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ORIGINAL ARTICLE

The effects of a single or multi-step drop-set training compared to traditional resistance training on muscle performance and body composition

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ABSTRACT

The purpose was to examine two drop-set (DS) protocols (single step vs. multi-step) compared to traditional resistance training (TRT) over 8 weeks on changes in muscular strength, endurance and body composition. Twenty-seven trained males were randomized to one of three groups: traditional resistance training (TRT: n = 9), the single step drop set group (DS-S: n = 10) and the multi-step drop set group (DS-M: n = 8). Before and after training, body composition (percent body fat and skeletal muscle mass), and muscular strength and endurance (bench and leg press) were determined. Results: There was a significant interaction for leg press 1-RM ($p < .001$) and absolute change for leg-press 1-RM was significantly greater for both drop set protocols compared to TRT ($p < .001$). There were significant interactions for both leg press and bench press endurance ($p < .001$), with post hoc analyses revealing that only DS-M was superior to TRT ($p < .001$). There was a significant main effect of time for % body fat ($p = .020$), SMM ($p < .001$), however there were no differences between groups. Conclusions: Overall, single-step and multi-step drop-set training to failure appear to be effective strategies to enhance lower body strength, while only the multi-step drop set training enhanced muscular endurance compared to TRT.

Keywords: Performance analysis, Physical conditioning, Muscle strength, Muscular failure, Muscle endurance, MVC, Mechanical tension.

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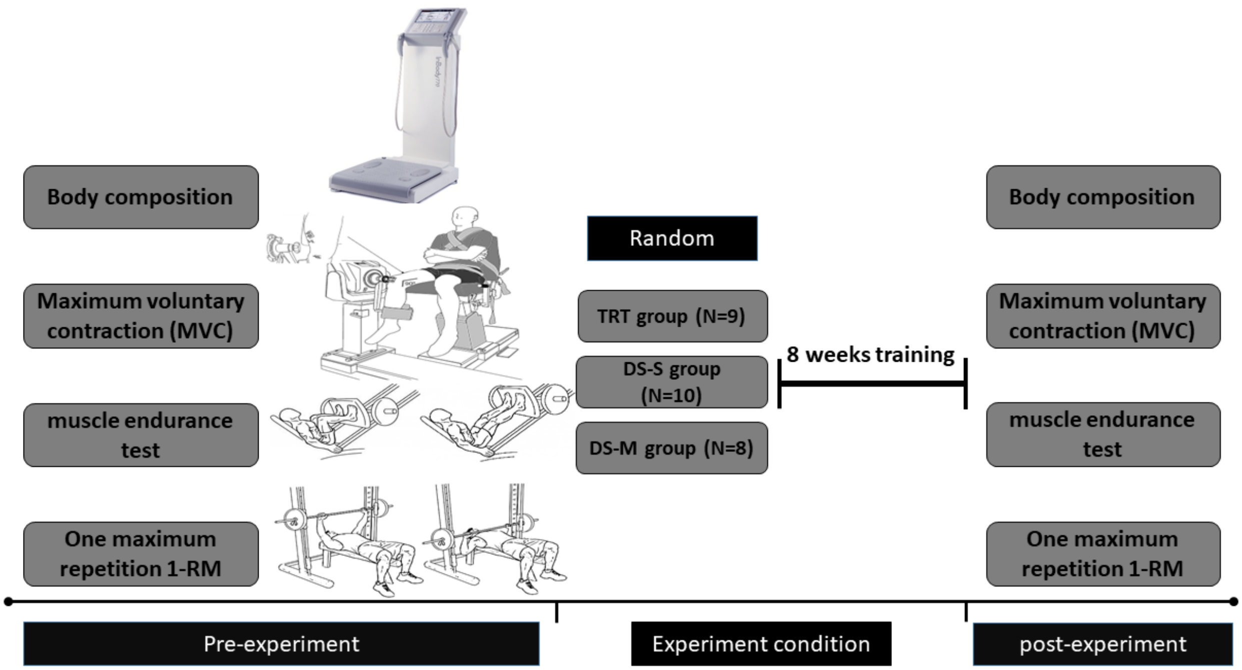
INTRODUCTION

Resistance training is a well-established robust strategy to augment gains in muscular strength and endurance and hypertrophy (Kraemer and Ratamess., 2004). Mechanistically, muscle hypertrophy appears to be associated with mechanical tension, metabolic stress, and cell swelling (Lawson et al., 2022; Wackerhage et al.,2019). Furthermore, resistance training alters structural elements of the muscle, such as the angle of tendon adhesion and length (Pallarés et al., 2021; Seynnes et al., 2007). From an applied perspective, manipulating resistance training programming variables (e.g., sets, repetitions, proximity to failure, volume, frequency, tempo, etc.) may alter the exercise-induced gains in muscle strength and endurance and muscle size (Wilk et al., 2021). Traditional resistance training (TRT) is an effective strategy to induce gains in muscle size and strength, however, alternative strategies, such as drop-sets (DS) have been purported to further enhance these adaptations (Krzysztofik et al., 2019; Angleri et al., 2017). TRT is characterized by multiple sets performed with the same load (i.e., % of 1-RM) with a pre-determined rest interval (Enes et al., 2021; Giessing, et al., 2016). In contrast, DS training involves performing an exercise to (or in close proximity to) momentary failure followed by an immediate reduction in load prior to performing an additional set (Lasevicius et al., 2022; Nuzzo et al., 2023). Depending on the protocol, single or multiple reductions or "*drops*" can be performed. DS training may benefit adaptations through enhanced time under tension, metabolic stress and metabolite accumulation, and cell swelling compared to TRT. Conversely, DS training may impair gains in strength since high load training with longer rest intervals appears to be ideal for optimizing strength gains (Coleman et al., 2022; Schoenfeld et al., 2021). A recent meta-analysis comparing DS to TRT indicated trivial point estimates of the effect sizes for gains in muscle size and strength, however, only 5 studies met the inclusion criteria Furthermore, there were numerous methodological differences between studies, including large variations in DS protocols (Coleman et al., 2022). For example, Angleri et al. and Fink et al., utilized two-step reduction drop-set protocols (20% reduction per step) (Angleri, et al., 2017; Fink et al., 2018), the previous study showed participants had performed 3 sets of 10 repetitions plus one drop set of 6 repetitions (Enes et al., 2021), another study implemented a single drop-set beginning with a high load (80% 1-RM) with 4 descending sets to 30% 1-RM (Ozaki et al., 2018), and also in the other research had participants perform a 5-RM to failure, immediately reducing load by 20%, and then another drop by 10-15% (Varovic et al., 2019). Presently the optimal DS protocol is unknown. Therefore, the purpose of this study was to compare two drop set protocols (single step vs. multi-step) on changes in muscle strength and endurance, and body composition after 8 weeks compared to TRT in resistance trained individuals. In theory, multi-step drop sets would induce greater metabolic disturbances and may result in greater gains in hypertrophy and muscular endurance but may impair muscular strength compared to a single drop set protocol and traditional resistance training.

METHODS

Experimental approach of the problem

A randomized pre-post repeated measure design was used to investigate changes in two DS protocols compared to TRT over 8 weeks. Healthy young resistance trained males were randomized to one of three independent groups: TRT (n = 9) completed 4 sets of 10 repetitions at 75% of 1-RM with 90 seconds rest between sets; the single step drop-set group (DS-S: n = 10) performed two sets beginning at 80% and dropping to 45% of 1-RM until failure with 90 seconds rest between sets; the multi-step drop-set group (DS-M: n = 8) performed a single drop set corresponding to 80, 65, 50, and 35% 1-RM performed until failure. All groups trained 3 times per week for 8 weeks. Before and after training, body composition (percent body fat and skeletal muscle mass), upper and lower body muscular strength (1-RM) and endurance (40% 1-RM to failure), and isometric leg extension strength were determined. Body composition was assessed via a bioelectrical impedance analysis (InBody 770). The experimental design is shown in Figure 1.



Note. TRT = Traditional resistance training, DS-S = Single step drop-set; DS-M = DS with multiple steps.

Figure 1. Experimental design.

Subjects

An a priori power analysis (G-Power v.3.1.5.1) indicated that N = 30 subjects were required (n = 10/group). This calculation was based on an effect size (0.25), an alpha level of .05, and a ß-value of 0.8 for a repeated measures analysis of variance (ANOVA) design with 3 groups and a correlation among repeated measures of 0.5. As such, thirty participants were recruited using the non-probabilistic sampling method.

Table 1. Descriptive data of the subjects, mean ± SD.

Variables	TRT (N = 9)	DS-S (N = 10)	DS-M (N = 8)
Age (years)	27 ± 5	27.6 ± 4.8	25.9 ± 7.1
Body mass (kg)	73 ± 9.3	75.5 ± 7.4	76 ± 6.2
Height (cm)	174 ± 4.5	179 ± 6.6	173 ± 7.5
Body Fat (%)	15.1 ± 2.35	15.5 ± 3.4	14.7 ± 2.1
SMM (Kg)	35.6 ± 3.5	36.2 ± 4.1	36 ± 3.7
MVC (Nm)	271.4 ± 15.8	278 ± 20.5	280.8 ± 24.3
1RM leg press (kg)	263.6 ± 25.3	248.2 ± 31.5	259.8 ± 26.9
1RM bench press (kg)	112 ± 10.7	120 ± 8.5	116 ± 5.9
ME leg press (reps)	43.4 ± 9.2	40.1 ± 7.5	42.7 ± 11.2
ME bench press (reps)	29.8 ± 5.7	32 ± 7.4	31.4 ± 6.6

Note. SMM = Skeletal muscle mass; MVC = Maximum voluntary isometric contraction; 1RM = One-repetition maximum; ME = Muscle endurance; TRT = Traditional resistance training; DS-S = Single step drop-set; DS-M = DS with multiple steps.

Participants were free of any disease including cardiovascular diseases, hypertension, diabetes, or any other chronic disease that would alter muscle biology or impact the safety of the exercise program. Participants were also not taking any medicine or dietary supplements (e.g., creatine) within 6 months before the start of the study. Furthermore, participants had to have at least 6 months of resistance training experience and not currently using drop set training in their programs. Lastly, participants were excluded if they have recently experienced a muscle, joint, or tendon injury that would impact their ability to train, or if they missed two or more training sessions, or were unable to follow the training protocols as prescribed. Prior to the start of the study, all participants were informed of the risks and benefits and signed an approved informed consent document to participate in the study. The study was approved by an Institutional Ethics Review Board at the Shahid Beheshti University of Tehran (IR.SBU.REC.1400.161). Subject characteristics are shown in Table 1.

Procedures

Muscular strength (1-RM) and endurance

For initial assessment a 1-RM test was used to assess upper (bench press) and lower body (leg press) muscular strength. At the start of the assessment a warm-up was performed that consisted of 5 minutes of low intensity walking on a treadmill followed by 8 repetitions with a load that would achieve a 4-6 score on a 1-10 ratings of perceived exertion (RPE) scale. After 1 minute of rest, 3 repetitions were performed with a load corresponding to ~70% of an estimated maximum RPE (7 out of 10). After 3 minutes of rest, participants completed three to five 1-RM attempts with progressively heavier loads (~5% increase following a successful attempt) interspersed with 3–5 minutes of rest until a 1-RM was achieved. Bench press was assessed first, followed by a 5-minute rest before the same protocol was followed for leg press. The range of motion and exercises technique were standardized according to previously described protocols (Recio et al., 2018). The 1-RM tests (test-retest) were conducted on 2 non-consecutive days (minimum of 72 hours between tests). The intraclass correlation coefficient was $r = 0.95$ for both upper and lower body 1-RM. Once the 1RM was determined, 40% of this value was calculated for the muscular endurance tests. After a standardized recovery period (5 minutes), the subjects performed as many repetitions as possible with 40% of 1RM until failure for both exercises (Recio et al., 2018; Lasevicius et al., 2022; , Schoenfeld et al., 2021). The maximum number of repetitions that were performed correctly without rest or stopping was recorded. All testing sessions were performed at the same time of day.

Resistance training protocols

Prior to each training session a standardized warm-up was completed (Ribeiro et al., 2014). The warm-up consisted of a 5-minute general warm-up that included running or walking on a treadmill and 5 minutes of specialized movements focused on the primary muscles and joints. Following the warm-up, participants trained their upper (bench press) and lower (leg press) body. In the traditional resistance training (TRT) group, participants performed each exercise for 4 sets of 10 repetitions, at an intensity based on their 10-RM or 75% of their 1-RM achieved at baseline. The rest interval between each set was 90 seconds, and the rest between exercises was 3 minutes. In the single-step drop-set (DS-S) group, the participants performed two sets each beginning at 80% of their 1-RM performed until exhaustion followed by a single step drop to 45% of their 1-RM completed to muscle exhaustion with 90 seconds rest between sets and with a 3-minute rest between exercises. In the multi-step drop-set (DS-M) group, the participants started with a load that corresponded to 80% of their 1-RM and continued until muscular exhaustion, then the load was immediately reduced by 15% to 65% of 1-RM, then 50% of 1-RM, and 35% of 1-RM. The load was changed as quickly as possible between step reductions and the rest time between exercises was 3 minutes. All groups completed each repetition at a tempo of 1.1.1.1 (concentric, pause, eccentric, pause). The exercise protocols in all 3 groups are shown in Table 2.

Table 2. Resistance training protocols.

Group	Set	Rep	Load	Rest	*Tempo*
TRT	4	10	75% 1RM	90s	1-1-1-1
DS-S	2	Failure	80% - 45%	90s (between sets)	1-1-1-1
DS-M	1	Failure	80% - 65% - 50% - 35%	-	1-1-1-1

Training volume

The average total training volume (TTV) during the 8 weeks of training was calculated based on (sets × repetitions × load [kg]) for bench press, leg press and for overall total volume (Schoenfeld et al., 2019). The total training volume in bench press, leg press and overall are shown in Table 3.

Table 3. Total training volume, mean ± SD.

Group	Ttv (Kg) Bench Press	Ttv (Kg) Leg Press	Ttv (Kg) Overall
TRT	3480 ± 390	8680 ± 525	12160 ± 915
DS-S	3418 ± 318	8362 ± 463	11780 ± 781
DS-M	3251 ± 384	8160 ± 585	11411 ± 969

Body composition

An InBody 770 multi frequency bioelectrical impedance analysis was used to estimate body fat percentage and skeletal muscle mass. Previous research has shown that multi-frequency bioelectrical impedance analysis (MF-BIA) is a suitable alternative to dual-energy x-ray absorptiometry (DXA) method (Antonio et al., 2019).

Maximum isometric strength

Maximal voluntary isometric contraction (MVC) strength was assessed with a System 4 Pro™ Biodex isokinetic dynamometer to determine the maximum amount of force that could be produced during a leg extension. Participants were seated on the chair of the machine, and the examiner adjusted the machine according to their individual characteristics to ensure proper movement mechanics. After a 5-minute general warm-up on a cycle ergometer, the subjects were asked to perform 10 submaximal isometric repetitions (holding for 3 seconds) at an angle of 75 degrees (relative to the zero angle in full extension). Three minutes later 5 maximum repetitions were performed interspersed with 15-second rest intervals between each attempt. The highest peak torque was considered the highest isometric voluntary contraction for each subject (Tittelboom et al., 2022).

Dietary intake

All participants completed a 3-day dietary record before the intervention and then at the mid-point and conclusion of the study. Total energy and macronutrient intake were calculated. Dietary intake was broken down into specific amounts of macronutrients (carbohydrate, protein, and fat) which included the total percentage of each macronutrient, the number of calories, and the amount consumed in grams, also the total number of daily calories was calculated. To enhance the accuracy of data, a certified nutritionist assisted participants to estimate their food and drink portions (Boidin et al., 2021). All participants were encouraged to maintain their habitual dietary intake throughout the entire study. No significant between-group differences were observed for the average total daily calories and macronutrients (Table 4).

Table 4. Average total daily calories and macronutrients, mean ± SD.

Variables	TRT	DS-S	DS-M
Total daily Kcal (Kcal)	2290 ± 251.9	2398 ± 215.8	2365 ± 260.1
Total CHO (%)	57 ± 6	58 ± 3	56 ± 5
CHO/kg (g/kg)	4.3	4.7	4.4
Total PRO (%)	18 ± 3	17 ± 2	17 ± 3
PRO/kg (g/kg)	1.35	1.32	1.35
Total FAT (%)	26 ± 2	25 ± 4	27 ± 3
FAT/kg	0.9	0.88	0.91

Note. CHO = Carbohydrate; PRO = Protein; Kcal = Kilocalorie.

Statistical analyses

The primary analysis performed was a 3 (group: TRT vs. DS-S vs. DS-M) by 2 (time: pre-training vs. post training) repeated measures ANOVA to determine differences between groups over time for changes in body composition (% body fat, SMM) and muscle performance measures. If a significant effect was found, a Tukey's pairwise post-hoc comparison was completed. Significance was set at $p \leq .05$. The magnitude of the difference between significant means was determined by partial eta squared (η^2). This is a measure of the effect size and therefore of the proportion of the total variance that can be explained by the effects of the treatment. A η^2 value of 0.15 represents large differences, 0.06 represents medium differences, and 0.01 represents small differences. A one-factor ANOVA was used to assess baseline data, training volume, and absolute change scores (post values minus pre values). All statistical analyses were performed using the Statistica v. 13.3 (StataCorp LLC, College Station, TX, USA).

RESULTS

Three subjects were excluded due low adherence and lack of availability to the exercise program. Therefore, only twenty-seven participants completed the training and were included in the analysis. Of these 27 participants, they all had high adherence (>95%) to the exercise program. There were no significant ($p > .05$) differences between groups for any participant characteristics or outcome variables at baseline, as shown in Table 1. Furthermore, there were no significant differences between groups for carbohydrates, protein, fat, or total caloric intake ($p > .05$), as shown in Table 4.

Body composition

There was no significant interaction ($p = .729$) for % body fat, however there was a significant main effect of time ($p = .020$; $\eta^2 = 0.206$; TRT: 15.1 ± 2.4 to 14.9 ± 2.1%; DS-S: 15.5 ± 3.4 to 15.3 ± 3.2%; DS-M: 14.9 ± 2.1 to 14.6 ± 2.5%). The absolute change in % body fat was similar between all groups (absolute Δ: $p = .729$; TRT: -0.2 ± 0.2%; DS-S: -0.1 ± 0.6%; DS-M: 0.3 ± 0.3%). Similarly, there was no significant interaction for SMM ($p = .694$). There was a significant main effect of time demonstrating an increase in muscle mass after 8 weeks of training ($p < .001$; $\eta^2 = 0.675$; TRT: 35.6 ± 3.5 to 36.7 ± 3.3 kg; DS-S: 36.2 ± 4.1 to 37.55 ± 3.9 kg; DS-M: 36 ± 3.7 to 37.47 ± 2.85 kg). The absolute change in SMM was similar between groups (absolute Δ: $p = .694$; TRT: 1.1 ± 0.8 kg; DS-S: 1.4 ± 0.9 kg; DS-M: 1.4 ± 1.1 kg).

Muscular strength and endurance

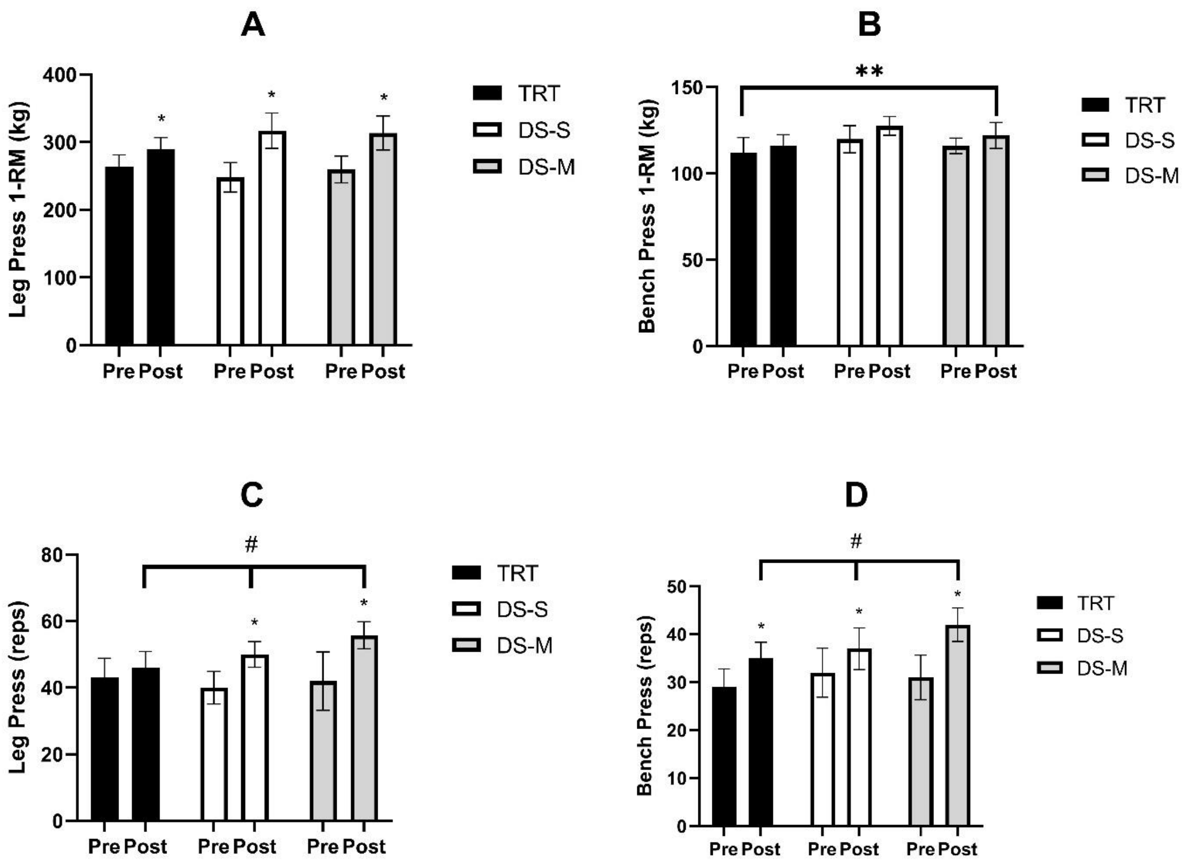
Isometric leg extension strength

There was no significant interaction for isometric MVC ($p = .579$), however there was a significant main effect of time ($p < .001$; $\eta^2 = 0.720$; TRT: 271.4 ± 15.8 to 279.6 ± 11.3 Nm; DS-S: 278 ± 20.5 to 286 ± 19.3 Nm;

DS-M: 280 ± 24.3 to 291.2 ± 18 Nm). The absolute change over time was similar between groups (absolute ∆: p = .579; TRT: 10.3 ± 8.9 Nm; DS-S: 7.9 ± 4.1 Nm; DS-M: 11.0 ± 5.3 Nm).

Leg press and bench press 1-RM

For leg press 1-RM there was a significant interaction ($p < .001$; $\eta^2 = 0.571$), as shown in figure 2A. Post hoc analysis revealed that all three groups increased over time (post > pre; $p < .001$), with no differences between post training values (TRT vs. DS-M, p = .24; DS-S vs. DS-M, p = 1.00; TRT vs. DS-S, p = .10); however, absolute change in leg press 1-RM values revealed a significant difference between groups (absolute ∆: $p < .001$; TRT: 26.5 ± 12.5 kg; DS-S: 69.0 ± 19.7 kg; DS-M: 53.9 ± 15.8 kg) with both DS groups increasing to a greater extent compared to TRT (DS-M vs. TRT, p = .01; DS-S vs. TRT, $p < .001$), with no differences between drop set groups (p = .155). For bench press 1-RM there was no significant interaction (p = .541), as shown in figure 2B, however there was a significant main effect of time ($p < .001$, $\eta^2 = 0.450$) demonstrating that post values were greater than pre training. Furthermore, there was no significant difference between groups for absolute change in bench press 1-RM (absolute ∆: p = .183; TRT: 4.1 ± 11.1 kg; DS-S: 7.7 ± 3.0 kg; DS-M: 6.1 ± 3.7 kg).



*Note. * = Significantly different than pre. ** = Main effect of time, # = Significant interaction.*

Figure 2. Pre post means and SD between groups for (A) leg press 1-RM, (B) bench press 1-RM, (C) leg press endurance, and (D) bench press endurance.

Leg press and bench press endurance

For leg press endurance there was a significant interaction (p < .001; η^2 = 0.661), as shown in figure 2C. Post hoc analysis revealed that the drop set groups increased over time (p < .001), while TRT did not (p = .109). Post training leg press endurance in the DS-M group was significantly greater than TRT (p = .012) but similar to DS-S (p = .269), while DS-S was not different than TRT (p = .618). The absolute change in leg press endurance was significantly different between groups (absolute ∆: p < .001; η^2 = 0.661; TRT: 3 ± 2 reps; DS-S: 10 ± 2 reps; DS-M: 14 ± 5 reps). Both drop set training protocols were superior to TRT (p < .001), with a trend for DS-M to be superior to DS-S (p = .063). For bench press endurance there was a significant interaction (p < .001; η^2 = 0.699), as shown in figure 2D. Post hoc analysis revealed that all groups increased over time (p < .001). In addition, post training bench press endurance values were significantly higher for DS-M compared to TRT (p < .001), however DS-S was similar to both TRT (p = .901) and DS-M (p = .157). Absolute change was significantly different between groups (absolute ∆: p < .001; TRT: 6 ± 2 reps; DS-S: 5 ± 2 reps; DS-M: 11 ± 2 reps). Post hoc analysis revealed that DS-M had a greater change than both DS-S and TRT (p < .001), while there were no differences between TRT and DS-S (p = .45).

DISCUSSION AND CONCLUSIONS

The purpose was to examine two different drop set protocols compared to traditional resistance training on muscular strength and endurance and body composition over 8-weeks (training 3 times per week) in trained participants. Specifically, the drop set protocols consisted of either a single-step or a multi-step reduction in load. The main findings were that both drop set protocols appeared to be superior to TRT to augment gains in lower body (leg press) muscular strength (however, caution is required since this was only noted for absolute change values and not within the post-hoc pairwise comparisons), however, only the multi-step drop set group was superior to TRT to enhance muscular endurance (both lower and upper body endurance), suggesting that variations in drop set protocols influences muscle adaptations and that performing multiple drops enhances muscular endurance without negatively impacting muscular strength comparing to a single reduction drop set training. Furthermore, there were no differences between training protocols with regards to body composition or upper body strength adaptations, but there was a significant main effect of time, suggesting that all three protocols similarly improved body composition and upper body strength over time. Resistance training adaptations are known to be influenced by intensity, duration, and training volume; however, the optimal training program remains to be elucidated (Brown et al., 2001; Schoenfeld et al., 2021). Gains in muscle hypertrophy and strength are associated with several factors, including metabolic and mechanical stress (Gligoroska et al., 2022). Drop set training is a form of training whereby participants rapidly reduce the load between sets which leads to large metabolic disturbances. Schoenfeld speculated that drop set training may elicit greater gains in hypertrophy due to the limited recovery time between sets thereby causing greater muscular fatigue and metabolic stress and Furthermore, drop set training increases time under tension and local hypoxia (ischemia), thereby creating a greater stimulus for muscle adaptations over time (Schoenfeld, 2013). Overall, resistance training is well-known to enhance gains in muscle mass (Kraemer et al., 2004). In the present study a main effect of time was observed for an increase in skeletal muscle mass (assessed via bioelectrical impedance), however, there were no difference between groups. Our results are in support of previous research comparing drops set training to traditional resistance training. For example, Enes et al. investigated 8 weeks of resistance training with either a drop-set training system or traditional resistance training or a rest-pause training system in trained males while They found similar improvements in lateral thigh muscle thickness (middle and proximal portions assessed with an ultrasound) between groups (main effect of time) (Enes et al., 2021). Interestingly, in the present study, there were no differences between traditional resistance training (4 sets of 10 at 75%) which was not performed to failure, while both drop set protocols were performed to failure. This suggests that training to failure is not required to increase muscle gains over time. Furthermore, in the previous study, a greater increase in back squat 1-RM was found in the rest-pause group, but similar increases were noted between the drop set training and the traditional resistance training groups. These results partially support our findings (Enes et al., 2021; Prestes et al 2019). Our results found a significant interaction for leg press 1-RM; however, the pairwise post hoc comparison revealed no differences between groups. However, absolute change (post values minus pre values) was significantly greater for both drop set groups compared to TRT, which suggests a greater change over time for drop set training induced gains in lower body strength. In contrast, Fink et al. reported that after 6 weeks of resistance training with drop set training compared to traditional resistance training, there were similar increases in muscle strength and muscle cross sectional area (Fink et al., 2018). With regards to changes in muscular endurance, our results revealed that the DS-M group had greater improvements following training compared to DS-S or TRT. These differences may be associated with greater alterations in metabolic disturbances and mechanical stress (Brown et al 2001; Ozaki et al 2016; Wackerhage et al 2019). Our findings are in support of previous research, for example, Recio et al. reported that a drop set protocol increased muscle endurance of the trunk extensor muscles of trained males (n = 30) assessed during a deadlift movement following 6-weeks of resistance training. From the results of their research in conjunction with our findings, it may be concluded that the multi-step drop set protocol enhances muscle endurance to a greater extent than single step reduction drops set protocol or traditional resistance training (Recio et al., 2018). Future research is required to explore mechanisms that may explain these findings, however, they are likely due to the greater metabolic stress. Ozaki et al. found that drop-set resistance training was an effective strategy to simultaneously increase muscle CSA, strength, and endurance in untrained young males, even with lower training time compared to traditional resistance exercise protocols using only high- or low-loads (Ozaki et al., 2018). However, the present study failed to find robust increases in strength and body composition changes relative to traditional resistance training, possibly due to investigating males with resistance training experience whereas Ozaki investigated untrained participants.

This study is not without limitations. Despite drop-set training appearing to be superior to TRT for gains in lower body strength, and multi-step drop set training being superior to TRT for muscle endurance, it is important to note that TRT was not performed to failure. Importantly, there was no differences between DS-S and TRT for muscle endurance and bench press 1-RM, suggesting that despite this limitation (i.e. one group training to failure and the other not), there were no differences found between these two groups. Overall, these suggest that the greater gains in muscle performance observed in the multi-step group are more likely due to other factors (such as metabolic stress). Another limitation of this study was the lack of mechanistic data, and future research exploring mechanisms are warranted. In addition, we only examined whole-body changes in skeletal muscle mass and percent body fat. in this regard, a study has found regional differences in muscle thickness changes with drop-set changes (Wackerhage et al., 2019). Lastly, future research in females is required to examine sex-based differences.

Practical application
Based on our findings, single-step and multi-step drop-set training to failure appear to be effective strategies to enhance lower body strength, while only the multi-step drop-set training protocol enhanced muscular endurance compared to TRT. All three training protocols were equally effective at improving body composition. Future research is required to explore mechanisms and potential sex-based differences in response to drop-set training protocols.

AUTHOR CONTRIBUTIONS

Conceptualization, M. F., M. B., B. D. and M. N.; research concept and study design, M. B. and B. D.; data collection, M. F.; data analysis and interpretation, M. T., M. F., M. N., and S. C. F.; writing of the manuscript, M. T. and M. F.; editing a draft of the manuscript, J. G-L. and S. C.F.; writing—review and editing, M. N., M. F., J. G-L. and S. C.F. All authors have read and agreed to the published version of the manuscript.

SUPPORTING AGENCIES

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS STATEMENT

The study was approved by an Institutional Ethics Review Board at the Shahid Beheshti University of Tehran (IR.SBU.REC.1400.161).

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

DATA AVAILABILITY STATEMENT

The data are available if there is justified research interest.

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