

# GREATER GAINS IN STRENGTH AND POWER WITH INTRASET REST INTERVALS IN HYPERTROPHIC TRAINING

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## ABSTRACT

Oliver, JM, Jagim, AR, Sanchez, AC, Mardock, MA, Kelly, KA, Meredith, HJ, Smith, GL, Greenwood, M, Parker, JL, Riechman, SE, Fluckey, JD, Crouse, SF, and Kreider, RB. Greater gains in strength and power with intraset rest intervals in hypertrophic training. *J Strength Cond Res* 27(11): 3116–3131, 2013—We sought to determine if hypertrophic training with intraset rest intervals (ISRs) produced greater gains in power compared with traditional rest (TRD) hypertrophic training. Twenty-two men (age  $25 \pm 5$  years, height  $179.71 \pm 5.04$  cm, weight  $82.1 \pm 10.6$  kg,  $6.5 \pm 4.5$  years of training) matched according to baseline characteristics were assigned to 12 weeks of training using TRD or ISR. Body composition, strength (1-repetition maximum [1RM] bench and squat), and power output (60% 1RM bench and squat, and vertical jump) were assessed at baseline, 4, 8, and 12 weeks. Determination of myosin heavy chain (MHC) percentage from the vastus lateralis was performed pretraining and posttraining. Body composition was analyzed by analysis of variance, whereas performance measures and MHC were analyzed by analysis of covariance with baseline values as the covariate. Data are presented as mean  $\pm$  SD changes pre to post. The ISR produced greater power output in bench (TRD  $32.8 \pm 53.4$  W; ISR  $83.0 \pm 49.9$  W,  $p = 0.020$ ) and vertical jump (TRD  $91.6 \pm 59.8$  W; ISR  $147.7 \pm 52.0$  W;  $p = 0.036$ ) with squat power approaching significance (TRD  $204.9 \pm 70.2$  W; ISR  $282.1 \pm 104.2$  W;  $p = 0.053$ ) after post hoc analysis ( $p < 0.10$ ). The ISR produced greater gains in

bench (TRD  $9.1 \pm 3.7$  kg; ISR  $15.1 \pm 8.3$  kg;  $p = 0.010$ ) and squat (TRD  $48.5 \pm 17.4$  kg; ISR  $63.8 \pm 12.0$  kg;  $p = 0.002$ ) strength. Both protocols produced significant gains in lean mass with no significant differences between groups ( $1.6 \pm 2.1$  kg;  $p = 0.869$ ). The MHC<sub>IIX</sub> percentage decreased ( $-31.0 \pm 24.5\%$ ;  $p = 0.001$ ), whereas the MHC<sub>IIA</sub> percentage increased ( $28.9 \pm 28.5\%$ ;  $p = 0.001$ ) with no significant differences between groups. Results indicate that hypertrophy training with ISR produces greater gains in strength and power, with similar gains in lean mass and MHC alterations as TRD. The ISR may be best used in hypertrophic training for strength and power sports.

**KEY WORDS** intraset rest intervals, cluster training, interrepetition rest, power, strength, performance

## INTRODUCTION

The velocity of contraction decreases over the course of performance of successive repetitions (21). In sports where the ability to generate power is a necessary aspect of performance, the resultant decrease in velocity is counter to the principle of specificity. One method for counteracting the aforementioned phenomenon is to reduce the number of repetitions performed at a given percentage repetition maximum (%RM). Although reducing the number of repetitions enables less reduction in power output over successive sets (35), to achieve the same volume of training this method extends the total training time. This is a consideration to both individuals and strength coaches as time with athletes is often regulated. Other methods for the maintenance of velocity, and thus power output, include interrepetition rest, intraset rest (27), and cluster sets (16,17). Interrepetition rest training involves a brief rest between each repetition, whereas intraset rest incorporates rest between groups of repetitions (27). Cluster sets is a more

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27(11)/3116-3131

*Journal of Strength and Conditioning Research*  
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specific form of interrepetition rest in which only a 10- to 30-second rest is employed between each repetition or group of repetitions within a set (16,17).

Previous studies comparing traditional (4 set  $\times$  6 repetitions with 260-second rest) and intraset rest (8 sets of 3 with 113-second rest) using intensities  $\geq 85\%$  1RM in upper body exercises have demonstrated that intraset rest intervals (ISRs) do not provide a benefit over training with traditional rest (TRD) (13,27). However, lower body training with cluster sets has demonstrated a tendency toward greater gains in measures of power output (19), whereas intraset rest has demonstrated significantly greater gains in power output compared with TRD between sets in athletes (22). The only study demonstrating significantly greater gains on power output was performed over a periodized training period to include phases of hypertrophy, strength, and power.

Izquierdo et al. (21) demonstrated that the reduction in average velocity was similar over all intensities examined using intensities prescribed for the development of hypertrophy. Although the process of hypertrophy is no doubt multifactorial, the recommended intensity for the development of hypertrophy (4) corresponds with that for the development of muscular power in trained subjects performing multijoint exercises (24). Furthermore, it has been demonstrated that the total volume load and intensity at which that volume load is performed are the primary variables associated with optimal gains in lean mass (10). Thus, if the total volume load is equated, intraset rest may allow for greater velocity training, resulting in a greater improvement in power over TRD while producing similar gains in lean mass. Despite this evidence, the effect of ISRs in a periodized resistance training program designed specifically to elicit hypertrophy has not been evaluated. Therefore, the purpose of our investigation was to determine if intraset rest hypertrophy training, equated for total volume load and rest, improved power more than traditional hypertrophy training. We hypothesized ISRs would result in greater gains in power output compared with TRD, whereas both training interventions would produce similar gains in strength and lean mass.

Although it is well established that resistance training results in a shift in myosin heavy chain (MHC) composition, primarily an increase in percentage of MHC<sub>IIA</sub> and MHC<sub>IIA/x</sub> hybrids with a concomitant decrease in MHC<sub>IIX</sub> (10), recent evidence suggests that changes in MHC composition may be velocity dependent. Liu et al. (29) demonstrated a shift in the MHC<sub>slow</sub> to MHC<sub>IIA</sub> with no change in the MHC<sub>IIX</sub> when performing traditional resistance training followed by ballistic exercise. Higher peak velocities have been reported using ISRs (17). However, whether or not differential effects manifest in MHC composition as a result of training with ISRs has yet to be determined. Therefore, a secondary purpose of our investigation was to evaluate changes in MHC composition as a result of ISRs. We hypothesized that ISRs would result in less reduction in the MHC<sub>IIX</sub> percentage compared with TRD.

## METHODS

### Experimental Approach to the Problem

A longitudinal research design was employed to compare the effects of TRD and ISRs in a program designed to elicit hypertrophy. To eliminate any possible confounding factors, the type and order of exercises performed and the volume load and total rest were equated between groups. This was critical to the design of the study as others have shown variations in these variables to impact training adaptations (10). After baseline testing, the subjects were matched according to baseline physical and performance characteristics and randomly assigned to perform hypertrophic training using TRD or intraset rest (ISR) within a periodized hypertrophic training program. Body composition, strength, and power output of the upper and lower body musculature were assessed at baseline, after 4, 8, and 12 weeks of training. Dietary intake was reported, and analysis was conducted before each testing session. Muscle biopsies for MHC content were performed at baseline and at the conclusion of the training program.

### Subjects

Twenty-two men completed this study. Selection criteria included (a) men between the ages of 20 and 35; (b) having at least 2 years of resistance training experience to include upper and lower body at least once per week; and (c) reporting not having consumed any nutritional or ergogenic supplements excluding protein supplementation and a daily vitamin for the previous 6-week period. Those meeting entry criteria were asked to fill out a medical history questionnaire to eliminate those with any possible contraindications to exercise. The subjects meeting all criteria were informed of the experimental procedures and asked to sign an informed consent approved by the Institutional Review Board. Baseline characteristics for the 22 subjects ( $n = 22$ ) are presented in Table 1.

Of the 22 subjects, 45% ( $n = 10$ ) were active duty military, 41% ( $n = 9$ ) were members of the Naval Reserve Officer Training Corps Unit, whereas the remaining 14% ( $n = 3$ ) were not involved in military operations. All the subjects reported participating in resistance training of both upper and lower body at least once a week for the previous 2 years. Evaluation of self-report logs demonstrated that the subjects primarily engaged in resistance training for the development of strength and hypertrophy. Additionally the subjects reported having consistently engaged in endurance (primarily running) and high-intensity interval training as part of their training before participation in training intervention. None of the subjects were competitive weightlifters.

### Testing Sessions

Figure 1 provides a summary of testing and training procedures. Before baseline testing, the subjects underwent an exercise familiarization session led by a National Strength and Conditioning Association (NSCA) Certified Strength

**TABLE 1.** Baseline group characteristics.\*†

	TRD	ISR	Combined	<i>p</i>
Age (y)	25 ± 5	25 ± 4	25 ± 5	0.790
Height (cm)	179.71 ± 6.18	179.71 ± 3.90	179.71 ± 5.04	1.000
Body mass (kg)	81.7 ± 11.6	82.5 ± 10.0	82.1 ± 10.6	0.878
Lean mass (kg)	61.9 ± 8.9	63.3 ± 7.0	62.6 ± 7.9	0.689
Fat percentage (%)	14.3 ± 2.7	12.9 ± 5.5	13.6 ± 4.3	0.466
Years trained	6.5 ± 4.0	6.0 ± 5.0	6.5 ± 4.5	0.815
# Days trained	3.5 ± 2.0	3.5 ± 2.0	3.5 ± 2.0	1.000

\*TRD = traditional rest; ISR = in-traset rest intervals; Combined = collapsed across time.  
 †Data are mean ± SD.

and Conditioning Specialist (CSCS) to demonstrate proficiency in all lifts used for training and testing. During the same week, the subjects attended a nutrition seminar detailing macronutrient guidelines for athletes involved in a resistance training program (5) and instruction on proper dietary intake recording provided by a registered dietitian. Before each testing session, the subjects completed a dietary record to include 3 weekdays and 1 weekend day. Dietary recording was completed 1 week before each testing session corre-

sponding to the highest volume and intensity of training during each 4-week cycle (Figure 1). All food logs were reviewed by a registered dietitian and analyzed using dietary analysis software (ESHA Food Processor Version 8.6, Salem, OR, USA). Postworkout supplementation (20 g of protein, 45 g of carbohydrates, 3.5 g of fat) was provided on training days (Muscle Milk Collegiate; Cytosport, Benicia, CA, USA) for all the subjects. In the week of testing sessions, the subjects reported to the laboratory after having fasted for at least 10 hours for body composition measurement. Height and body mass were recorded to the nearest 0.01 cm and 0.02 kg, respectively, using a self-calibrating digital scale (Healthometer, Bridgeview, IL, USA) in socks or bare feet. Body composition was then determined using dual x-ray absorptiometry (DEXA; Hologic Discovery W DXA software version 12.1, Waltham, MA, USA) calibrated according to the manufacturer's guidelines and performed by a trained technician.

Previous studies indicate DEXA to be an accurate and reliable means to assess changes in body composition (3). The subjects had their strength and power output assessed according to standardized procedures outlined below. Muscle biopsies were obtained before baseline testing and at the conclusion of the exercise intervention.

**Strength Testing**

Upper and lower body strength was assessed using the 1RM parallel back squat (1RM<sub>BS</sub>) and bench press (1RM<sub>BP</sub>) exercises. The subjects reported to the laboratory after having refrained from any exercise outside of daily living for at least 72 hours before baseline testing and at least 48 hours before testing in weeks 4, 8, and 12. The initial progression strategy for 1RM determination of both exercises was estimated from self-reporting. Subsequent 1RM progression strategies were based on

Familiarization, nutrition seminar, and muscle biopsy (1 week prior to baseline)	
Body composition, strength and power testing - Baseline	
Standard Rest (STD) Protocol	Intra-Set Rest (ISR) Protocol
4 x 10 with 120 sec rest compound lifts	8 x 5 with 60 sec rest compound lifts
3 x 10 with 90 sec rest assistive lifts	3 x 10 with 90 sec rest assistive lifts
<b>Week 1</b> - 65% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 1</b> - 65% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 2</b> - 70% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 2</b> - 70% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 3</b> - 75% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 3</b> - 75% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 4</b> - 60% 1RM (2 days • wk <sup>-1</sup> )	<b>Week 4</b> - 60% 1RM (2 days • wk <sup>-1</sup> )
Body composition, strength and power testing - Week 4	
4 x 10 with 120 sec rest compound lifts	8 x 5 with 60 sec rest compound lifts
3 x 10 with 90 sec rest assistive lifts	3 x 10 with 90 sec rest assistive lifts
<b>Week 5</b> - 65% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 5</b> - 65% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 6</b> - 70% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 6</b> - 70% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 7</b> - 75% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 7</b> - 75% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 8</b> - 60% 1RM (2 days • wk <sup>-1</sup> )	<b>Week 8</b> - 60% 1RM (2 days • wk <sup>-1</sup> )
Body composition, strength and power testing - Week 8	
4 x 10 with 120 sec rest compound lifts	8 x 5 with 60 sec rest compound lifts
3 x 10 with 90 sec rest assistive lifts	3 x 10 with 90 sec rest assistive lifts
<b>Week 9</b> - 65% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 9</b> - 65% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 10</b> - 70% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 10</b> - 70% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 11</b> - 75% 1RM (4 days • wk <sup>-1</sup> )	<b>Week 11</b> - 75% 1RM (4 days • wk <sup>-1</sup> )
<b>Week 12</b> - 60% 1RM (2 days • wk <sup>-1</sup> )	<b>Week 12</b> - 60% 1RM (2 days • wk <sup>-1</sup> )
Body composition, strength, power testing, and muscle biopsy - Week 12	

**Figure 1.** Testing and training program design.

**TABLE 2.** The ICCs and Pearson product-moment coefficient (*r*) between trials.\*†

	Day 1	Day 2	ICC	<i>r</i>
Bench press 1RM	135.4 ± 28.6	137.0 ± 28.0	0.99	0.001
Back squat 1RM	171.9 ± 47.4	173.5 ± 47.6	0.99	0.001
Bench press power (60% 1RM)	657 ± 147	665 ± 140	0.98	0.001
Back squat power (60% 1RM)	860 ± 295	868 ± 275	0.97	0.001

\*ICC = Intraclass correlation coefficients; RM = repetition maximum.

†Day 1 and day 2 values are mean ± SD.

training logs kept throughout the study. A dynamic warm-up lasting approximately 8–10 minutes was performed before 1RM determination. Two warm-up sets of 5 repetitions at 40–60% 1RM separated by 2 minutes of rest were followed by a 3-minute rest period and 1–2 sets of 2–3 repetitions at a load corresponding to 60–80% 1RM. The subjects then began performing sets of 1 repetition of increasing weight for 1RM determination. Three to 5 minutes of rest was provided between each successive attempt. All 1RM determinations were made within 3–5 attempts. The subjects were required to reach parallel in the 1RM<sub>BS</sub> for an attempt to be considered successful as determined by a CSCS certified individual providing a verbal “up” command. The 1RM<sub>BP</sub> was considered successful if the subject remained in contact with the bench during the entire concentric phase of the lift. The 1RM<sub>BS</sub> testing was conducted before 1RM<sub>BP</sub> separated by a 5-minute rest period. The same 1RM testing procedure was used for both exercises. All strength testing took place on an Optima Smith Machine (LifeFitness, Schiller Park, IL, USA) without counterbalance technology. Foot placement was recorded during baseline 1RM<sub>BS</sub> testing, and hand placement was recorded at baseline 1RM<sub>BP</sub> testing.

These measurements were then used in subsequent testing for strength and power. All testing sessions were supervised by 2 CSCS certified individuals to determine success during each attempt.

### Power Testing

Power testing commenced at least 48 hours post 1RM testing. The subjects performed the

same warm-up before initiation of power testing. Body mass and reach height were recorded for calculation of power as determined by vertical jump. Two countermovement vertical jumps (CMJs) using less than maximal effort were allowed before testing. Three maximum effort CMJs were then recorded separated by 2 minutes of rest. If the third attempt was greater than the first 2, another attempt was allowed until a decrease in jump height was observed with not >5 maximum CMJs allowed. Reach height and jump height were recorded using a commercially available Vertec system (Sports Imports, Columbus, OH, USA). The maximum attempt of record was later converted to power in watts (PWR<sub>VJ</sub>) using previously described procedures (38).

After vertical jump testing, power output was assessed during the concentric phase of the parallel back squat (PWR<sub>BS</sub>) and bench press (PWR<sub>BP</sub>) exercises using a relative load of 60% 1RM per each respective exercise. The PWR<sub>BS</sub> was determined preceding PWR<sub>BP</sub> separated by 5 minutes of rest. All testing was performed on the same Smith machine used for 1RM testing. The subjects were instructed to perform the concentric phase of each lift as explosively as possible, preceded by the eccentric phase. After warm-up sets,

**TABLE 3.** Exercise performed during training.\*

Day 1 (upper body push)	Day 2 (lower body + upper body pull)	Day 3 (upper body push)	Day 4 (lower body + upper body pull)
Bench press†‡	Squats†‡	Incline press†‡	Front squat†‡
Incline DB press†	Leg press†	DB bench†	DB RDL†
Seated DB military press†	Partial DL to power shrug†	Push press†	DB step-up†
DB flat fly	Pull-ups§	DB incline fly	Pull-ups§
Front DB raise	One arm DB row	DB rear delt	Close grip lat pull-down
Side DB raises	Hamstring curl	Side DB raises	T bar row
Straight bar skull crusher	EZ bar curl	EZ bar skull crusher	Straight bar curl
Dips§	DB curl	Dips§	DB curl

\*DB = dumbbell; DL = deadlift; RDL = Romanian deadlift.

†Main lift exercise performed according to training protocol (TRD or ISR), concentric phase explosively as possible.

‡Exercise performed on the Smith Machine.

§Exercise performed with 3 sets of maximum repetitions with 1.5 minutes of rest.

**TABLE 4.** Kilocalories, protein, carbohydrate, and fat intake, percent of total kilocalories, and relative intake at baseline, 3, 7, and 11 weeks of training.\*†

	Baseline	3 wks	7 wks	11 wks	<i>p</i>
Overall					
kcal	2,620 ± 581	2,918 ± 601	2,923 ± 573	2,793 ± 481	<i>T</i> = 0.084
Protein (g)	147 ± 39	196 ± 50‡	191 ± 34‡	201 ± 40‡	<i>T</i> = 0.001
Carbohydrate (g)	261 ± 94	270 ± 63	231 ± 85§	182 ± 69‡§	<i>T</i> = 0.001
Fat (g)	101 ± 33	109 ± 32	110 ± 32	101 ± 26	<i>T</i> = 0.517
Percent total kcal					
Protein (%)	22.7 ± 4.6	26.8 ± 3.5‡	27.2 ± 8.0‡	29.1 ± 5.8‡§	<i>T</i> = 0.001
Carbohydrate (%)	40.1 ± 13.3	37.4 ± 6.9	31.0 ± 9.0‡§	26.0 ± 8.5‡§	<i>T</i> = 0.001
Fat (%)	34.4 ± 8.0	33.5 ± 4.7	33.8 ± 5.6	32.7 ± 7.2	<i>T</i> = 0.754
Relative to bodyweight					
kcal (g · kg <sup>-1</sup> )	32.3 ± 7.9	35.5 ± 8.2	35.7 ± 9.5	33.6 ± 6.8	<i>T</i> = 0.128
Protein (g · kg <sup>-1</sup> )	1.8 ± 0.5	2.4 ± 0.7‡	2.3 ± 0.5‡	2.4 ± 0.5‡	<i>T</i> = 0.001
Carbohydrate (g · kg <sup>-1</sup> )	3.3 ± 1.3	3.3 ± 0.8	2.8 ± 1.1‡§	2.2 ± 0.8‡§	<i>T</i> = 0.001
Fat (g · kg <sup>-1</sup> )	1.2 ± 0.4	1.3 ± 0.4	1.4 ± 0.5	1.2 ± 0.4	<i>T</i> = 0.424

\**T* = time effect.  
 †Data are mean ± *SD*.  
 ‡Significantly different from baseline.  
 §Significantly different from 3 weeks.  
 ||Significantly different from 7 weeks.

3 sets of 5 repetitions at 40–50% 1RM, the subjects began performing single repetitions at 60% 1RM for determination of mean power output. During the parallel back squat, rubber tubing was placed at the parallel point. This position was determined during strength testing and ensured the subjects reached the appropriate parallel position for the attempt to be a success. Three attempts were allowed with the best recorded for further analysis. If the third attempt was greater than the first 2, another attempt was recorded until power output declined with not >5 attempts allowed. Three minutes rest was used between successive maximal power attempts. Power output was measured using a linear position transducer (Tendo Fitrodyne; Tendo Sport Machines, Slovak Republic) with only bar weight used for

the determination of average power. The highest average power output was used for statistical analysis. The reliability of the Fitrodyne (Tendo Fitrodyne; Tendo Sport Machines, Slovakia) has been previously reported (23). During post-training (12 weeks), power output was assessed on both parallel back squat (APWR<sub>BS</sub>) and bench press (APWR<sub>BP</sub>) using loads corresponding to 60% baseline 1RM followed by 60% posttraining 1RM.

**Reliability of Strength and Power Testing**

The reproducibility of the methods for determination of strength and power were assessed in 2 trials separated by 7 days in 10 resistance trained men (age 25 ± 5 years, height 181.48 ± 11.21 cm, weight 91.3 ± 14.0 kg with 8 ± 5 years 5 ± 1 d · wk<sup>-1</sup>

resistance training experience). After signing consent forms approved by the Institutional Review Board, the subjects performed strength and power output assessment according to the previously described procedures. After 7 days, the subjects returned to perform the same testing protocol. The reliability statistics are presented in Table 2.

**Training**

All training sessions commenced with a dynamic

**TABLE 5.** Total training volume for TRD and ISR over 12 weeks of training.\*†‡

	TRD	ISR	<i>p</i>
Major lifts (kg)			
Upper body	102,711.67 ± 25,484.80	119,728.80 ± 22,587.40	0.113
Lower body	220,811.80 ± 35,827.50	235,807.10 ± 35,002.30	0.333
Assistive lifts			
Push	34,041.40 ± 9,085.40	37,356.70 ± 10,251.40	0.432
Pull	58,978.80 ± 7,697.00	60,791.90 ± 11,089.70	0.661

\*TRD = traditional rest; ISR = intraset rest intervals.  
 †Data are mean ± *SD*.  
 ‡Major lifts performed according to group assignment. Assistive lifts all performed same rest to work ratio.

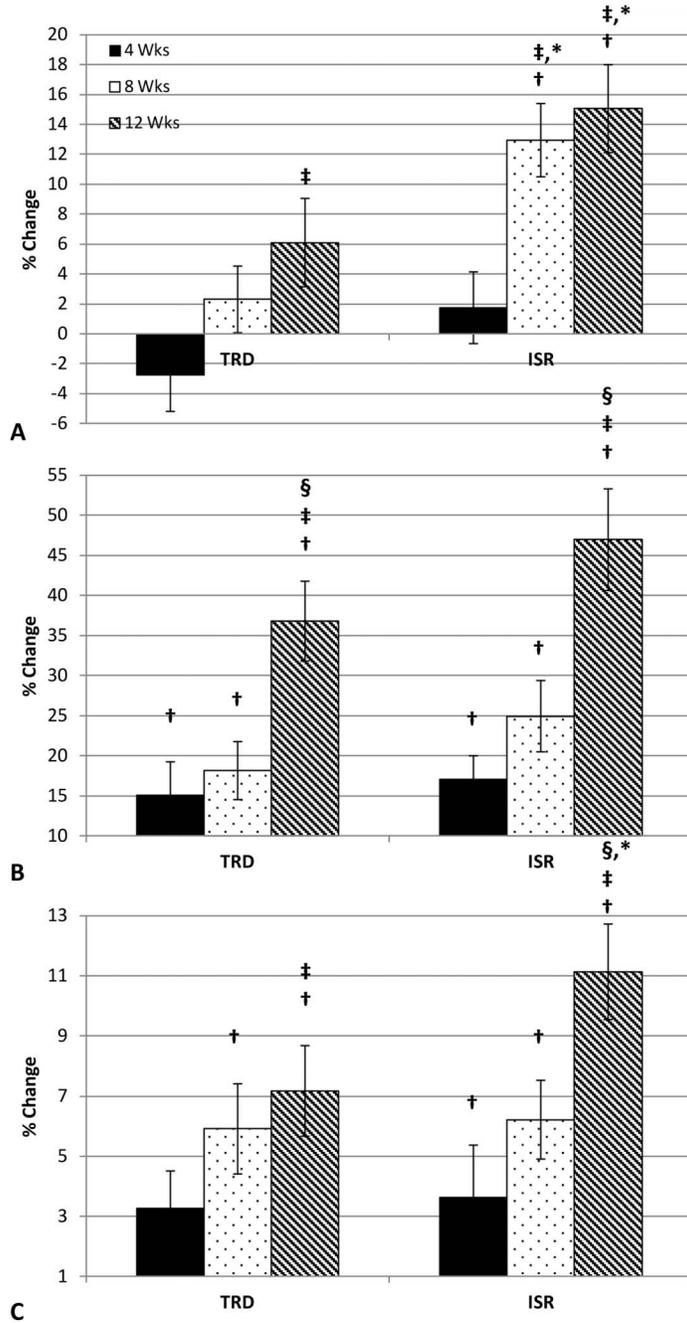
**TABLE 6.** Power measures at baseline, 4, 8, and 12 weeks of training.\*†

	TRD	ISR	<i>p</i>
<b>Bench press power (W)</b>			
Baseline	560 ± 122	575 ± 102	<i>T</i> = 0.568
4 wks	541 ± 105	586 ± 123	<i>G</i> = 0.011
8 wks	572 ± 122	646 ± 103‡§	<i>T</i> × <i>G</i> = 0.020
12 wks	593 ± 135	658 ± 113‡§	
<b>Bench press power to body mass ratio</b>			
Baseline	6.84 ± 0.96	6.99 ± 1.10	<i>T</i> = 0.627
4 wks	6.46 ± 0.91	7.09 ± 1.28	<i>G</i> = 0.056
8 wks	6.77 ± 0.92	7.77 ± 0.92‡§	<i>T</i> × <i>G</i> = 0.003
12 wks	6.96 ± 0.96	7.90 ± 1.24‡§	
<b>Bench press to lean mass ratio</b>			
Baseline	9.01 ± 1.14	9.07 ± 1.21	<i>T</i> = 0.793
4 wks	8.56 ± 1.24	9.18 ± 1.32	<i>G</i> = 0.066
8 wks	8.88 ± 1.11	10.02 ± 0.96‡§	<i>T</i> × <i>G</i> = 0.006
12 wks	9.20 ± 1.39	10.21 ± 1.17‡§	
<b>Back squat power (W)¶ </b>			
Baseline	625 ± 245	632 ± 171	<i>T</i> = 0.001
4 wks	704 ± 233§	734 ± 179§	<i>G</i> = 0.081
8 wks	723 ± 227§	783 ± 179§	<i>T</i> × <i>G</i> = 0.053
12 wks	830 ± 232§  #	914 ± 207§  #	
<b>Back squat to body mass ratio¶ </b>			
Baseline	7.57 ± 2.23	7.83 ± 2.33	<i>T</i> = 0.001
4 wks	8.37 ± 2.14§	9.09 ± 2.42§	<i>G</i> = 0.101
8 wks	8.53 ± 1.94§	9.57 ± 2.35‡§	<i>T</i> × <i>G</i> = 0.015
12 wks	9.78 ± 2.03§  #	11.11 ± 2.64§  #	
<b>Back squat to lean mass ratio¶ </b>			
Baseline	9.96 ± 2.77	10.19 ± 2.62	<i>T</i> = 0.001
4 wks	11.04 ± 2.57§	11.83 ± 2.65§	<i>G</i> = 0.068
8 wks	11.15 ± 2.31§	12.41 ± 2.63‡§	<i>T</i> × <i>G</i> = 0.017
12 wks	12.86 ± 2.49§  #	14.45 ± 2.87‡§  #	
<b>Vertical jump power (W)¶ </b>			
Baseline	1,378 ± 237	1,389 ± 179	<i>T</i> = 0.001
4 wks	1,418 ± 214	1,434 ± 152	<i>G</i> = 0.205
8 wks	1,452 ± 210§	1,470 ± 149§	<i>T</i> × <i>G</i> = 0.036
12 wks	1,470 ± 215§	1,537 ± 150‡§  #	
<b>Vertical jump to body mass ratio¶ </b>			
Baseline	16.83 ± 1.36	17.12 ± 2.05	<i>T</i> = 0.001
4 wks	16.93 ± 1.28	17.71 ± 1.98§	<i>G</i> = 0.243
8 wks	17.27 ± 1.22	18.01 ± 1.76§	<i>T</i> × <i>G</i> = 0.001
12 wks	17.36 ± 1.13	18.68 ± 1.72‡§  #	
<b>Vertical jump to lean mass ratio¶ </b>			
Baseline	22.19 ± 1.37	22.40 ± 1.95	<i>T</i> = 0.001
4 wks	22.40 ± 1.10	22.16 ± 1.72	<i>G</i> = 0.141
8 wks	22.66 ± 1.11	23.41 ± 1.42§	<i>T</i> × <i>G</i> = 0.004
12 wks	22.89 ± 1.11	24.40 ± 1.38‡§  #	

\*TRD = traditional rest; ISR = intraset rest intervals; *T* = time effect; *G* = group effect; *T* × *G* = time × group interaction effect.  
 †Data are mean ± *SD*.  
 ‡Significantly different from TRD.  
 §Significantly different from baseline.  
 ||Significantly different from 4 weeks.  
 ¶One subject was excluded because of failure to follow protocol.  
 #Significantly different from 8 weeks.

warm-up identical to that used for strength and power testing. Four supervised workouts a week were performed in the following sequence: 2 days on, 1 day off, 2 days on, 2 days off. Training intensity was structured into 4-week cycles

of increasing intensity as described in Figure 1 with an unloading week during each week of testing. All the sessions were supervised by trained staff with at least 1–2 CSCS certified personnel leading sessions. The subjects were not



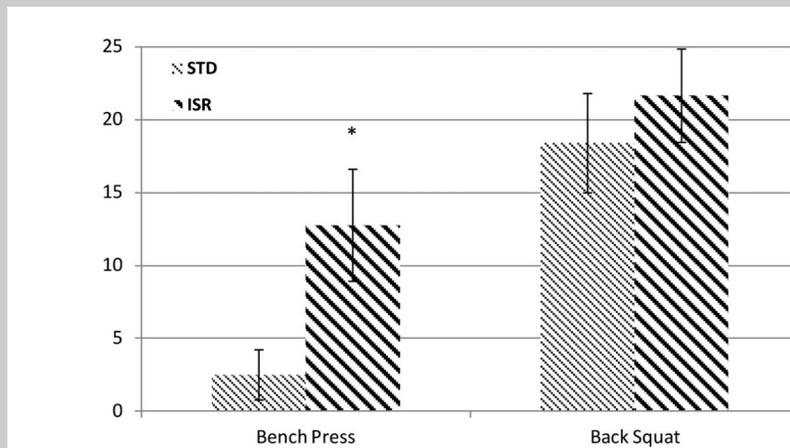
**Figure 2.** Percent change in mean power from baseline in bench press (A), parallel back squat (B), and vertical jump (C). Data are mean  $\pm$  standard error. TRD = traditional rest; ISR = intraset rest intervals; †significantly different from baseline; ‡significantly different from 4 weeks; § significantly different from 8 weeks; \*significantly different from TRD.

Table 3 provides the exercises performed and the order in which they were performed. All major lifts tested for strength and power output were performed on the same apparatus used for the determination of 1RM and power output. The subjects were instructed to perform the concentric phase of all major lifts in an explosive manner. Verbal encouragement was provided throughout training. To determine differences between training programs, groups differed on the sets, repetitions and rest in all major lifts performed (Figure 1). The subjects in TRD performed a standard hypertrophic training protocol of 4 sets of 10 repetitions for all major lifts with 120 seconds of rest between sets. In accordance with previous studies evaluating ISR (12,27), each set was divided into half, and rest was equated so that the ISR group performed 8 sets of 5 repetitions with 60 seconds of rest. This manipulation of rest to work where the set is divided in half using an intraset rest and equating rest between groups has previously been used for the determination of differences between TRD and ISR in strength training (12,27). Both TRD and ISR performed 3 sets of 10 repetitions with 90 seconds of rest for all assistive lifts. The load was reduced if the subjects were unable to complete the prescribed number of repetitions. Intensity was increased if the subjects were able to complete at least 85% of the total volume on major lifts. Timing of rest was performed using stop watches on all lifts

engaged in any other training outside of daily living for the duration of the study.

Throughout the training program, both groups performed the same exercises, in the same order and intensity (Figure 1).

by trained personnel. The total volume load (weight  $\times$  reps  $\times$  sets) was grouped according to lifts using the upper and lower body for main lifts and push and pull exercises for assistive exercises for later analysis. The training intensity



**Figure 3.** Percent change in the absolute mean power from baseline in bench press and parallel back squat. Data are mean  $\pm$  standard error. TRD = traditional rest; ISR = intraset rest intervals; \*significantly different from TRD.

(total volume load/repetitions performed) was grouped according to upper and lower body for main lifts only. Workout logs were maintained and verified throughout the 12-week period. Compliance throughout the entire 12-week study was 95%.

**Biopsy and Myosin Heavy Chain Analysis**

Before baseline testing and within 72 hours of posttesting, a 100- to 200-mg muscle biopsy of the vastus lateralis was obtained from the participant’s right leg with suction using a 5-mm biopsy needle (Pelomi Industries, Denmark) according to a modification of Bergstrom’s technique (8) as described by Evans et al. (14). All muscle samples were cleansed of visible fat, connective tissue, and blood and immediately frozen in liquid nitrogen ( $-190^{\circ}\text{C}$ ), then transferred and stored at  $-80^{\circ}\text{C}$  until analyzed. Muscle samples were later prepared (6), and MHC was analyzed according to previously described procedures (30). Briefly, after the samples were loaded ( $15\ \mu\text{l}$ ), electrophoresis was performed at a constant voltage of 200 V for 22 hours in a gel system (R. Shadel, San Francisco, CA, USA). For stacking gel penetration, the first hour, the voltage was kept at 160 V. During electrophoresis, the gel system was kept in a temperature-controlled ventilated hood. The gels were subsequently stained with a silver staining kit (Bio-Rad, Hercules, CA, USA) according to the manufacturer’s instructions. The protein bands of each MHC isoform on the silver-stained acrylamide gel were densitometrically digitalized using a digital camera (Fugi LAS 4000; Fujifilm Life Sciences, Wayne, NJ, USA). The densitometric values were derived as an integral of the band density and band area (MultiGauge 3.0; Fujifilm Life Sciences). The amount of each isoform was expressed as a percentage calculated as  $(\text{IntegProtein}/\text{IntegAll}) \times 100\%$ , where IntegProtein is the densitometric integral of the cor-

responding protein band, and the IntegAll is the densitometric integral of all isoforms in the sample.

**Statistical Analyses**

All statistical analyses were performed using SPSS Version 19.0 (Chicago, IL, USA). One-way analysis of variance (ANOVA) was used to determine baseline differences in physical and performance characteristics. A  $2 \times 4$  (group  $\times$  time) ANOVA was used to determine differences in body mass, lean mass, and percent body fat. Macronutrient content was analyzed in a  $2 \times 4$  (group  $\times$  time) ANOVA. Overall total volume load and training intensity were analyzed by independent *t*-test. A  $2 \times 4$

(group  $\times$  time) analysis of covariance (ANCOVA) covaried for baseline values as the covariate was used to determine changes over the training period in  $1\text{RM}_{\text{BP}}$ ,  $1\text{RM}_{\text{BS}}$ ,  $\text{PWR}_{\text{BP}}$ ,  $\text{PWR}_{\text{BS}}$ , and  $\text{PWR}_{\text{VJ}}$ . Independent *t*-tests were used to determine the difference between pre- and post- $\text{APWR}_{\text{BP}}$  and  $\text{APWR}_{\text{BS}}$ . A  $2 \times 2$  (group  $\times$  time) repeated measure ANCOVA using baseline values as the covariate was used to determine changes in percentage  $\text{MHC}_{\text{slow}}$ ,  $\text{MHC}_{\text{IIA}}$ , and  $\text{MHC}_{\text{IIX}}$ . Statistical power for all tests was  $>0.82$ . Where necessary, post hoc analysis was performed using the Bonferroni correction. Statistical significance was defined as  $p \leq 0.05$ .

The use of null-hypothesis testing in sports science to assess practical significance may be inadequate (7). As such, the effect size was used in accordance with the scale proposed by Rhea (32) for highly trained individuals to determine the treatment effect of both training programs. Additionally, Batterham and Hopkins’ (7) method for the determination of magnitude-based inference was used at 5% for both TRD and ISR to provide a qualitative inference. The difference in the absolute change from pre to post between ISR and TRD was also calculated, and a qualitative inference was determined on the effect of ISR (7).

**RESULTS**

**Baseline Characteristics**

No significant differences were observed at baseline in age, height, body mass, or lean mass. Additionally, no significant differences were observed in training status between subjects (Table 1).

**Macronutrient Intake**

Absolute macronutrient intake and percent total calories and intake relative to body mass are presented in Table 4. No significant between-group differences were observed in any

**TABLE 7.** Strength measures (1RM) at baseline, 4, 8, and 12 weeks.\*†

	TRD	ISR	<i>p</i>
<b>Bench press 1RM (kg)</b>			
Baseline	104.1 ± 27.6	110.9 ± 20.1	<i>T</i> = 0.018
4 wks	102.7 ± 29.0	117.5 ± 23.7‡§	<i>G</i> = 0.013
8 wks	107.0 ± 25.3	120.8 ± 22.6‡§	<i>T</i> × <i>G</i> = 0.010
12 wks	113.2 ± 27.3§  ¶	126.0 ± 22.8‡§  ¶	
<b>Bench press to body mass ratio</b>			
Baseline	1.27 ± 0.22	1.35 ± 0.23	<i>T</i> = 0.016
4 wks	1.22 ± 0.24	1.42 ± 0.24‡	<i>G</i> = 0.035
8 wks	1.26 ± 0.18	1.45 ± 0.23‡§	<i>T</i> × <i>G</i> = 0.002
12 wks	1.33 ± 0.19  ¶	1.51 ± 0.22‡§  ¶	
<b>Bench press to lean mass ratio</b>			
Baseline	1.67 ± 0.27	1.75 ± 0.26	<i>T</i> = 0.101
4 wks	1.61 ± 0.29	1.84 ± 0.30‡	<i>G</i> = 0.066
8 wks	1.66 ± 0.22	1.88 ± 0.29‡§	<i>T</i> × <i>G</i> = 0.007
12 wks	1.75 ± 0.25  ¶	1.95 ± 0.29‡§  ¶	
<b>Back squat 1RM (kg)</b>			
Baseline	123.3 ± 39.3	130.1 ± 25.1	<i>T</i> = 0.001
4 wks	139.6 ± 38.7§	152.6 ± 24.8§	<i>T</i> = 0.016
8 wks	160.2 ± 36.1§	179.8 ± 24.5‡§	<i>T</i> × <i>G</i> = 0.010
12 wks	171.8 ± 34.5§  ¶	193.9 ± 24.2‡§  ¶	
<b>Back squat to body mass ratio</b>			
Baseline	1.50 ± 0.34	1.59 ± 0.30	<i>T</i> = 0.001
4 wks	1.66 ± 0.34§	1.85 ± 0.27§	<i>G</i> = 0.038
8 wks	1.90 ± 0.30§	2.17 ± 0.25‡§	<i>T</i> × <i>G</i> = 0.001
12 wks	2.03 ± 0.30§  ¶	2.33 ± 0.27‡§  ¶	
<b>Back squat to lean mass ratio</b>			
Baseline	1.97 ± 0.42	2.05 ± 0.30	<i>T</i> = 0.001
4 wks	2.19 ± 0.41§	2.40 ± 0.27§	<i>G</i> = 0.045
8 wks	2.49 ± 0.36§	2.79 ± 0.26‡§	<i>T</i> × <i>G</i> = 0.001
12 wks	2.67 ± 0.36§  ¶	3.02 ± 0.26‡§  ¶	

\*TRD = traditional rest; ISR = in-traset rest intervals; *T* = time effect; *G* = group effect; *T* × *G* = time × group interaction effect.

†Data are mean ± *SD*.

‡Significantly different from TRD.

§Significantly different from baseline.

||Significantly different from 4 weeks.

¶Significantly different from 8 weeks.

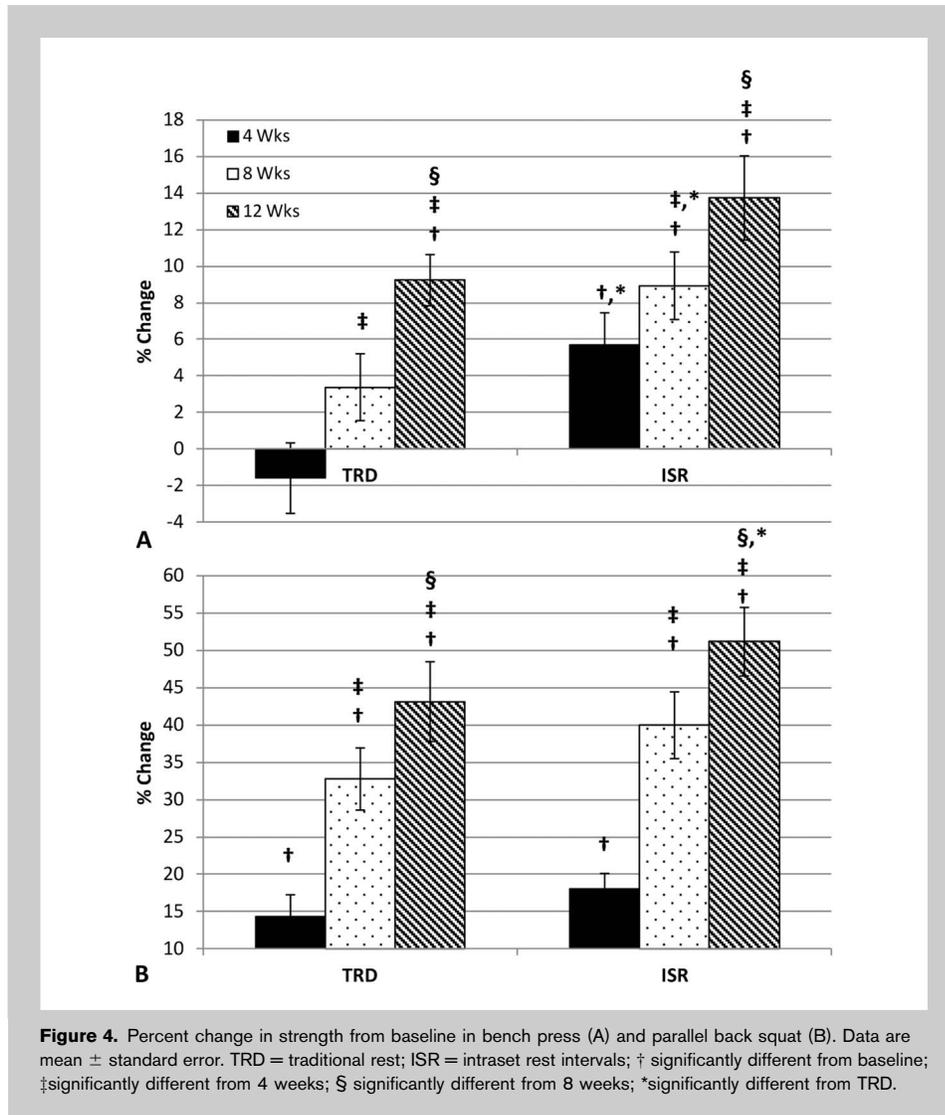
of the macronutrients measured. Caloric intake did not change over the course of the study. Protein intake increased significantly from baseline to 3 weeks with no further increase observed. Carbohydrate intake decreased over the course of the experimental period. No significant changes were observed in absolute fat intake, as a percentage of total calories or relative to body mass.

**Training Volume Load and Intensity**

Total volume load of main lifts (upper and lower body) and assistive exercises (push and pull) is provided in Table 5. There were no significant differences between groups for total volume load of main lifts or assistive exercises. Additionally, there were no significant differences in upper (*p* = 0.113) or lower body (*p* = 0.333) training intensity between TRD and ISR.

**Power Output**

Data from power output assessments are presented in Table 6. There were no significant differences between groups in any power measurements at baseline. The subjects in ISR experienced greater gains in PWR<sub>BP</sub>. A graphical representation of percentage increase in PWR<sub>BP</sub> is presented in Figure 2A. Similar increases were observed in PWR<sub>BS</sub> in both groups. A significant interaction was observed with post hoc analysis revealing no significant between-group differences at any training time point. However, the difference between groups at both 8 (ISR, 151.0 ± 74.0 W; TRD, 97.5 ± 60.9 W; *p* = 0.084) and 12 (ISR, 282.1 ± 104.1 W; TRD, 204.9 ± 70.2 W; *p* = 0.063) weeks approached significance with the subjects in ISR showing a greater increase. The magnitude of the effect was also greater in ISR and the qualitative inference on the effect of ISR demonstrated a likely positive effect



(Table 10). Evaluating PWR<sub>BS</sub> relative to lean mass, the subjects in ISR showed a greater increase at both 8 ( $p = 0.016$ ) and 12 ( $p = 0.038$ ) weeks. Although the pattern of increase appeared greater when evaluating percentage change from baseline in PWR<sub>BS</sub> (Figure 2B), only a time effect was noted with no group or interaction effects observed. The subjects in ISR experienced a greater increase in PWR<sub>VJ</sub>. This corresponded to a significant difference at 12 weeks compared with TRD in absolute (Table 6) and percentage change from baseline (Figure 2C).

Percentage change from baseline in APWR<sub>BP</sub> and APWR<sub>BS</sub> is presented in Figure 3. The subjects in ISR demonstrated a significantly greater improvement in the percentage increase from baseline in APWR<sub>BP</sub> ( $p = 0.012$ ), corresponding to an absolute increase of 71.0 W compared with 13.5 W for TRD ( $p = 0.010$ ). Both ISR and TRD increased in APWR<sub>BS</sub> from baseline, no significant differences were observed ( $p = 0.496$ ). However, the magnitude of effect size was greater for the ISR group (Table 10).

### Muscular Strength

The results of strength testing are presented in Table 7. There were no significant differences between groups observed at baseline in either 1RM<sub>BP</sub> or 1RM<sub>BS</sub>. Only the subjects in ISR experienced an increase at 4, 8, and 12 weeks. This corresponded to greater increases at 4 (ISR,  $6.6 \pm 6.6$  kg; TRD,  $-1.4 \pm 6.2$  kg;  $p = 0.012$ ), 8 (ISR,  $9.9 \pm 6.8$  kg; TRD,  $2.9 \pm 5.8$  kg;  $p = 0.016$ ), and 12 (ISR,  $15.1 \pm 8.3$  kg; TRD,  $9.1 \pm 3.7$  kg;  $p = 0.051$ ) weeks. Percent change in the 1RM<sub>BP</sub> from baseline is presented in Figure 4A. Again, only ISR increased at 4, 8, and 12 weeks. Greater percent increase from baseline was observed in ISR at 4 and 8 weeks ( $p = 0.017$  and  $0.034$ , respectively), with 12 weeks approaching significance ( $p = 0.082$ ).

The subjects in the ISR experienced greater increases in the 1RM<sub>BS</sub> at both 8 weeks (ISR,  $49.7 \pm 13.8$  kg; TRD,  $36.9 \pm 13.5$  kg;  $p = 0.024$ ) and 12 weeks (ISR,  $63.8 \pm 12.0$  kg; TRD,  $48.5 \pm 17.4$  kg;  $p = 0.011$ ). Percent change from baseline demonstrated a significant interaction

( $p = 0.048$ ) in which post hoc analysis revealed an almost significant greater gain in week 8 ( $p = 0.066$ ) and a significant greater gain in week 12 ( $p = 0.041$ ) for the subjects in ISR.

### Body Composition

The results of body composition testing are presented in Table 8. Although the subjects in TRD experienced an increase in body mass at 4 weeks, no further increase was observed, and post hoc analysis revealed no significant difference between groups at any time point. Lean mass increased in both groups from baseline to 4 weeks and showed a continued increase at 8 weeks. No further increases were noted. No between-group differences were identified. When evaluating percentage change from baseline, a significant time effect was noted ( $p = 0.001$ ) with no significant group ( $p = 0.124$ ) or interaction effects ( $p = 0.219$ ) observed. There were no significant changes in percent body fat as measured by DEXA during the 12-week training.

**TABLE 8.** Body composition at baseline, 4, 8, and 12 weeks of training.\*†

	TRD	ISR	Combined	<i>p</i>
<b>Weight (kg)</b>				
Baseline	81.7 ± 11.6	82.5 ± 10.0	82.1 ± 10.6	<i>T</i> = 0.001
4 wks	83.6 ± 10.0‡	82.7 ± 9.7	83.1 ± 9.6	<i>G</i> = 0.898
8 wks	84.1 ± 10.7‡	83.1 ± 9.2	83.6 ± 9.7	<i>T</i> × <i>G</i> = 0.018
12 wks	84.7 ± 10.9‡	83.6 ± 9.2	84.1 ± 9.9	
<b>Lean mass (kg)</b>				
Baseline	61.9 ± 8.9	63.3 ± 7.0	62.6 ± 7.9	<i>T</i> = 0.002
4 wks	63.2 ± 8.2	63.5 ± 7.3	63.4 ± 7.6‡	<i>G</i> = 0.869
8 wks	64.0 ± 8.3	64.3 ± 6.9	64.2 ± 7.4‡§	<i>T</i> × <i>G</i> = 0.227
12 wks	64.2 ± 8.5	64.3 ± 6.8	64.2 ± 7.5‡§	
<b>Percent fat (%)</b>				
Baseline	14.3 ± 2.7	12.9 ± 5.5	13.6 ± 4.3	<i>T</i> = 0.133
4 wks	15.0 ± 3.3	13.3 ± 5.9	14.1 ± 4.7	<i>G</i> = 0.445
8 wks	14.7 ± 3.5	13.2 ± 5.5	14.0 ± 4.6	<i>T</i> × <i>G</i> = 0.869
12 wks	15.1 ± 3.5	13.5 ± 5.6	14.3 ± 4.6	

\*TRD = traditional rest; ISR = in-traset rest intervals; *T* = time effect; *G* = group effect; *T* × *G* = time × group interaction effect.  
 †Data are mean ± *SD*.  
 ‡Significantly different from baseline.  
 §Significantly different from 4 weeks.

**Myosin Heavy Chain Composition**

Studentized *t*-tests of baseline MHC demonstrated a significantly higher percentage of the MHC<sub>IIx</sub> in the ISR group (*p* = 0.023) compared with TRD. No significant differences

group effect was noted. A small but significant decrease in the percentage MHC<sub>slow</sub> was observed in both groups. However, when evaluating percent change from baseline, this did not reach significance (*p* = 0.164).

**TABLE 9.** Myosin heavy chain isoform in percentage total at baseline and 12 weeks of training.\*†

	TRD	ISR	Combined	<i>p</i>
<b>MHC<sub>IIx</sub></b>				
Baseline	11.1 ± 4.2	16.5 ± 5.7	13.9 ± 5.7	<i>T</i> = 0.020
12 wks	7.9 ± 2.5	9.8 ± 4.5	8.9 ± 3.7‡	<i>G</i> = 0.649
				<i>T</i> × <i>G</i> = 0.649
<b>MHC<sub>IIA</sub></b>				
Baseline	35.6 ± 7.7	34.5 ± 7.6	35.0 ± 7.5	<i>T</i> = 0.001
12 wks	43.2 ± 7.5	43.9 ± 6.2	43.6 ± 6.7‡	<i>G</i> = 0.002
				<i>T</i> × <i>G</i> = 0.756
<b>MHC<sub>slow</sub></b>				
Baseline	53.3 ± 7.9	49.0 ± 7.6	51.1 ± 7.9	<i>T</i> = 0.002
12 wks	48.9 ± 5.9	46.2 ± 7.1	47.5 ± 6.5‡	<i>G</i> = 0.568
				<i>T</i> × <i>G</i> = 0.568

\*TRD = traditional rest; ISR = in-traset rest intervals; *T* = time effect; *G* = group effect; *T* × *G* = time × group interaction effect.  
 †Data are mean ± *SD*.  
 ‡Significantly different from baseline.  
 §One subject was excluded because of lack of sufficient sample.

were observed at baseline in the percentage MHC<sub>IIA</sub> or MHC<sub>slow</sub>. Results from MHC analysis are presented in Table 9. Both training protocols experienced a significant reduction in MHC<sub>IIx</sub> after 12 weeks of training, with a concomitant increase in the MHC<sub>IIA</sub>. No interaction or group effects were observed in either MHC<sub>IIx</sub> or MHC<sub>IIA</sub>. Evaluating the percentage change from baseline, a significant time effect (*p* = 0.001) was noted with both ISR and TRD experiencing a decrease in the MHC<sub>IIx</sub>, -37.9 ± 24.1% and -23.4 ± 23.8%, respectively, with no differences noted between groups. A time effect was also noted in the percentage change from baseline in MHC<sub>IIA</sub> for both ISR and TRD, with both showing an increase, 32.0 ± 28.8 and 25.4 ± 29.1%, respectively (*p* = 0.001). Again, no interaction or

**Effect Size and Magnitude**

Effect size, magnitude of effect size, and qualitative inferences are reported in Table 10. The ISR magnitude of effect sizes were all moderate or large in performance measures, whereas TRD was found to have a small magnitude of effect as defined by Rhea (32) for highly trained individuals in 1RM<sub>BP</sub>, PWR<sub>BP</sub>, and PWR<sub>VJ</sub>. The TRD had a greater effect size magnitude for lean mass gain; however, the effect size for both TRD and ISR were small and trivial, respectively. The ISR demonstrated a greater effect size magnitude in both MHC<sub>IIx</sub> and MHC<sub>IIA</sub> (large) compared with TRD, whereas TRD demonstrated a greater effect size for MHC<sub>slow</sub>. Qualitative inferences were greater for IRS at the

**TABLE 10.** Effect size, magnitude of effect (32), and qualitative inferences (7).\*

	Magnitude of effect size†		Qualitative inference‡		Qualitative inference on difference§
	TRD	ISR	TRD	ISR	
Bench press 1RM	0.33 (Small)	0.75 (Moderate)	Likely	Likely	Likely
Back squat 1RM	1.23 (Large)	2.54 (Large)	Likely	Very likely	Very likely
Bench press power	0.27 (Small)	0.81 (Moderate)	Very unlikely	Possibly	Very likely
ABS bench press power	0.11 (Trivial)	0.69 (Moderate)	Most unlikely	Unlikely	Very likely
Back squat power	0.84 (Moderate)	1.65 (Large)	Likely	Likely	Likely
ABS back squat power	0.41 (Small)	0.76 (Moderate)	Possibly	Likely	Likely
Vertical jump power	0.39 (Small)	0.83 (Moderate)	Possibly	Likely	Very likely
Lean mass	0.25 (Small)	0.14 (Trivial)	Unlikely	Most unlikely	Very unlikely
MHC <sub>ILx</sub>	0.72 (Moderate)	1.18 (Large)	Very unlikely	Possibly	Likely
MHC <sub>IIA</sub>	0.99 (Moderate)	1.25 (Large)	Very unlikely	Unlikely	Unclear
MHC <sub>slow</sub>	0.57 (Moderate)	0.36 (Small)	Most unlikely	Most unlikely	Unclear

\*TRD = traditional rest; ISR = intraset rest intervals.  
 †Effect size and magnitude of effect size.  
 ‡Qualitative inference with reference to smallest worthwhile change of 5%.  
 §Qualitative inference based on difference between groups.

smallest worthwhile change 5%, which is much larger than expected in highly trained athletes, ISR demonstrated greater qualitative inferences in 1RM<sub>BS</sub>, PWR<sub>BP</sub>, APWR<sub>BP</sub>, APWR<sub>BS</sub>, PWR<sub>VJ</sub>, MHC<sub>ILx</sub>, and MHC<sub>IIA</sub>, with TRD demonstrating a greater qualitative inference in lean mass only. Additionally, a likely or very likely positive effect of ISR was demonstrated in all measured variables except lean mass, MHC<sub>IIA</sub>, and MHC<sub>slow</sub>.

**DISCUSSION**

In this study, we sought to determine if ISR hypertrophic training resulted in greater power gains than TRD hypertrophic training did. We further sought to determine changes in MHC composition as a result of ISR. The major findings of this study were that after 12 weeks (a) ISR resulted in greater power output in the bench press exercise and vertical jump, (b) power output as measured during parallel back squat approached significance compared to TRD, and (c) when normalized to bodyweight and lean mass, ISR were superior, (d) absolute power difference in the bench press was greater in the bench press exercise with the use of ISR, (e) ISR resulted in greater increases in strength in the bench press and parallel back squat exercises, (f) ISR resulted in similar gains in lean mass, and finally (g) changes in percentage MHC<sub>ILx</sub> and MHC<sub>IIA</sub> are similar to those experienced during TRD hypertrophic training.

To effectively compare, it was necessary to control for total volume load and training intensity. This was accomplished as no significant between-group differences were observed in major lifts or assistance exercises in total volume

load or training intensity in major lifts. Additionally, although dietary intake was not controlled, no significant between-group differences were observed in any macronutrients. Data suggest that the loss of calories from carbohydrate intake was made up by the high intake of protein, which met current guidelines (5), as evidenced by increased protein intake with a concomitant decrease in carbohydrate intake with no change in total calories or fat over the 12-week period.

Our original hypothesis regarding power output was supported only in part because power difference in the parallel back squat exercise only approached significance. However, the effect size was greater, and the magnitude-based qualitative inference demonstrated a likely positive effect of ISR. When power output was evaluated using the initial load from baseline, ISRs resulted in greater increases in bench press but not in parallel back squat, though the effect size and qualitative inference at 5% were greater for ISRs and a likely positive magnitude-based inference from ISR. In contrast to trends observed in bench press and parallel back squat exercises, the difference in power output of the vertical jump took the full 12 weeks to manifest. Once demonstrated, the difference in the change from the baseline, magnitude of effect size, and qualitative inference at 5% were greater in ISR.

The role of inorganic phosphate (P<sub>i</sub>) in the velocity of shortening has recently received considerable attention. Increases in P<sub>i</sub> occur during muscle contractions, mainly from the breakdown of phosphocreatine (PCr). Models of cross-bridge cycling propose that P<sub>i</sub> is released in the transition

from low force weakly attached states to high force strongly attached states (2). Westerblad et al. (39) suggested this implies that the transition to the high force states is hindered by increased levels of  $P_i$ . Increases in adenosine diphosphate (ADP) have also been suggested to occur during repeated contractions, coincident with PCr depletion (33). Westerblad et al. (40) demonstrated that in the fatigued state, the velocity of shortening was slower after a longer tetanus compared with a shorter contraction. The authors suggested this was because of transient increases in ADP. Partial recovery occurred in a matter of seconds thought to be because of rapid removal of ADP by enzyme action or diffusion.

Although the exact cause of reduced velocity of shortening is still debated (39), this study suggests that ISR allows for a greater power output after training for hypertrophy. It is therefore possible that ISR in this study allowed for a partial reduction of either  $P_i$  or ADP by enzyme action or diffusion. Furthermore, the ISR may have allowed for an almost complete resynthesis of PCr, as after a fatiguing maximum voluntary contraction lasting approximately 54 seconds PCr has been shown to be resynthesized to 67% original concentration in just 2 minutes and 87% after 4 minutes (34). The truncated number of repetitions performed per set, 5 in this study, would use less PCr and result in less metabolite accumulation than more traditional hypertrophic training. Although not recorded, it was observed that the time to complete the 5 repetitions performed by ISR was approximately 10–15 seconds, whereas it took almost twice the time for TRD to complete the desired number of repetitions (20–25 seconds).

Support for the superiority of ISR on power output of the upper and lower body musculature has been provided by acute studies in which greater power output (21.6–25.1%) in the bench press exercise compared with TRD has been demonstrated (28), and higher peak velocity in the power clean using cluster sets (17,20). Although these results support the use of ISR and cluster sets in chronic training, long-term studies have demonstrated a tendency toward greater gains in power output of the lower body musculature (19), and significantly greater gains in power output of the lower body musculature compared with TRD in athletes (22). The results of ISR on upper body power output are controversial, with some reporting no difference (22,27) and one reporting less (13) improvement in power output of the upper body musculature. In the current investigation, we report greater gains in power output of both the upper and lower body musculature after 12 weeks of training.

Differences between this study and those reporting no difference or less improvement in power output of the bench press exercise may at least partially explain the differing results. It has been demonstrated peak power occurs between 40 and 60% 1RM in the bench press using a Smith machine (36), which was the apparatus used in this study. Although loads in this study were greater (65–75%) than those prescribed for bench press power, they fall closer to

the desired range than intensities used in previous investigations in which no difference (22,27) or less improvement (13) was observed (85% 1RM or greater).

The only study to date using loads similar to the current study using multijoint exercises was conducted by Izquierdo et al. (22); however, the authors failed to demonstrate differences in power output in the initial phase of training with loads corresponding to 10 RM (~75% 1RM) for the bench press. Greater improvements in power output were not completely realized in this study until 8 weeks of training. The initial phase in which intensity of the 2 studies was similar lasted only 6 weeks. Therefore, the differences in power output may not have had an opportunity to be realized. Additionally, the assessment of power output by Izquierdo et al. (22) involved only the concentric action beginning from a stop position, compared with our determination, which allowed a descent phase corresponding to an eccentric component.

In agreement with previous studies, we demonstrated ISR to be superior in the development of lower body power output. Although back squat power only approached significance, the magnitude of effect size was greater, and the qualitative inference on the effect of ISR was likely positive. Hansen et al. (19) recently compared TRD with cluster sets on strength and power of the lower body musculature in elite rugby union players. Cluster sets were only used in strength and power training involving squat and clean movements. Similar to this study, calculations of magnitude-based inference demonstrated a likely positive effect of cluster sets in peak power and peak velocity at 40 kg, and peak velocity at bodyweight during the jump squat. The authors concluded that TRD resulted in greater strength improvements, whereas some evidence suggested a possible benefit for ISR in lower body power development.

It has been demonstrated that peak power occurs between 50 and 70% in the parallel back squat exercises using a Smith machine (36). The loads in this study fall within this range (65–75%). Izquierdo et al. (22) have been the only group to demonstrate significantly greater gains in lower body power output after long-term training. Again the study by Izquierdo et al. (22) allowed multiple comparisons in a 16-week training period corresponding to 3 microcycles. During the first 6 weeks, the subjects performed 3 sets of 10 (10RM) repetitions or 6 sets of 5 (10RM) repetitions corresponding to a hypertrophic phase. Strength training commenced in week 7 and lasted 5 weeks with the subjects performing either 3 sets of 6 (6RM) repetitions or 6 sets of 3 (6RM) repetitions. Training concluded with both groups performing 3 sets of 2–4 repetitions with intensities corresponding to 85–90% 1RM. Differences in power output were not observed until the last testing session. This is unique because there were no differences in training intervention during the last 5 weeks. Based on the current results, adaptations may have occurred during the initial few weeks of training and not been realized until the end of training.

Contrary to our original hypothesis, the ISR resulted in greater increases in both bench press and parallel back squat strength. This is the first study to report greater strength gains with ISR. Studies comparing ISR with TRD using multijoint exercises have demonstrated that ISR resulted in smaller (13,19,27) or no difference (22) in strength gains compared with TRD. Studies demonstrating smaller strength gains with ISR used loads corresponding to  $\geq 85\%$  1RM. At those intensities, this may very well be the case because increased recruitment of muscle fibers results in greater stimulation, particularly in the fast MHC<sub>IIX</sub> fibers, as measured by electromyography (EMG) techniques. The EMG activity has been shown to increase leading up to the sixth repetition in a 6RM (85% 1RM) bench press exercise (25). On the other hand, Burd et al. (9) demonstrated that maximal EMG activity occurred half way through (i.e., repetitions 5–6) the performance of a set of leg extensions using a load corresponding to 70% 1RM. The results by Burd et al. (9) suggest that when performing exercise with loads in this intensity range, maximal recruitment occurs at approximately 50% completion during the initial set, and performance of repetitions past this point results in reduced activation of fibers, which are considered quick to fatigue, primarily MHC<sub>IIX</sub>. Similar to previous studies comparing TRD with ISR (12,27), this study divided the number of repetitions performed in TRD hypertrophic training in half and equated rest using intensities ranging from 65 to 75% 1RM. This may have resulted in greater neuromuscular activation over consecutive sets compared with TRD, which may have contributed to the greater strength gains demonstrated in this study. However, further research is needed to answer this question conclusively.

Izquierdo et al. (22) demonstrated no significant difference in strength between TRD and ISR over a 16-week periodized training period. Intensities during the first 6-week cycle corresponded to those used in this study (10RM or  $\sim 75\%$  1RM). In contrast to the results obtained by Izquierdo et al. (22), we observed greater strength gains with ISR after only 4 weeks in the bench press exercise. Difference in the back squat approached significance after 4 weeks and reached significance by week 8. Although both studies used the same relative intensities, the subjects in this study were only participating in the training outlined, whereas the subjects in the study by Izquierdo et al. (22) were also participating in additional training to include sport-specific and endurance training. This may have contributed to the differing results. Furthermore, although it is doubtful, the differences in ISR may also have contributed to the divergent findings (1 vs. 2 minutes).

In support of our original hypothesis and in support of Ahtiainen et al. (1), training with TRD and ISR resulted in similar increases in lean mass over the duration of the 12-week training program. Although TRD appeared to have greater increases, this did not reach significance when evaluating the absolute or percentage change from baseline. In this study, rest intervals were short and congruent with cur-

rent recommendations for the development of hypertrophy (4). The use of shorter rest intervals using moderate intensities has been associated with greater acute elevations in growth hormone when compared with longer rest periods using higher intensity loads (26). However, Ahtiainen et al. (1) demonstrated that hormonal and hypertrophic response did not vary when short (2 minutes) or long (5 minutes) rest intervals were used in a chronic training program when volume was equated. There were no differences in total volume load over the 12-week training period ( $p > 0.05$ ). These data support the previous work by Ahtiainen et al. (1) demonstrating similar hypertrophic response regardless of rest when total volume load is equated.

Contrary to our original hypothesis, no significant differences were observed between groups in changes in MHC percentage after 12 weeks of resistance training. Both groups experienced a significant increase in the MHC<sub>IIA</sub> percentage with a concomitant reduction in the MHC<sub>IIX</sub> percentage. Furthermore, a small decrease in the MHC<sub>slow</sub> was also observed, although when evaluating percentage change from baseline this did not reach significance. It is well established that the increase in lean mass associated with hypertrophic training is accompanied by a shift in MHC isoforms, identified by a decrease in the percentage of MHC<sub>IIX</sub> fibers with a concomitant increase in MH<sub>IIA/x</sub> and MHC<sub>IIA</sub> fibers (10,15,31). However, Liu et al. (29) previously reported strength training combined with ballistic exercise lead to a differential effect on MHC shifts after 12 weeks of training, shifting from percentage MHC<sub>slow</sub> to MHC<sub>IIA</sub>. Although the training protocol in this study did not explicitly include ballistic movements, the use of ISR has been shown to result in greater velocity of contraction compared with TRD training (17,18).

The differences in intensity and length of time of the current protocol and that of Liu et al. (29) may at least partially explain our divergent findings. Liu et al. (29) used loads corresponding to a much higher intensity than the one used in the current protocol, 93% 1RM vs. 65–75% 1RM. Additionally, the length of training of this study was twice that of the study by Liu et al. (11). Both protocols fall within the time course of adaptations as have been previously reported (37). Claffin et al. (11) recently suggested that an alternative explanation must be responsible for the enhanced fiber function as a result of high-velocity training because they did not find any differences at the single fiber level in size, force, or power of type II fibers after 14 weeks of training with high velocities. Although Claffin et al. (11) did not directly assess changes in the MHC<sub>IIA</sub> and MHC<sub>IIX</sub> percentage, the results from this study and that of Claffin et al. (11) suggest that the increased performance evidenced as a result of high-velocity contractions may in fact result from neural adaptations rather than from physiological adaptations.

## PRACTICAL APPLICATIONS

The results from this study support the use of ISR during training for muscle hypertrophy. The ISR resulted in greater

gains in power output and strength when compared with TRD hypertrophic training. Furthermore, ISR produced similar gains in lean mass over the course of the training period. The length of time prescribed in this study for ISR intervals did not impact the total training time. This is of importance to coaches and strength and conditioning professionals who have rules and regulations dictating the time allowed for training. Based on these results, it could be suggested that the incorporation of ISR in the hypertrophic phase of a traditional or nontraditional periodized training program would allow for greater improvements in strength and power. Whether these improvements would result in greater gains in strength and power output over an entire mesocycle is unknown, but hypothetically entering the strength and power phases of a training mesocycle at higher performance ability (strength and power) would allow a continued improvement above that achieved during traditional training models.

#### ACKNOWLEDGMENTS

The authors would like to thank the United States Marine Corps for their participation in this study and the members of the Texas A&M University Naval ROTC Unit and Corps of Cadets. This study was funded by the National Strength and Conditioning Association (NSCA) Doctoral Research Grant. The results presented herein do not constitute endorsement by the NSCA.

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