Effects of drop set resistance training on acute stress indicators and long-term muscle hypertrophy and strength

Article · April 2017

DOI: 10.23736/S0022-4707.17.06838-4

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The Journal of Sports Medicine and Physical Fitness 2017 Apr 26
DOI: 10.23736/S0022-4707.17.06838-4

Article type: Original Article

Title

Effects of drop set resistance training on acute stress indicators and long-term muscle hypertrophy and strength

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There is no funding received for this work (from NIH, Wellcome Trust, HHMI, or any others). There are no professional relationships with companies or manufacturers who will benefit from the results of the present study for each author.

ABSTRACT

Background: We investigated the effects of 2 different resistance training (RT) protocols on muscle hypertrophy and strength. The first group ($n = 8$) performed a single drop set (DS) and the second group ($n = 8$) performed 3 sets of conventional RT (normal set, NS).

Methods: Eight young men in each group completed 6 weeks of RT. Muscle hypertrophy was assessed via magnetic resonance imaging (MRI) and strength via 12 RM tests before and after the 6 weeks. Acute stress markers such as muscle thickness (MT), blood lactate (BL), maximal voluntary contraction (MVC), heart rate (HR) and rating of perceived exertion (RPE) before and after one bout of RT.

Results: Both groups showed significant increases in triceps muscle cross-sectional area (CSA) (10.0 ± 3.7%, effect size (ES) = 0.47 for DS and 5.1 ± 2.1%, ES = 0.25 for NS). Strength increased in both groups (16.1 ± 12.1%, ES = 0.88 for DS and 25.2 ± 17.5%, ES = 1.34 for NS). Acute pre/post measurements for one bout of RT showed significant changes in MT (18.3 ± 5.8%, $p < 0.001$) and MVC (-13.3 ± 7.1, $p < 0.05$) in the DS group only and a significant difference ($p < 0.01$) in RPE was observed between groups (7.7 ± 1.5 for DS and 5.3 ± 1.4 for NS).

Conclusions: Superior muscle gains might be achieved with a single set of DS compared to 3 sets of conventional RT, probably due to higher stress experienced in the DS protocol.

Keywords: Descending loads, mechanical and metabolic stress, cross-sectional area

INTRODUCTION

Several methods to increase the intensity of effort in resistance training (RT) such as forced repetitions (FR), eccentric training (ET) and drop sets (DS) are widely used by athletes in an attempt to increase muscle mass [1]. Unlike FR and ET, which require external help to increase intensity of effort, DS increases intensity by dropping the load each time the point of failure is reached. The improved mechanical and metabolic stress and muscle damage experienced with DS may lead to improved muscle hypertrophy via several anabolic pathways such as increased muscle protein synthesis [2], muscle fiber recruitment [1, 3], hormonal increases and cell swelling [4].

Even though the DS method is widely used by many athletes in order to maximize muscle gains, only a few studies compared muscle hypertrophy in DS and conventional RT. Indeed, research on increased intensity training methods, especially DS training, is incomplete in regard to its long-term effects on muscle and strength gains [1]. Only a few studies have endeavored to specifically investigate the effects of DS training on muscular adaptations [5-7]. Goto et al [5] found significantly greater increases in cross-sectional area (CSA) and strength (1 repetition maximum (RM), maximum voluntary contraction (MVC)) after 4 weeks of RT when a single drop set was added to a traditional strength-type routine versus performing the strength routine alone. However, no direct comparison with fixed load multiple set RT was made [5]. Recently, Fisher and Steele [8] reported no significant differences in muscular endurance or body composition for a single set total body routine versus the same protocol performed with drop sets. A major limitation of the study was that body composition was assessed by air displacement plethysmography, which does not have the ability to determine site specific changes in muscle growth. Another recent study directly assessing site specific changes in muscle mass has found similar results for both drop set and traditional RT [9]. However the study design differed in many ways (number of sets, total training volume, study length, method of CSA measurement, trained muscle group, level of experience in RT) making it difficult for a direct comparison.

In order to explain potential differences in long-term effects among RT protocols, several acute responses may be used as accurate indicators for mechanical and metabolic stress and muscle damage. Indeed, neuromuscular fatigue and physiological responses have been measured via changes in MVC, blood lactate (BL), strength and rating of perceived exertion (RPE) [7]. In addition, acute muscle swelling and heart rate (HR) might be an indicator for mechanical and metabolic stress. Increased intracellular hydration (muscle swelling) has been shown to preferentially occur with exercise using glycolysis, ultimately leading to osmotic changes via metabolite accumulation [4]. Therefore muscle thickness (MT) can be considered as a potential marker for metabolic stress including metabolite accumulation [4] and muscle damage [10]. Heart rate measurement is often used to asses internal load in athletes and training intensity [11, 12] and might therefore be appropriate to measure training induced stress.

Even though the exact hypertrophic mechanisms and pathways triggered by DS training are not yet completely understood, we hypothesized that the increased mechanical and metabolic stress and muscle damage occurring with DS would result in superior muscle hypertrophy as compared to conventional RT. The outcomes with regard to strength as compared to conventional training are of great interest.

MATERIALS (PATIENTS) AND METHODS

Subjects

Sixteen active male college students (20-32 yrs) volunteered to participate in this study. All participants had previous recreational experience in strength training but did not regularly train for more than 1 year before the experiment start and refrained to participate in any other strength training for the duration of the experiment. The participants were randomly assigned to either the drop set group (DS, n = 8, age: 21.6 ± 1.9 yrs, height: 171.5 ± 3.1 cm, weight: 66.3 ± 8.4 kg, body fat: 15.5%) or the normal set group (NS, n = 8, age: 22.8 ± 3.9 yrs, height: 172.8 ± 4.8 cm, weight: 66.5 ± 6.7 kg. body fat: 14.0%). All the participants were informed about the potential risks of the experiment and gave their written consent to participate in the experiment. This study was approved by the Ethics Committee of the Nippon Sport Science University (Chairperson: Koichi Nakazato, protocol number: 015-H120, date of approval: March 3, 2016) in accordance with the Declaration of Helsinki for Human Research. The sample size for this study was calculated (GPower 3.1, Dusseldorf, Germany) a priori as follows: Effect size f = 0.25, α err prob = 0.05, power = 0.8. The required total sample size was n =16, n = 8 for each group.

Resistance training

Training in both groups consisted of cable triceps push-downs (HOIST Fitness Systems, USA). We chose this exercise in order to isolate the triceps muscle and avoid the utilization of other muscles. The DS group performed a single set with an initial load of 12 repetition maximum (RM), decreasing the load by 20% each time failure was reached 3 times consecutively. The number of repetitions was not fixed after each drop but all participants did as many repetitions as possible for each bout. Every time the point of failure was reached, a staff member adjusted the weight stack pin in order to minimize time loss between load changes and maximize continuous time under tension. The NS group performed 3 sets to failure at 12RM with 90 s between sets. The participants were told to perform each repetition with a fast movement (1 s) on the concentric and a slow movement (2 s) on the eccentric part. Twelve RM measurements for the exercise have been assessed 1 week prior to the experiment. Initial training load was 12RM in both groups. RT sessions were supervised by qualified personal trainers in order to ensure correct execution of the exercises.

Dietary adherence

In order to avoid external effects due to different caloric intakes, participants were asked to record total calories consumed every day for the period of the experiment. Food record sheets were distributed before the experiment end collected after the 6 weeks. For calculation, each meal was broken down into macronutrients (carbohydrate, protein and fat) and the total number of calories was calculated by the addition of all macronutrients.

Total training volume

The number of repetitions and load for each set were recorded for each RT session. Volume was calculated as load (% 1RM) × repetitions.

Acute measurements (performed during one particular RT session)

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Muscle thickness

Acute changes of muscle thickness (MT) have been assessed during one RT session before and immediately after a single bout of RT via ultrasound imaging (Prosound 2; Hitachi Aloka Medical, Ltd., Tokyo, Japan). For measurements, participants were sitting with their arm extended and relaxed. Three images of the left long head of the triceps measured 60 % distal between the lateral epicondyle of the humerus and the acromion process of the scapula at the midline of the arm [13] have been recorded for each participant before and immediately after RT. After application of transmission gel to the measurement site, the ultrasound probe (7.5 MHz) was positioned perpendicular to the muscle without depressing the skin. The distance between the subcutaneous adipose tissue-muscle interface to the muscle-bone interface has been measured via imageJ (National Institutes of Health) and the mean value of the 3 images was recorded as final value. The test-retest intraclass correlation coefficient (ICC) has been assessed prior to the study and showed a value of 0.87.

Blood lactate

Blood lactate (BL) concentrations were measured from capillary finger blood collected from the finger tips during one RT session before, immediately after, 2 and 5 minutes after RT by using a portable lactate analyzer (Lactate Pro 2; ARKRAY, Inc., Kyoto, Japan).

Maximal voluntary contraction

Maximal voluntary isometric contraction (MVC) of the triceps was measured before and immediately after a single RT session (Biodex System 3 dynamometer; Sakai Medical Instrument, Tokyo, Japan). While sitting in a chair, the participant's left arm was strapped at an elbow joint angle of 90° to a fixed platform at chest height. The participants were holding the Biodex handle in a supinated position. Each participant was told to try to extend his arm against the handle as strong as possible and performed 2 MVC's separated by 60 sec rest intervals. The highest value was recorded for each participant. ICC was > 0.9 for MVC measurements.

Heart rate

Heart rate was measured by the use of a heart rate monitor (HRM) (Polar V800; Polar Electro Inc., New York, USA) with a chest strap worn by the participants during the entire length of a single RT session. The heart rate before and after each RT protocol has been recorded.

Rating of perceived exertion

Each participant rated the intensity of RT using the ratings perceived exertion (RPE) revised category-ratio scale (0 to 10 scale) which can be used to rate physiological and perceived stress in RT [14]. After the last set, the 0 to 10 scale was displayed and each participant rated his effort.

Chronic measurements

Muscle CSA

Participants underwent magnetic resonance imaging (MRI) (AIRIS Ⅱ, Hitachi, Ltd., Tokyo, Japan) scans of the right upper arm (biceps, brachialis and triceps) muscles during the week before training start and 72-96 hours after the last RT session (week 7). To ensure accuracy of the measurements, markers filled with water were placed exactly at half-distance of each participant's upper arm (measured from the lateral epicondyle of the humerus to the acromion process of the scapula). The following parameters were used to acquire 20 axial scans: repetition time/echo time, 460 ms/26 ms; field of view 20 cm, phase/frequency, 320; slice thickness, 3mm; gap, 10mm. The images showing the markers were then analyzed via imageJ (National Institutes of Health) and the square area of the triceps was calculated twice by the same investigator. The mean value was used for calculations. A reliability test showed an intraclass correlation coefficient (ICC) of > 0.9 for our CSA calculations.

Muscle strength

Because 1RM testing on small muscle groups is not practical, 12RM tests for the cable triceps push-down (HOIST Fitness Systems, Poway, USA) were conducted during the week before and 72-96 hours after the last RT. A team of qualified trainers supervised the tests and assured correct execution of the exercises. After a warm-up set of 10 repetitions performed with a load corresponding to approximately 20RM, 12RM was assessed within 5 tries separated by 180 s. The initial weight for the 12RM assessment was adjusted for each participant's personal record and was increased by one plate (8 lb) of the weight stack each try. ICC was > 0.8 for 12RM measurements.

Statistical analyses

Data are displayed as mean ± SD. We used two-way analysis of variance (ANOVA) (time x groups) to analyze the significance of our values and post-hoc Bonferroni tests (SPSS for Macintosh version 22) were employed when appropriate. Effect size (ES) [15] was calculated for each group and parameter. The significance level was set a priori at $p < 0.05$.

RESULTS

Long-term results

Muscle CSA changes (Figure 1, table 1)

The DS group's triceps CSA significantly increased 10.0 ± 3.7% ($p < 0.001$)

compared to a 5.1 ± 2.1% ($p < 0.05$) increase for the NS group. However, no significant between-group differences were observed ($p = 0.577$).

Muscle strength (Figure 2, table 2)

Both groups significantly increased triceps push-down 12RM (DS: 16.1 ± 12.1%, $p < 0.05$; NS: 25.2 ± 17.5%, $p < 0.001$). However, no significant between-group differences were observed ($p = 0.570$).

Total training volume

No significant between-group differences were observed for the average total training volume for a single RT session (number of repetitions × load) (DS: 38.3 ± 6.7, NS: 38.9 ± 6.3, $p > 0.5$).

Total training time

Significant between-group differences for the total length of a single session including rest intervals were observed, with DS showing a shorter duration of training compared to NS (DS: 145.4 ± 21.0 s, NS: 315.8 ± 42.2 s, $p < 0.001$).

Total daily calories

No significant between-group differences were observed for the average total daily calories and macronutrients (Table 3).

Acute results

Muscle thickness (Figure 3)

Significant increases of MT in the long head of the triceps after a single bout of RT were observed in the DS group only (18.3 ± 5.8%, $p < 0.001$).

Blood lactate (Figure 4)

BL showed similar changes in both groups immediately after, 2 and 5 min after RT in both groups. However, BL peaked immediately after RT (408.9 ± 316.0%) in the NS group and 2 min after RT in the DS group (313.2 ± 136.3%).

Maximal voluntary contraction (Figure 5)

Only the DS group showed significant decreases (-13.3 ± 7.1%, $p < 0.05$) in MVC after a single bout of RT.

Heart rate (Figure 6)

Hear rate increased (pre vs. post RT values) 80 ± 49.5%, $p < 0.001$ in the DS group compared to 47.5 ± 37.8%, $p < 0.05$ in the NS group. However, no significant between-group differences were observed.

Rating of perceived exertion (Figure 7)

The exertion perceived after a single bout of RT by the participants in the DS group was significantly larger compared to the NS group (DS: 7.7 ± 1.5; NS: 5.3 ± 1.4, $p < 0.01$).

DISCUSSION

In this study, we investigated whether drop set RT leads to superior muscle hypertrophy as compared to conventional RT. The results showed significant increases of triceps CSA in both groups, but the increase rate of the DS group (10.0 ± 3.7%, ES = 0.47) was markedly larger than that of the NS group (5.1 ± 2.1%, ES = 0.25). Metabolic and perceived stress markers such as MT, HR and RPE were significantly higher in the DS group than in the NS group. External effects such as different dietary intakes have been monitored and both groups showed average daily caloric intakes for young men without significant differences between groups. Macronutrients (carbohydrate, protein and fat) also did not show significant differences between groups.

We showed that a single set of drop set RT < 150 s 2 times/week over a period of 6 weeks leads to CSA increases > 10%. Even though significance among groups could not be observed, the triceps CSA increased twice as much in the DS group as compared to a volume-matched conventional RT protocol. ES for CSA increases was also larger for DS (0.47) than NS (0.25), lending support to a potential benefit for a drop sets in promoting an enhanced hypertrophic response. Strength significantly increased in both groups without differences among groups.

Acute results for stress markers after a single bout of RT such as larger values for MT and RPE, decreased MVC and a trend for increased HR in the DS group indicate that the DS protocol induces larger stress and damage compared to the NS protocol. However, BL did not show any significant differences among groups. Indeed, BL responses seem to depend on the size of the muscle trained [16] and may not improve with longer time under tension [17]. Since both RT protocols in our study have been performed on a small muscle group with different continuous time under tension lengths, we could not expect major differences among groups. The results for acute BL changes are in line with a previous study showing no differences among DS and NS RT [7]. However, our results for acute MVC changes and RPE are inconsistent with the results of the aforementioned study showing no differences between DS and NS RT [7]. Differences in the time course of measurement for MVC (immediately after in our study vs. post 30 min in the study of Raeder et al. [7]) and the time lag between weight adjustments for each bout of the drop set protocol (no rest in our study vs. 10 sec rest in the study of Raeder et al. [7]) might have caused the observed discrepancies in MVC and RPE results among studies. Furthermore in our study each set was conducted to failure whereas the number of repetitions was fixed in previous research [7].

The triceps CSA increases observed in our study (5.1%) for the NS group are similar to those recorded in previous research (6.0%) [13] with a similar training protocol (3 sets of bench press at 75% 1RM) and period of time (3 times/week for 8 weeks). The CSA increases observed in the DS group have been more than twice as large compared to those observed in previous research using a drop set RT protocol (10% vs. 4%) for the same period of time (6 weeks) [5]. Even though the drop set protocol was similar in regard to the loads [5], 30 s rest between sets may have attenuated the hypertrophic effects. We propose that the larger CSA increase in the DS group observed in our study might be due to increased mechanical and metabolic stress and muscle damage due to dropping the load without rest. Indeed, longer time under tension has been shown to increase muscle protein synthesis [2] while improved metabolic stress might increase muscle fiber recruitment, hormonal responses and cell swelling among other anabolic responses [4]. The accumulation of metabolites such as inorganic phosphate and hydrogen ions may inhibit the action of contractile proteins [18] possibly leading to larger motor unit recruitment. High metabolic stress has also been shown to increase hormonal responses [19] which may create an enhanced anabolic milieu [20], although it is questionable whether such an acute systemic elevation actually mediates muscle protein accretion [21]. Increased acute hormonal responses have been observed after a DS protocol decreasing load each set with 30 s rest intervals between sets [5]. Muscle hypertrophy induced by the hormonal pathway potentially occurs via increased protein synthesis and satellite cell activation [22, 23]. High metabolic stress triggers intracellular hydration (cell swelling) believed to increase satellite cell proliferation [24] and protein synthesis [25] ultimately leading to muscle hypertrophy. Further, RT relying on glycolysis may improve glycogen storage capacity [26]. Therefore, a larger glycogen storage capacity that evokes chronic muscle swelling may trigger muscle gains [4]. Furthermore, satellite cell proliferation and differentiation triggered by growth factors released in response to inflammation caused by muscle damage is also believed to be a factor affecting muscle hypertrophy [1]. When taken together, it can be hypothesized that the effects of increased mechanical and metabolic stress and muscle damage trigger a cascade of anabolic pathways resulting in increased muscle hypertrophy rates as compared to conventional RT.

Exercises such as the bench press involving the triceps have previously recorded up to 21% 1RM increases after 6 weeks of 3 weekly RT sessions (3 sets) at 75% 1RM [27]. Another study with similar RT parameters conducted on an arm isolation exercise showed a 26.5% increase in strength [28]. In our study, we observed a similar increase (25.2%) in the triceps push-down 12RM for the NS groups while an increase of 16.1% has been observed in the DS group. Indeed, after the first load drop, the DS protocol used lower loads compared to the NS protocol, probably resulting in attenuated strength increases. These results are in line with previous research showing that strength increases are load dependent [13, 27].

This study has several limitations. First, the short duration (6 weeks) does not allow us to predict the outcomes for longer time periods. It would be of interest to investigate if the groups adapt differently over a longer time period. However, previous research showed significant biceps and triceps CSA increases after 6 weeks of RT with no significant improvements after 8 and 12 weeks as compared to 6 weeks [29]. Second, the findings are specific to a small muscle group (triceps brachii) using a single-joint exercise; it remains to be determined whether similar responses are seen in large muscle multi-joint movements.

CONCLUSIONS

Our study provides evidence that DS may help to enhance the hypertrophic response to RT. Even though the exact hypertrophic mechanisms of DS training is not yet clear, the high metabolic and mechanical stress and muscle damage might lead to superior anabolic responses compared to NS training. DS training might be an efficient way to increase muscle mass with minimal time spent training. However, the hypertrophic increases appear to occur without corresponding increases in muscle strength. Trainees seeking fast muscle gains without focusing on strength gains such as bodybuilders may want to include a DS protocol into their RT regimen.

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Table 1. CSA changes

Table 2. Cable push-down 12RM changes

Table 3. Average macronutrients and total daily calories

TITLES OF FIGURES

Figure 1.

Average CSA changes for the triceps after 6 weeks of drop set (DS) or normal set (NS) RT. Values represent mean % change ± SD.

Figure 2.

Average 12RM changes for the cable push-down after 6 weeks of drop set (DS) or normal set (NS) RT. Values represent mean % change ± SD.

Figure 3.

Average change in MT after a single RT session of drop set (DS) or normal set (NS) RT. Values represent mean % change ± SD.

Figure 4.

Average BL values before (B), immediately after (post 0 min), 2 min after (post 2 min) and 5 min after (post 5 min) a single RT session of drop set (DS) or normal set (NS) RT. Values are expressed in mmol/L, mean ± SD, * $p < 0.01$ versus before.

Figure 5.

Average change in MVC after a single RT session of drop set (DS) or normal set (NS) RT. Values represent mean % change ± SD.

Figure 6.

Average change in HR after a single RT session of drop set (DS) or normal set (NS) RT. Values represent mean % change ± SD.

Figure 7.

Average RPE after a single RT session of drop set (DS) or normal set (NS) RT. Values expressed in RPE (1-10), mean ± SD.

Table 1. CSA changes

	DS			NS		
	Pre (cm^2)	Post (cm^2)	ES	Pre (cm^2)	Post (cm^2)	ES
CSA	7.0 ± 1.3	7.7 ± 1.6 *	0.47	6.9 ± 1.4	7.25 ± 1.4 *	0.25

Pre and post values (mean ± SD) for the cross-sectional area (CSA) of the triceps for the DS (drop set) and NS (normal set) groups. ES = Effect size of training. * $p < 0.05$ significant increase compared to pre values.

Table 2. Cable push-down 12RM changes

	DS			NS		
	Pre (lb)	Post (lb)	ES	Pre (lb)	Post (lb)	ES
12RM	101.5 ± 18.2	117.9 ± 18.9 *	0.88	99.25 ± 9.8	124.3 ± 24.6 *	1.34

Pre and post values (mean ± SD) for the cable push-down 12 repetition maximum (12RM) for the DS (drop set) and NS (normal set) groups. ES = Effect size of training. * $p < 0.05$ significant increase compared to pre values.

Table 3. Average macronutrients and total daily calories

	Carbohydrates (gr)	Proteins (gr)	Fats (gr)	Total (kcal)
DS (n = 8)	364.9 ± 184.4	88.6 ± 41.7	60.1 ± 29.7	2355.2 ± 661.2
NS (n = 8)	309.6 ± 79.5	94.1 ± 44.6	63.3 ± 27.6	2184.1 ± 430.4

DS (drop set) and NS (normal set) groups. All values represent mean ± SD.

Figure 1

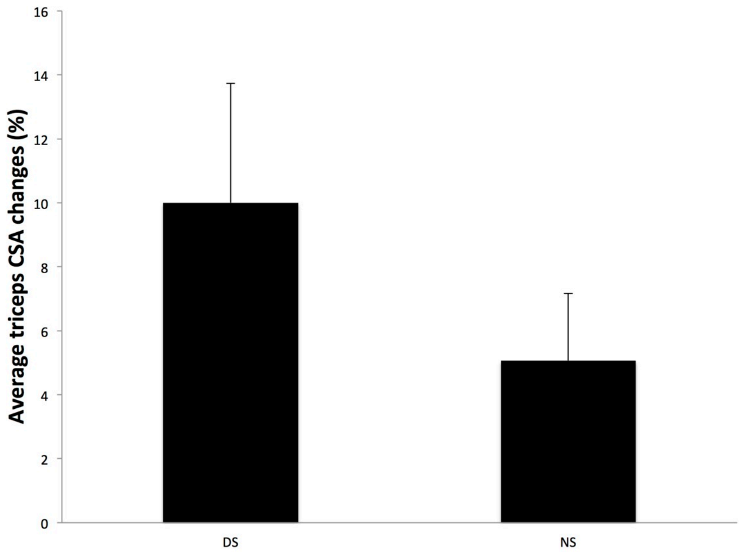


Figure 2

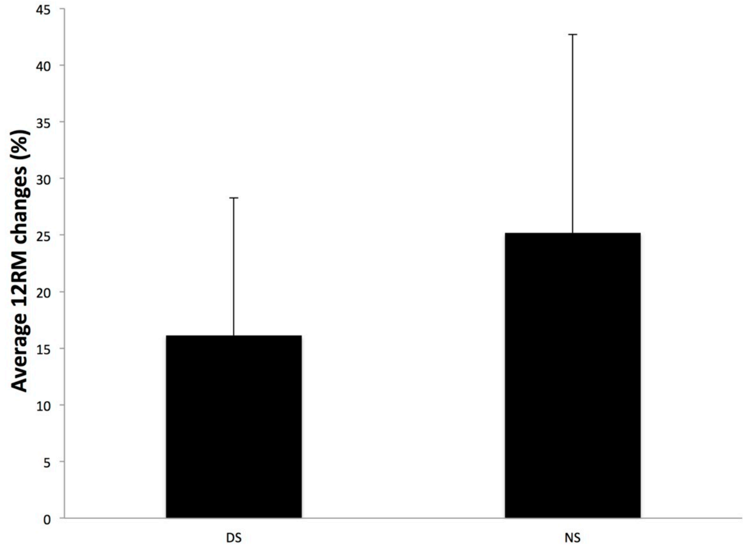


Figure 3

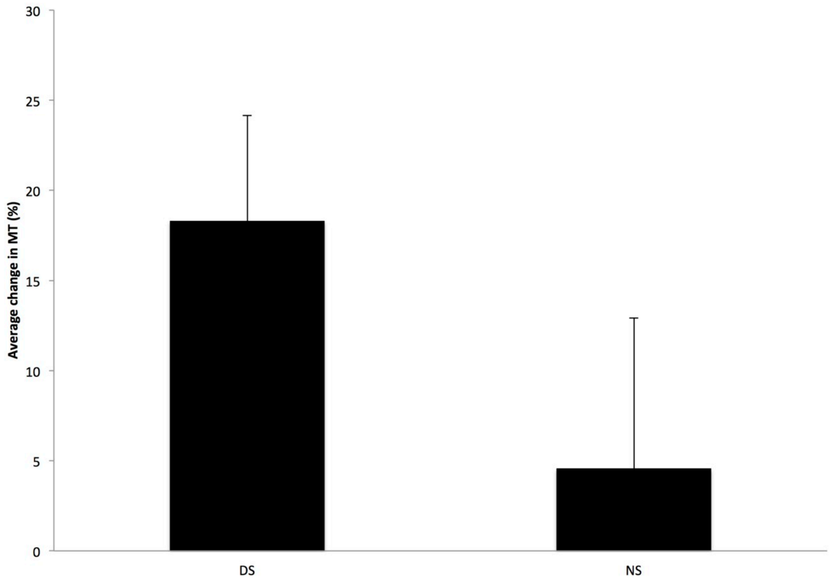
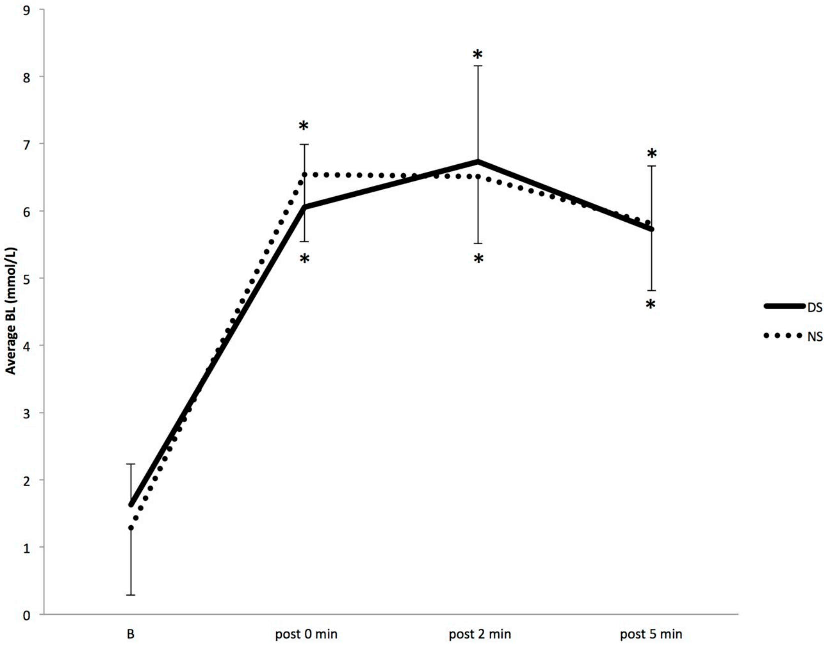


Figure 4



9
8
7
6
5
4
3
2
1
0
Average BL (mmol/L)
*
*
*
*
*
*
*
B
post 0 min
post 2 min
post 5 min
DS
NS

Figure 5

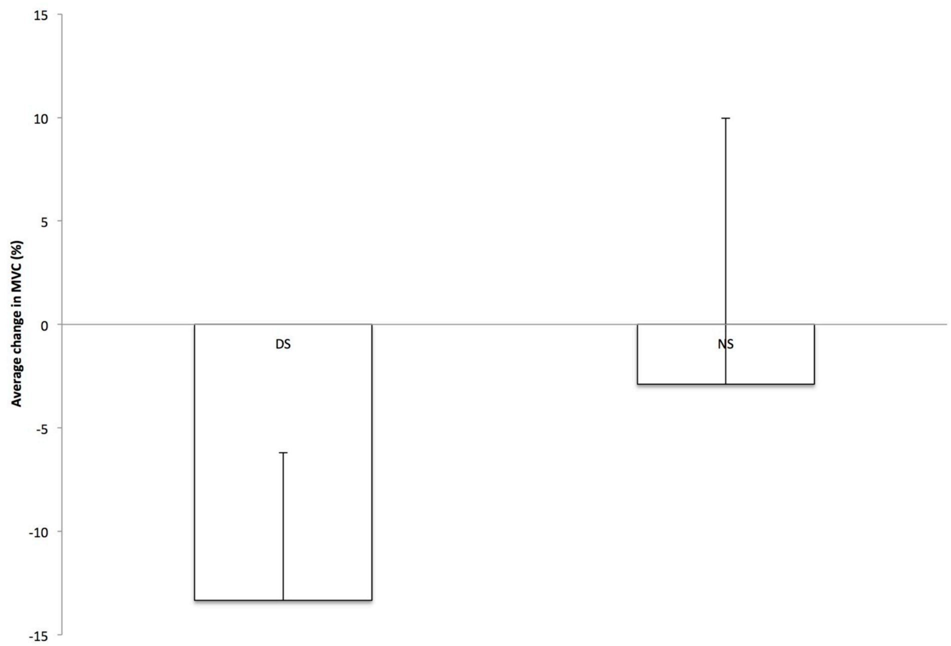


Figure 6

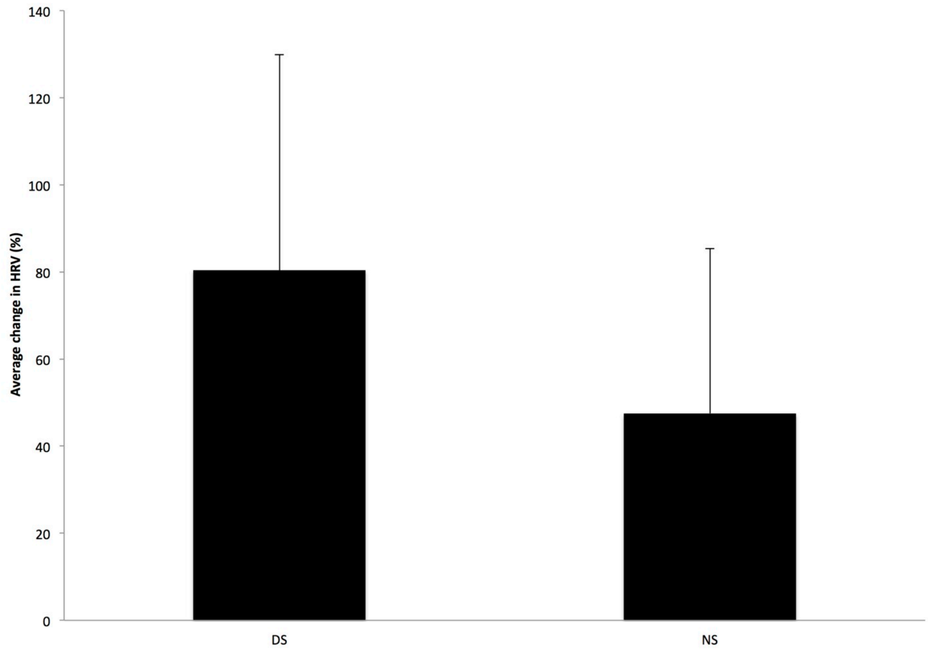


Figure 7