be satisfactory, the technician saved the image to a hard drive and obtained MT dimensions by measuring the distance from the subcutaneous adipose tissue-muscle interface to either the aponeurosis or the muscle-bone interface. Measurements were taken on the right side of the body at the mid-thigh (a composite of the rectus femoris and vastus intermedius), lateral thigh (a composite of the vastus lateralis and vastus intermedius), medial gastrocnemius, lateral gastrocnemius, and lateral soleus muscles. For the quadriceps, measurements were obtained at 30%, 50% and

70% between the lateral condyle of the femur and greater trochanter. For the calf muscles, measurements were taken on the posterior surface of both legs at 25% of the lower leg length (the distance from the articular cleft between the femur and tibia condyles to the lateral malleolus). To ensure that swelling in the muscles from training did not obscure MT results, images were obtained at least 48 hours after exercise/training sessions both in the pre- and post-study assessment. This is consistent with research showing that acute increases in MT return to baseline within 48 hours following a RT session [20] and that muscle damage is minimal after repeated exposure to the same exercise stimulus over time [21 22]. To further ensure accuracy of measurements, 3 successive images were obtained for each site and then averaged to obtain a final value. The test-retest intraclass correlation coefficients (ICC) from our lab for MT measurements are excellent (>0.94) with coefficients of variation (CV) of ≤3.3%.

Lower Body Muscle Power: Lower body muscle power was assessed via the vertical jump test. As previously described [17], each participant was instructed on proper performance of the countermovement jump (CMJ) prior to testing. Performance was carried out as follows: The participant began by assuming a shoulder-width stance with the body upright and hands on hips. When ready for the movement, the participant descended into a semi-squat position and then forcefully reversed direction, jumping as high as possible before landing with both feet on the ground.

Assessment of jump performance was carried out using a Just Jump mat (Probotics, Huntsville, AL), which was attached to a hand-held computer that records airtime and thereby ascertains the jump height. The participant stood on the mat and performed 3 maximal-effort CMJs with a 1-minute rest period between each trial. The highest jump was recorded as the final value.

Isometric Muscle Strength: Isometric strength assessment was carried out using dynamometry testing (Biodex System 4; Biodex Medical Systems, Inc. Shirley, NY, USA). After familiarization with the dynamometer and protocol, the participant was seated in the chair and performed unilateral isometric actions of the knee extensors on his/her dominant limb.

During each trial, the participant sat with his/her back flush against the seat back pad and maintained a hip joint angle of 85 degrees with the center of his/her lateral femoral condyle aligned with the axis of rotation of the dynamometer. The dynamometer arm length was adjusted to allow the shin pad to be secured with straps proximal to the medial malleoli. A strap was secured across the participant's ipsilateral thigh, hips, and torso to help prevent extraneous movement during performance and the participant was instructed to hold onto handles for greater stability. Testing was carried out at a knee joint angle of 70-degrees [23].

Each maximum voluntary contraction trial lasted 5 seconds and was followed by a 30-second rest period, for a total of 4 trials. Participants were verbally encouraged to produce maximal force throughout each contraction. The highest peak net extension moment from the 4 trials was used for analysis.

Dynamic Muscle Strength: Dynamic lower body strength was assessed by 1RM testing in the back squat ($1RM_{SQUAT}$) exercise performed on a Smith machine (Hammer Strength Equipment, Life Fitness, Rosemont, IL, USA). As previously described [17], participants reported to the lab having refrained from any exercise other than activities of daily living for at least 48 hours prior to baseline testing and at least 48 hours prior to testing at the conclusion of the study. The RM testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association [18]. In brief, participants performed a general warm-up prior to testing consisting of light cardiovascular exercise lasting approximately 5-10 minutes. Next, a specific warm-up set of the squat of 5 repetitions was performed at ~50% 1RM followed by 1 or 2 sets of 2-3 repetitions at a load corresponding to ~60-80% 1RM. Participants then performed sets of 1 repetition of increasing weight for 1RM determination. Three to 5 minutes rest was provided between each successive attempt. Participants' upper thighs had to reach parallel in the $1RM_{SQUAT}$ for the attempt to be considered successful. Confirmation of squat depth was obtained by a research assistant positioned laterally to the participant to ensure accuracy. 1RM determinations were made within 5 attempts. The ICC from our lab for the Smith machine back squat is 0.953 and the CV is 2.8%.

Muscle Strength-Endurance: Lower-body muscular strength-endurance was assessed by performing the leg extension exercise on a selectorized machine (Life Fitness, Westport, CT) using 60% of the participant's initial body mass. As previously described [17], participants sat with their back flat against the backrest, grasping the handles of the unit for support. The backrest was adjusted so that the anatomical axis of the participant's knee joint aligned with the axis of the unit. Participants placed their shins against the pad attached to the machine's lever arm. Participants performed as many repetitions as possible using a full range of motion (90-0 degrees of knee flexion) while maintaining a constant cadence of 1-0-1-0 as monitored by a metronome. The test was terminated when the participant could not perform a complete repetition with proper form in tempo. Muscular endurance testing was carried out after assessment of muscular strength to minimize effects of metabolic stress potentially interfering with performance of the latter.

Readiness to Train Questionnaire: To assess participants' subjective feelings toward training across the study period, we employed a readiness-to-train questionnaire as previously described in the literature [24]. The questionnaire comprised 7 questions using Likert-type scales ranging from 1 to 4, 1 to 5 and 1 to 10 (see supplementary file S2). As previously explained [24], the upper and lower boundaries of the scale were defined as follows: "*1 can be described as not at all/extremely low and 4, 5, 10 (depending on lower/upper end of the scale) can be described as extreme amount/extremely high."* The questionnaire was given to participants 24-48 hours after the fourth and ninth weeks of the study.

Blinding

To minimize the potential for bias, both the sonographer who conducted ultrasound testing and the statistician who analyzed data were blinded to group allocation.

Statistical Analyses

All analyses were conducted in R (version 4.2.0) [25] within a Bayesian framework, with descriptive values expressed in means ± SDs. Bayesian statistics represents an approach to data analysis and parameter estimation based on Bayes' theorem [26] and can provide several advantages over frequentist approaches including: 1) formal inclusion of information regarding likely differences between interventions based on knowledge from previous studies (i.e., through informative priors); 2) flexible model building to capture a range of complexities within the data; and 3) presentation of inferences based on intuitive probabilities [27] [26]. Inferences were not drawn on baseline nor within-group change, as baseline testing is inconsequential [28] and within-group outcomes are not the subject of our research question [29], although we descriptively presented within-group changes to help contextualize our findings. The effect of group (DELOAD vs. TRAD) on outcome variables were estimated using multivariate multilevel regression models [30]. This approach provides improved precision by modeling all outcome variables simultaneously, taking advantage of the correlations between outcomes [30] and avoiding limitations associated with separate inferences with related outcomes [31]. Additionally, the multilevel component of the analysis accounted for the repeated measures made on each participant across outcomes and time points. Recent data quantifying comparative distributions and correlations across outcomes following interventions in strength and conditioning were used to obtain informative priors [32]. Inferences were made based on estimates of the difference in change between DELOAD and TRAD and their credible intervals.

Secondary analyses were performed on nutrition and readiness to train data, which were analyzed using multilevel regression models. Individual Likert readiness to train items were summed to create scales suitable for linear models assuming normal distribution of errors. All analyses were performed using the R wrapper package brms interfaced with Stan to perform sampling [33]. There are three main areas where Bayesian analyses can be performed inappropriately and/or result in poor inferences. These areas include: 1) issues related to prior selection; 2) misinterpretation of Bayesian features and results; and 3) improper reporting [34]. To improve accuracy, transparency and replication in the analyses, the WAMBS-checklist (When to worry and how to Avoid Misuse of Bayesian Statistics) was used and we incorporated sensitivity analyses of influential data points and priors, which has been shown to be important in all cases including when diffuse priors are used [35].

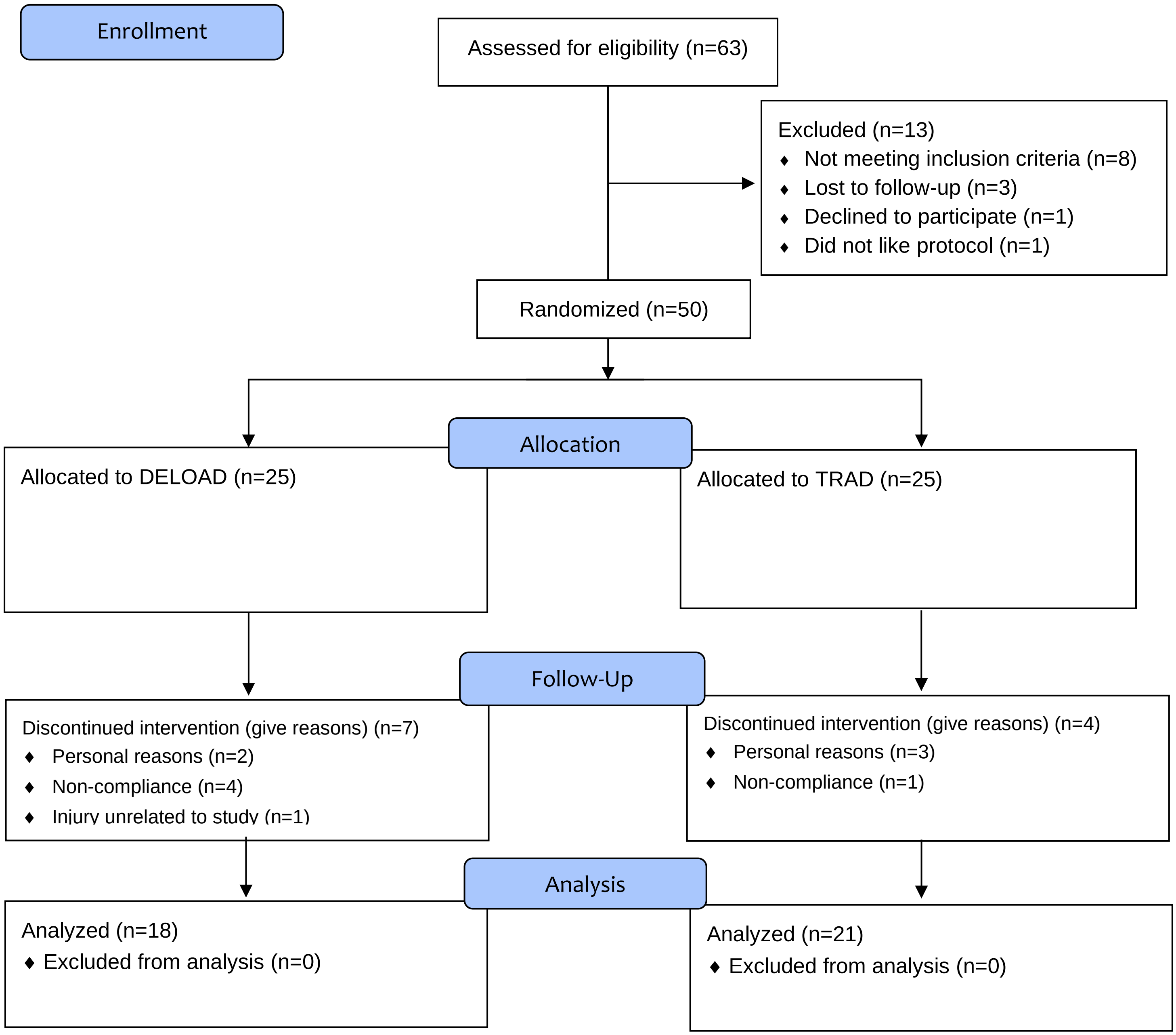
Results

Of the initial 50 participants who volunteered to participate, 39 completed the study (DELOAD: n = 18 [12 male, 6 female], height [cms] = 170.7 ± 7.7, weight [kgs] = 77.7 ± 15.8, age [yrs] = 22.2 ± 6.1, training experience [yrs] = 3.7 ± 4.5; TRAD: n = 21 [17 male, 4 female], height [cms] = 172.9 ± 8.8, weight [kgs] = 79.1 ± 13.5, age [yrs] = 21.4 ± 3.9, training experience [yrs] = 3.2 ± 2.6). Reasons for dropouts were: Personal reasons (n = 5), lack of compliance (n = 5), and training-related injury not related to the study (n=1). All participants that completed the study attended >85% of the total sessions, with both groups displaying an average attendance of ~96%. Figure 1 displays a CONSORT diagram of the data collection process. Table 1 presents the pre/post-study intervention effects for all outcomes.

Table 1: Pre/post-study intervention effects for all outcomes

	DELOAD (n=18)		TRAD (n=21)	
Variable	Pre	Post	Pre	Post
1RM (kgs)	92.8 ± 38.5	105.8 ± 32.1	95.9 ± 21.7	112.3 ± 21.3
Isometric Strength (N·m)	258.8 ± 60.6	261.8 ± 70.5	268.4 ± 55.0	288.6 ± 55.0
Mid-quad 30% (mm)	50.8 ± 8.3	54.3 ± 8.8	53.6 ± 8.2	57.1 ± 8.0
Mid-quad 50% (mm)	41.4 ± 8.1	45.5 ± 9.0	44.7 ± 8.1	49.3 ± 7.5
Mid-quad 70% (mm)	29.8 ± 7.0	33.9 ± 8.0	32.1 ± 6.4	36.0 ± 6.5
Lateral quad 30% (mm)	34.2 ± 5.9	36.5 ± 6.0	34.2 ± 7.9	36.6 ± 7.8
Lateral quad 50% (mm)	36.0 ± 5.4	38.8 ± 5.7	36.6 ± 6.5	39.6 ± 6.8
Lateral quad 70% (mm)	31.5 ± 4.8	34.4 ± 5.3	32.7 ± 4.9	34.9 ± 5.6
Medial Gastrocnemius (mm)	19.3 ± 4.2	20.5 ± 3.7	19.2 ± 2.7	20.6 ± 2.8
Lateral Gastrocnemius (mm)	16.5 ± 2.5	17.3 ± 2.4	16.5 ± 3.5	17.6 ± 3.5
Soleus (mm)	15.2 ± 3.2	16.2 ± 3.8	15.7 ± 3.3	16.3 ± 3.4
Jump (cms)	39.9 ± 9.4	41.4 ± 9.1	45.2 ± 8.4	46.0 ± 9.7
Muscular Endurance (reps)	16.3 ± 6.0	20.4 ± 3.8	15.5 ± 5.8	20.6 ± 6.9

Figure 1: CONSORT 2010 Flow Diagram



Body Composition and Muscle Morphology

Initial univariate analyses are presented in Table 2. The evidence obtained did not support greater body composition changes when including a period of detraining as indicated by median group difference estimates close to zero, and all 95% credible intervals substantially overlapping zero. Posterior probabilities that group differences favored the inclusion of a period of detraining were generally low ($0.273 \leq p \leq 0.835$; Table 1). Multivariate analysis comprising muscle thickness measurements did not alter findings (Table 2). Illustration with standardized mean difference effect sizes showed consistency in results and that if group differences did exist, they were likely to be small in magnitude (Figure 2). Calculation of within group differences demonstrated that both groups achieved positive adaptations with small to medium increases in muscle thickness; however, body fat percentage and lower body lean mass showed minimal change (see supplementary file S3). Diagnostic evaluations across all analyses identified no causes for concern and no changes in conclusions based on sensitivity analyses (see supplementary file S3).

Table 2: Multivariate and univariate analyses of potential group differences for body composition variables.

Variable	Multivariate Group Difference [95%CrI]	Posterior probability favoring inclusion of detraining	Univariate Group Difference [95%CrI]	Posterior probability favoring inclusion of detraining
Rectus femoris 30% (mms)	-0.33 [-2.0 to 1.4]	$p = 0.347$	-0.16 [-2.1 to 1.8]	$p = 0.434$
Rectus femoris 50% (mms)			-0.63 [-2.8 to 1.5]	$p = 0.273$
Rectus femoris 70% (mms)			-0.17 [-1.9 to 1.6]	$p = 0.563$
Vastus lateralis 30% (mms)	0.08 [-1.5 to 1.6]	$p = 0.540$	-0.07 [-1.8 to 1.7]	$p = 0.466$
Vastus lateralis 50% (mms)			-0.27 [-1.9 to 1.4]	$p = 0.373$
Vastus lateralis 70% (mms)			0.53 [-1.2 to 2.2]	$p = 0.730$
Lateral gastrocnemius (mms)	-0.07 [-0.65 to 0.48]	$p = 0.400$	-0.23 [-1.2 to 0.71]	$p = 0.317$
Medial gastrocnemius (mms)			-0.22 [-1.0 to 0.59]	$p = 0.290$
Soleus (mms)			0.35 [-0.36 to 1.0]	$p = 0.835$
Body fat (%)	*	*	-0.10 [-1.2 to 1.1]	$p = 0.424$
Lower body lean mass (kgs)	*	*	-0.12 [-0.37 to 0.14]	$p = 0.185$

Multivariate analysis of muscle thickness data combined for single rectus femoris, vastus lateralis, and calf thickness variables. *Not included in analysis

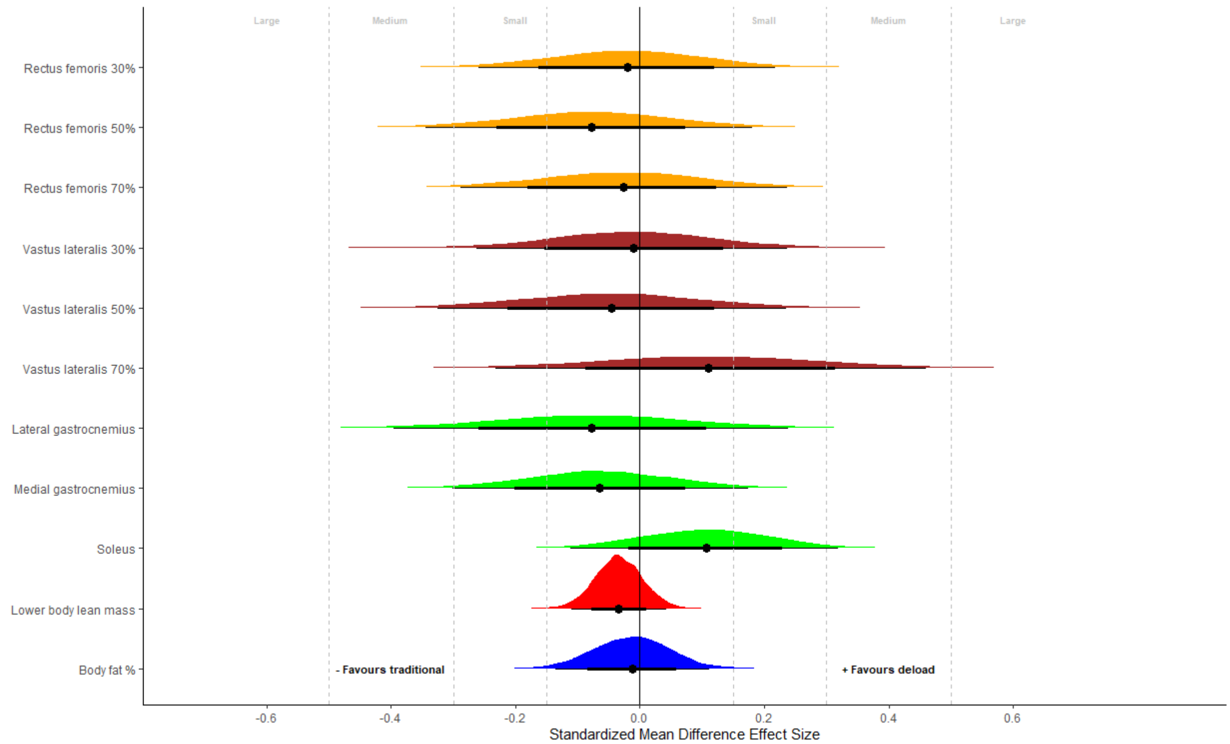


Figure 2: Posterior distributions of group differences for body composition outcomes expressed as standardized mean difference effect sizes. Negative values favor control and positive values favor the inclusion of a detraining period. Effect sizes were calculated by dividing group differences by the pooled baseline standard deviation. Small (0.15), medium (0.30) and large (0.50) thresholds derived for strength and conditioning interventions are presented with grey lines.

Strength and Performance

Initial univariate analyses are presented in Table 3. Results were inconsistent, with median group difference estimates close to zero and 95% credible intervals substantially overlapping zero for endurance and CMJ performance (Table 3). In contrast, some evidence was obtained for greater strength adaptations of control relative to inclusion of a detraining period (Table 3), with posterior probabilities that group differences favored control equal to p = 0.851 for 1RM, and p = 0.924 for isometric strength. Multivariate analysis for strength outcomes did not alter findings (Table 3). Illustration with standardized mean difference effect sizes showed that if group differences did exist, they were likely to be small in magnitude for endurance and CMJ performance (Figure 3), whereas they may be small to large in favor of control for 1RM and isometric strength. Calculation of within group differences were mixed with some evidence that both groups improved across all variables (see supplementary file S3). Diagnostic evaluations across all analyses (see supplementary file S3) identified no causes for concern, with sensitivity analyses producing similar findings to those presented in the main text.

Table 3: Multivariate and univariate analyses of potential group differences for performance variables.

Variable	**Univariate Group Difference [95%CrI]**	**Posterior probability favoring inclusion of detraining**	**Univariate Group Difference [95%CrI]**	**Posterior probability favoring inclusion of detraining**
Isometric (N·m)	-11.5 [-33.5 to 8.2]	*p* = 0.245	-14.4 [-34.3 to 5.8]	*p* = 0.076
One-repetition maximum (kgs)	-4.5 [-10.4 to 2.8]	*p* = 0.116	-3.6 [-10.4 to 3.2]	*p* = 0.149
Endurance (# repetitions)	*	*	-0.55 [-2.9 to 1.9]	*p* =0.321
Countermovement jump (cms)	*	*	0.61 [-1.5 to 2.8]	*p* = 0.715

*Not included in analysis

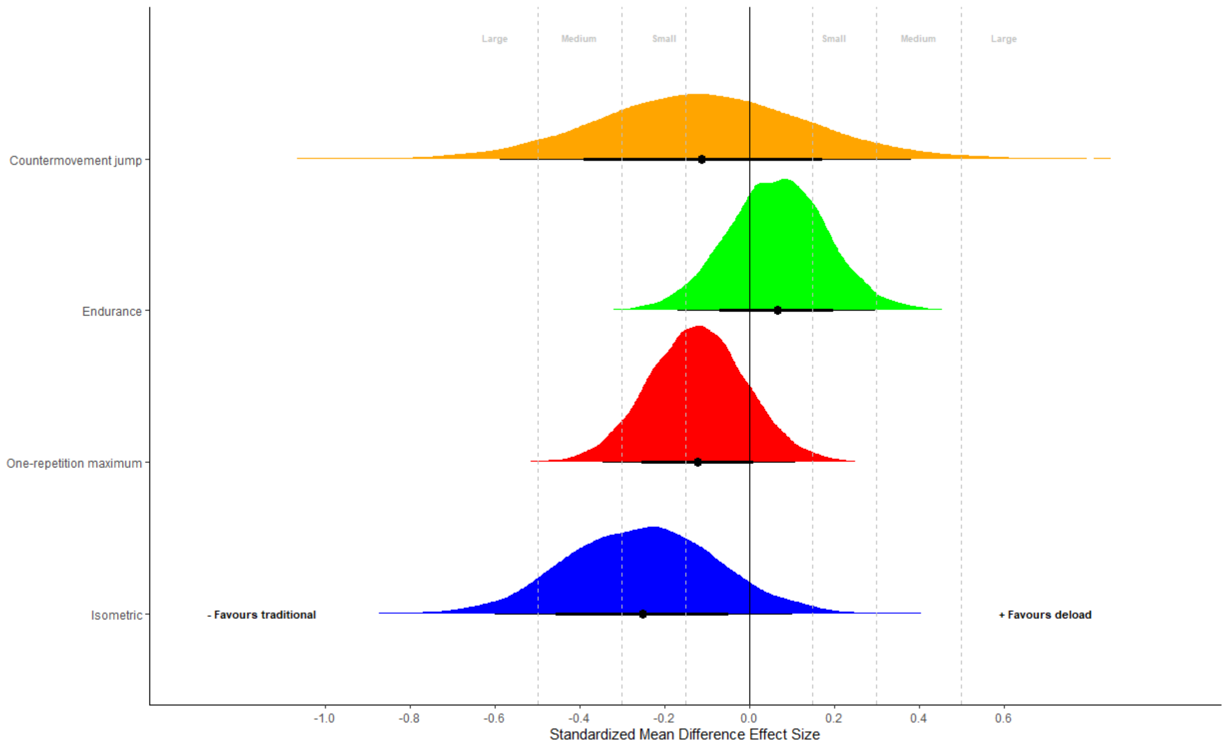


Figure 3: Posterior distributions of group differences for performance outcomes expressed as standardized mean difference effect sizes. Negative values favor control and positive values favor the inclusion of a detraining period. Effect sizes were calculated by dividing group differences by the pooled baseline standard deviation. Small (0.15), medium (0.30) and large (0.50) thresholds derived for strength and conditioning interventions are presented with grey lines.

Secondary Analyses

Results from secondary analyses are presented in the supplementary file. No substantial evidence was found to indicate a difference in nutritional intake between groups. Some evidence was obtained to indicate greater sleep quality in the deload group at mid-intervention, and greater muscle soreness in the deload group at post-intervention (supplementary file S3).

Discussion

This is the first study to directly assess the effects of a deload period on muscular adaptations. Our novel results suggest that a 1-week deload, in the form of complete cessation from training, has a minimal impact on measures of muscle hypertrophy, endurance, or power in the context of a 9-week training block; correspondingly, we found no evidence of a potentiating effect pursuant to re-sensitization. Conversely, the traditional training group experienced modest benefits in measures of both isometric and dynamic strength. In the ensuing sections, we discuss these results within the context of the current literature as well as their practical implications for exercise prescription.

Hypertrophy

Both groups increased muscle size over the course of the study. Pooled mean increases ranged from 3.6% to 13.6% across the assessed sites, with similar between-group increases observed in all measurements. These findings suggest that 1 week of detraining does not attenuate the hypertrophic adaptations seen in the first half of a 9-week training block but also does not enhance results over time. The findings are generally consistent with the body of literature, which suggests little to no differences in longitudinal muscle growth when relatively short periods of detraining are utilized [7 14]. Previous studies on the topic employed longer detraining periods (3 weeks), recruited untrained participants, and used relatively low-volume RT protocols specific to the bench press exercise [7 14], thus compromising the ecological validity of findings. Alternatively, the design of our investigation aligns more closely with the manner in which deloads are commonly employed in the field, thus filling an important gap in the literature.

We originally hypothesized that individuals in the deload group would experience superior muscle growth due to the dissipation of fatigue accrued in the first 4 weeks of training and potential re-sensitization to hypertrophic stimuli. However, participants anecdotally often reported feeling lethargic after the detraining period rather than refreshed. This may be because participants in the deload group detrained during the fifth week, rather than using deload paradigms often employed by coaches and athletes in strength and physique sports that involve reduced training volumes and/or intensities [3]. Perhaps a period of reduced training volume and intensity, but not complete cessation, would allow for the dissipation of fatigue without bringing about a feeling of lethargy upon return. Whether different deload paradigms may result in hypertrophic benefits warrants further investigation.

Strength

Both groups experienced increases in dynamic and isometric strength; however, these measures generally showed superiority for TRAD. The between-group differences were most apparent in the isometric knee extension, where the CIs encapsulated effects ranging from a small negative effect to a large positive effect favoring TRAD (−5.1 and 42.1 nM, respectively). For 1RM squat testing, the results were somewhat more equivocal, but nevertheless indicate a potential benefit for TRAD. The spread of the CIs encapsulated effects ranging from a modest negative effect to an appreciable positive effect favoring TRAD (−3.0 and 12.1 kg, respectively).

The relative benefits seen by those in the TRAD group are unexpected given that the current body of literature suggests relatively short periods of detraining have little to no effect on strength [14 7]. These findings are particularly surprising considering the extensive use of deloads in athletes involved in strength sports (i.e., powerlifting and weightlifting) [3]. It is important to note that the aim of RT protocol in this study was not to maximize strength, but rather to maximize hypertrophy (i.e., moderate loads, higher volumes). Therefore, it is conceivable that deloads may confer different effects when employing an RT protocol consistent with that of strength athletes. It also is unknown if a brief period of reduced training, similar to deload strategies often employed in the field, may help to attenuate the observed negative effects on strength or perhaps even potentiate improvements. These hypotheses should be explored in future research.

Another variable that warrants consideration is that of specificity. Although both strength assessments suggested superior improvements for TRAD, isometric outcomes showed a greater benefit than dynamic testing. Although speculative, this discrepancy may be attributed to the specificity of transfer between use of Smith machine squats in both the training and testing protocols. Simply stated, the 1-week detraining period may have had a true negative impact on strength, but the similarities between the training and dynamic testing somewhat masked those detriments, whereas the lack of transfer from training to isometric testing did not. This hypothesis warrants further investigation.

Local Strength-Endurance

Leg extension endurance slightly favored the TRAD group. However, the magnitude of difference between groups was less than a single repetition, thus not likely to be of practical significance. Research regarding the effects of detraining on local muscle endurance is very limited, making it difficult to compare our results with similar study designs.

It has been proposed that strength-endurance performance is predicated on adaptations including increases in capillarization and mitochondria activity as well as enhanced metabolic enzymatic activity [36]. Interestingly, all these adaptations seem to be negatively impacted by short periods of complete training cessation [37]. Additionally, increases in maximal strength have been speculated to enhance local muscular endurance due to loads used in testing being a lower percentage of an individual's 1RM. Therefore, periods of detraining may further hinder muscular endurance adaptations because of their concomitant detriments to maximal strength.

A similar issue to strength data extrapolation can be seen in our muscle endurance results. Specifically, this study design employed a moderate repetition range (8-12 repetitions), whereas muscle endurance is seemingly best trained through sets containing 15 or more repetitions [38]. Thus, it is possible that training with the explicit goal to elicit increases in muscular endurance may yield alternate results. More research is needed to fully understand the effects of detraining on local muscular endurance.

Muscular Power

Differences between groups in CMJ performance were trivial. Our findings are generally consistent with the body of literature, which suggests power adaptations observed in training are not attenuated by short periods ($\leq$ 2 weeks) of detraining [8]. Importantly, our protocol required that participants control each repetition both eccentrically and concentrically, likely resulting in little adaptation to the stretch shortening cycle used in explosive movements. Perhaps greater differences between groups would be realized by incorporating plyometric-based training into the design. Whether different RT designs will result in differences in lower body power following detraining warrants further investigation.

Readiness to Train

Participants in the TRAD group showed potential advantage in their perception of some readiness to train components compared to those in the DELOAD group. For example, the DELOAD group reported an increase in muscle soreness whereas individuals in the TRAD group reported decreases in soreness from week 4 to week 9. Additionally, individuals in the DELOAD group reported a decrease in motivation to train from week 4 to 9 as opposed to those in the TRAD group, who reported no differences in motivation. The magnitude of differences in these values can be considered relatively modest and their practical meaningfulness thus remains questionable.

In an attempt to promote functional overreaching, we employed a relatively high-volume program where the participants were pushed to volitional failure on each set during the supervised aspect of the protocol and instructed to do the same during unsupervised upper body training. In total, the participants performed 90 weekly sets for all muscle groups combined during each training week of the intervention period. On the final testing day, participants were asked if they felt the need for a deload following the study period. During these post-study conversations, virtually every participant stated that they trained consistently harder than at any point in their previous training experience. However, quite surprisingly, almost none of the participants felt they needed a break after the study, with nearly all stating they would return to normal training routine within a couple of days of the study's completion.

These findings warrant speculation as to the possible use of autoregulatory deloads versus more proactive deloads. Our results suggest that, from a strength-related standpoint, having participants perform a deload even if they do not feel the need for a break may do more harm than good. This is perhaps why more strength and physique coaches prefer to employ a flexible deload approach as opposed to a more pre-planned paradigm [3]. Whether the use of an autoregulated deload would result in differential results warrants further investigation.

Limitations

Our study contained multiple limitations that should be noted when extrapolating the findings to ecologically valid settings. First and foremost, this experiment was conducted on young men and women with a minimum of 1 year training experience. Therefore, our findings cannot necessarily be generalized to other populations including individuals over the age of 40, adolescents, and untrained individuals. Second, participants were not required to have training experience specific to the Smith machine squat. Thus, increases in 1RM strength may have been influenced by neural adaptations that would not likely be seen by individuals who regularly perform variations in the back squat in their training program. Third, while research assistants verbally encouraged participants to perform sets with maximum intensity of effort, some individuals volitionally ended their sets prior to reaching momentary muscular failure throughout the study period. However, all participants trained with a high level of effort on all supervised sets; thus, any differences in proximity to failure likely had little consequence on study outcomes. Fourth, the outcomes assessed in this study were specific to the lower body musculature; thus, inferences regarding the effect of detraining on the upper body muscles cannot be drawn. To this point, while we can be confident that all participants trained with high intensities of effort during the supervised lower body sessions, we cannot be sure as to the effort exerted during upper body training. Although we attempted to collect weekly upper body training logs from each participant as to their upper body routines, the quality of reporting was often inconsistent, thus raising uncertainty about overall adherence to this aspect of the program. Fifth, we employed a pre-planned deload after a 4-week training cycle, which is a common strategy employed in real-world settings. However, we cannot necessarily draw inferences as to the effect of deloads after longer training cycles or autoregulated deloads on muscular adaptations. Sixth, our findings are the result of a short, 9-week training block and a relatively high training volume (90 weekly sets). Therefore, questions remain regarding the effects of deload periods within the context of longer training periods as well as higher weekly training volumes sometimes performed by physique athletes and other gym enthusiasts. Finally, our results are specific to a deload involving a cessation of RT. In practice, deloads can employ a wide range of strategies designed to reduce training load, volume and/or intensity as opposed to abstention. Future studies should seek to investigate the effects of different deload approaches on muscular adaptations.

Conclusion

The implementation of a 1-week detraining period at the midpoint of a 9-week training block produced similar increases in lower body muscle size, endurance, and power when compared to a continuous training block. These results suggest that both continuous and periodic training blocks are viable options when attempting to maximize hypertrophy, at least within a 9-week period. Conversely, continuous training showed superior improvements in measures of lower body strength compared to deloading. Thus, when trying to optimize increases in maximal strength, periods of complete training cessation likely should be used more sparingly. Ultimately, more research is needed to fully elucidate when and how periods of detraining can be employed to maximize muscular adaptations as well as to determine for which populations these periods are best suited.

Contributions

MC and BJS conceived of the idea for the study. MC, MI, JPF and BJS designed the methodology for the study. MC, RB, FA, AP, JM, PAK and DJO assisted with acquisition of data. PAS conducted the statistical analysis. All authors critically interpreted the data, drafted and/or revised the article, and approved the final version of the manuscript draft.

Conflict of interest

BJS serves on the scientific advisory board for Tonal Corporation, a manufacturer of fitness equipment. All other authors report no competing interests with the content of this manuscript.

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Data and Supplementary Material Accessibility

Data and supplementary material are available on the Open Science Framework project page: https://osf.io/kdgv3/

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