to impact training adaptations (16, 29). Testing included measurements of body composition, strength and power output of the upper and lower body musculature and MHC content. Dietary intake was not controlled, but a nutrition education session was provided and dietary intake analyzed.

After baseline testing, subjects were matched according to age, height, body composition, training experience, strength and power output of the upper and lower body musculature and randomly assigned to either a standard (STD) training group or an alternate (ALT) training group. Body composition, strength and power output of the upper and lower body musculature was assessed at baseline, after 4, 8, and 12 weeks of training. Dietary intake recording and analysis was conducted prior to each testing session. Muscle biopsies for MHC content were performed prior to initiation of training (baseline) and at the conclusion of the training program (12 weeks).

Subjects

Twenty eight males were eligible for participation. Selection criteria included 1) males between the ages of 20 and 35, 2) having at least 2 years resistance training experience to include training of the upper and lower body musculature weekly, and 3) reporting not having consumed any nutritional or ergogenic supplements excluding protein supplementation and/or a daily vitamin for the previous 6 week period leading up to baseline testing. Those meeting entry criteria were asked to fill out a medical history questionnaire to eliminate those with any possible contraindications to exercise. Subjects meeting all criteria were informed of the experimental procedures and asked to sign an informed consent approved by the Institutional Review Board of Texas A & M

University (College Station, TX). Twenty two subjects were included in final analysis. A consort diagram is provided in Figure 1 outlining reasons for drop out and/or exclusion. Baseline characteristics for the final 22 subjects (n = 22) are presented in Table 1. No significant differences were noted in any of the baseline variables prior to group assignment.

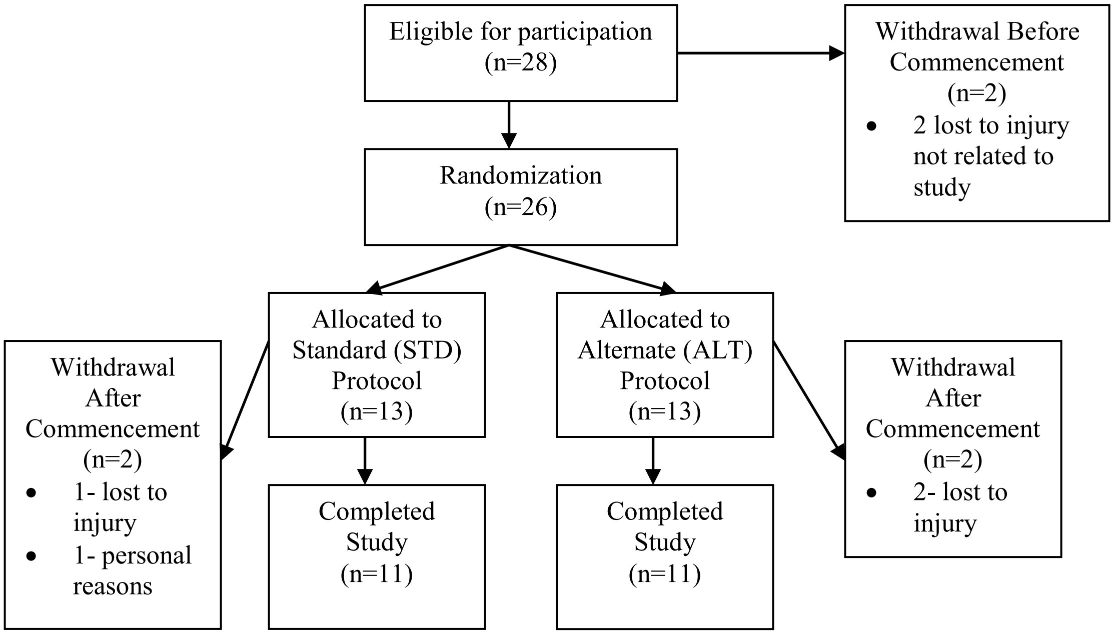


Figure 1. Consort diagram for participation.

Table 1. Baseline group characteristics. Data are means ± SD.

	STD			ALT			COMBINED			P Value
Age (yr)	25	±	5	25	±	4	25	±	5	0.790
Height (cm)	179.71	±	6.18	179.71	±	3.90	179.71	±	5.04	1.000
Weight (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 (yrs)	6.5	±	4.0	6.0	±	5.0	6.5	±	4.5	0.815
# Days Trained (days)	3.5	±	2.0	3.5	±	2.0	3.5	±	2.0	1.000

Data are means ± SD. STD, standard group; ALT, alternate group.

Testing Sessions

Figure 2 provides a summary of testing and training procedures. Prior to baseline testing, subjects underwent an exercise familiarization session led by a Certified Strength and Conditioning Specialist (CSCS). Proficiency in all lifts utilized for training and testing was required. During the same week, a nutrition seminar outlining current macronutrient guidelines for athletes involved in a resistance training program was also provided by a registered dietitian (7) including instruction on proper dietary intake recording. Preceding baseline testing, subjects completed a four day dietary record to include three week days and one weekend day. Thereafter, subjects completed a four day dietary recording one week prior to subsequent testing sessions. The same protocol was followed prior to each testing session. Every effort was made to schedule follow up testing sessions at the same approximate time to reduce any diurnal variations. Subjects were tested at baseline, in weeks 4, 8 and 12 of the exercise intervention. In the week of testing sessions, subjects were weighed, had their body composition determined using dual-energy x-ray absorptiometry (DEXA), and had their strength and power output assessed according to standardized procedures outlined below. Muscle biopsies were obtained prior to baseline testing and at the conclusion of the exercise intervention.

<table>
<tr><td colspan="2">Familiarization, Nutrition Seminar, and Muscle Biopsy (1 week prior to baseline)</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing Baseline</td></tr>
<tr><td>Standard Training Group (STD)</td><td>ALT Training Group (ALT)</td></tr>
<tr><td>4 x 10 with 2 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 1 – 65% 1RM (4 days • wk^{-1})
Week 2 – 70% 1RM (4 days • wk^{-1})
Week 3 – 75% 1RM (4 days • wk^{-1})
Week 4 – 60% 1RM (2 days • wk^{-1})</td><td>8 x 5 with 1 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 1 – 65% 1RM (4 days • wk^{-1})
Week 2 – 70% 1RM (4 days • wk^{-1})
Week 3 – 75% 1RM (4 days • wk^{-1})
Week 4 – 60% 1RM (2 days • wk^{-1})</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing Week 4</td></tr>
<tr><td>4 x 10 with 2 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 5 – 65% 1RM (4 days • wk^{-1})
Week 6 – 70% 1RM (4 days • wk^{-1})
Week 7 – 75% 1RM (4 days • wk^{-1})
Week 8 – 60% 1RM (2 days • wk^{-1})</td><td>8 x 5 with 1 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 5 – 65% 1RM (4 days • wk^{-1})
Week 6 – 70% 1RM (4 days • wk^{-1})
Week 7 – 75% 1RM (4 days • wk^{-1})
Week 8 – 60% 1RM (2 days • wk^{-1})</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing Week 8</td></tr>
<tr><td>4 x 10 with 2 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 9 – 65% 1RM (4 days • wk^{-1})
Week 10 – 70% 1RM (4 days • wk^{-1})
Week 11 – 75% 1RM (4 days • wk^{-1})
Week 12 – 60% 1RM (2 days • wk^{-1})</td><td>8 x 5 with 1 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 9 – 65% 1RM (4 days • wk^{-1})
Week 10 – 70% 1RM (4 days • wk^{-1})
Week 11 – 75% 1RM (4 days • wk^{-1})
Week 12 – 60% 1RM (2 days • wk^{-1})</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing, and Muscle Biopsy Week 12</td></tr>
</table>

Figure 2. Testing and training program design.

Dietary Recording and Analysis

Prior to each testing sessions subjects completed a dietary record to include 3 weekdays and 1 weekend day. Dietary recording was completed one week prior to baseline and in weeks 3, 7, and 11 corresponding to the highest volume of training during each four week cycle (Figure 2). All food logs were entered and analyzed using dietary analysis software (ESHA food Processor Version 8.6, Salem, OR). Analysis was subsequently reviewed by a registered dietitian. Post workout supplementation (20 g protein, 45 g carbohydrates, 3.5 g fat) was provided on training days (Muscle Milk Collegiate, Cytosport, Benicia, CA).

Body Composition Testing

Body composition testing occurred at baseline; in weeks 4, 8 and 12 coincident with testing of strength and power output (Figure 2). Subjects reported to the laboratory having fasted for at least 10 hours prior to body composition measurement. Height and weight were recorded to the nearest .02 kg and .01 cm respectively using a self-calibrating digital scale (Bridgeview, IL) in socks or bare feet. Body composition was then determined using DEXA (Hologic Discovery W DXA software version 12.1, Waltham, MA) calibrated according to 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 (5).

Strength Testing

Upper and lower body strength was assessed using 1RM parallel back squat ($1RM_{BS}$) and bench press ($1RM_{BP}$) exercises. On the day of strength testing, subjects reported to the laboratory having refrained from any exercise outside of daily living for at least 72 hours prior to baseline testing and at least 48 hours prior to testing in weeks 4, 8 and 12. Baseline 1RM of both exercises was estimated from self-reporting. After baseline, all 1RM estimations were based on training logs kept throughout the study. A dynamic warm up lasting approximately 8-10 minutes was performed prior to determination 1RM. Strength testing for both $1RM_{BS}$ and $1RM_{BP}$ commenced with two warm up sets of 5 repetitions at 40-60% 1RM separated by two minutes rest. After a three minute rest period one to two sets of 2-3 repetitions at a load corresponding to 60-80% 1RM were performed. Subjects then began performing sets of 1 repetition of increasing weight for 1RM determination. Three to five minutes rest was provided between each successive attempt. All 1RM determinations were made within 3-5 attempts. Subjects were required to reach parallel in the $1RM_{BS}$ for an attempt to be considered successful as determined by a CSCS certified individual providing an “up” command. $1RM_{BP}$ was considered successful if subject remained in contact with the bench during the entire concentric phase of the lift. $1RM_{BS}$ testing was conducted prior to $1RM_{BP}$ after a five minute rest period. The same 1RM testing procedure was utilized for both exercises. All strength testing took place on an Optima Smith Machine (LifeFitness, Schiller Park, IL) without counterbalance technology. Foot placement was recorded during baseline $1RM_{BS}$ testing; hand placement was recorded at baseline

$1RM_{BP}$ testing. These measurements were then used in all subsequent testing procedures for strength and power output. All testing sessions were supervised by two CSCS certified individuals to determine success during each attempt.

Power Testing

Power testing commenced at least 48 hours post 1RM testing. Subjects performed the same warm up prior to initiation of power testing. Weight and reach height were recorded for calculation of power as determined by vertical jump. Two countermovement vertical jumps (CMJ) using less than maximal effort were allowed prior to testing. Three maximum effort vertical CMJ were then recorded separated by two minutes rest. If the third attempt was greater than the first three, another attempt was allowed until a decrease in jump height was observed. No more than five maximum vertical CMJ were allowed. Reach height and jump height were recorded using a commercially available Vertec system (Sports Imports, Columbus, OH). The maximum attempt of record was later converted to power in watts (PWR_{VJ}) using previously described procedures (71).

After vertical jump testing, power output was assessed during the concentric phase of the parallel back squat (PWR_{BS}) and bench press (PWR_{BP}) exercises using a relative load of 60% 1RM. PWR_{BS} was determined preceding PWR_{BP} separated by five minutes rest. All testing was performed on the same smith machine used for 1RM testing. A warm-up of 3 sets of 5 repetitions at 40-50% 1RM was provided on both exercises prior to power output assessment. Subjects were instructed to perform the concentric phase of each lift as explosively as possible. After warm up sets, 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 subjects reached the appropriate parallel position for the attempt to be a success. Three attempts were allowed with the best recorded for further analysis. Again, if the third attempt was greater than the first two another attempt was recorded until power output declined. No more than five attempts were recorded with the highest mean power output being used for statistical analysis. Three minutes rest was utilized between successive maximal power attempts. Power output was measured using a Tendo Fitrodyne (Sorinex, Irmo, SC). During post training (12 weeks) power output was assessed on both parallel back squat ($APWR_{BS}$) and bench press ($APWR_{BP}$) using loads corresponding to 60% baseline 1RM followed by 60% post training 1RM.

Reliability of Strength and Power Testing

Ten resistance trained males age 25±5 yrs, 181.48±11.21 cm, 91.3±14.0 kg with 8±5 years 5±1 days per week resistance training experience having signed consent forms approved by the Institutional Review Board of Texas A & M University performed strength and power output assessment according to previously described procedures to determine reliability of measurement. After one week, subjects returned to perform the same testing procedures. Table 2 provides the reliability statistics for strength and power output measurements.

Table 2. Intraclass correlation coefficients (ICC) and Pearson product-moment coefficient (r) between trials for strength and power testing procedures.

	Day 1	Day 2	ICC	r
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

Day 1 and Day 2 values are means ± SD.

Training

All training sessions commenced with a dynamic warm up identical to that used for strength and power testing. Training consisted of 4 supervised workouts a week in the following sequence; two days on, one day off, two days on, two days off. The training program intensity was structured into four week cycles with increasing intensity as described in Figure 2 providing an unload week during each week of testing. All sessions were supervised by trained staff with at least 1 – 2 CSCS certified personnel leading sessions.

Throughout the training program, both groups performed the same exercises, in the same order and intensity (Figure 2). Table 3 provides the exercises performed as well as the order in which they were performed. All major lifts tested for strength and power output were performed on the same apparatus used for determination of 1RM and power output. Additionally, all derivations of major lifts tested were also performed on the same apparatus used for strength and power testing. Therefore, all squat, front squat, bench and incline presses were performed on the smith machine in which testing was performed. 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 2). Briefly, the STD group performed 4 sets of 10 repetitions for all major lifts with 2 minutes rest between sets, while the ALT group performed 8 sets of 5 repetitions for all major lifts with 1 minute rest between sets. All assistive lifts were performed 3 sets of 10 repetitions with 1.5 minutes rest. The load was reduced if subjects were unable to complete the prescribed number of repetitions. Intensity was increased if subjects were able to achieve at least 85% of total volume on major lifts. Timing of rest was performed using stop watches on all lifts by trained personnel. The total sum of work (weight x reps x sets) was grouped according to lifts utilizing the upper and lower body for main lifts and push and pull exercises for assistive exercises for later analysis. Workout logs were maintained and verified throughout the 12 week period. Compliance throughout the entire 12 week study was 95%.

Table 3. Exercises performed during training.

Day 1 (Upper Body Push)	**Day 2 (Lower Body + Upper Body Pull)**	**Day 3 (Upper Body Push)**	**Day 2 (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 Flies	Pull-ups†	DB Incline Flies	Pull-ups†
Front DB Raises	One Arm DB Row	DB Rear Delt	Close Grip Lat Pulldowns
Side DB Raises	Hamstring Curl	Side DB Raises	T Bar Row
Straight Bar Skull Crusher	EZ Bar Curls	EZ Bar Skull Crusher	Straight Bar Curl
Dips†	DB Curl	Dips†	DB Curl

* Main lift exercises performed according to group (STD or ALT), concentric phase explosively as possible. †exercise performed 3 sets of maximum repetitions with 1.5 minute rest. ‡exercise performed on Smith Machine. DB = Dumbbell, DL = Deadlift, RDL = Romanian Deadlift.

Carbohydrate intake decreased over the course of the experimental period decreasing from week 3 to week 7, with a continued decrease in week 11. Percentage carbohydrate from total calories as well as $g \bullet kg^{-1}$ experienced a decrease from 3 weeks to 7 weeks and again from week 7 to week 11. No significant changes were observed in absolute fat intake, as a percentage of total calories or relative to body weight.

Training Volume

Total volume 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 of main lifts or assistive exercises.

Table 4. Kcalories, protein, carbohydrate and fat intake, percent of total kcalories, and relative intake at baseline, 3, 7, and 11 weeks of training.

	Baseline	**3 Weeks**	**7 Weeks**	**11 Weeks**	**P Value**
Overall					
Kcalories	2620 ± 581	2918 ± 601	2923 ± 573	2793 ± 481	T = 0.084
Protein (g)	147 ± 39	196 ± 50†	191 ± 34†	201 ± 40†	T = 0.001
Carbohydrate (g)	261 ± 94	270 ± 63	231 ± 85‡	182 ± 69†‡§	T = 0.001
Fat (g)	101 ± 33	109 ± 32	110 ± 32	101 ± 26	T = 0.517
Percent Total Kcal					
Protein (%)	22.7 ± 4.6	26.8 ± 3.5†	27.2 ± 8.0†	29.1 ± 5.8†‡	T = 0.001
Carbohydrate (%)	40.1 ± 13.3	37.4 ± 6.9	31.0 ± 9.0†‡	26.0 ± 8.5†‡§	T = 0.001
Fat (%)	34.4 ± 8.0	33.5 ± 4.7	33.8 ± 5.6	32.7 ± 7.2	T = 0.754
Relative to Bodyweight					
Kcalories (g•kg^{-1})	32.3 ± 7.9	35.5 ± 8.2	35.7 ± 9.5	33.6 ± 6.8	T = 0.128
Protein (g•kg^{-1})	1.8 ± 0.5	2.4 ± 0.7†	2.3 ± 0.5†	2.4 ± 0.5†	T = 0.001
Carbohydrate(g•kg^{-1})	3.3 ± 1.3	3.3 ± 0.8	2.8 ± 1.1†‡	2.2 ± 0.8†‡§	T = 0.001
Fat (g•kg^{-1})	1.2 ± 0.4	1.3 ± 0.4	1.4 ± 0.5	1.2 ± 0.4	T = 0.424

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect. †significantly different than baseline. ‡significantly different from 3 weeks. § significantly different from 7 weeks.

Table 5. Total training volume for STD and ALT over 12 weeks of training.

	STD			ALT			P Value
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 (kg)							
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

Data are means ± SD. STD, standard group; ALT, alternate group. Major lifts performed according to group assignment. Assistive lifts all performed same rest to work ratio.

Muscular Strength

The results of strength testing are presented in Table 6. There were no significant differences between groups observed at baseline in either $1RM_{BP}$ or $1RM_{BS}$. Both groups experienced a significant improvement in $1RM_{BP}$ after 12 weeks of training. A significant difference was observed between groups at 4, 8 and 12 weeks. The ALT group experienced an increase at 4, 8 and 12 weeks of which all three time points corresponded to values greater than the STD group. The STD group decreased at 4 weeks and then increased at 8 and 12 weeks for an overall improvement in $1RM_{BP}$ from baseline. Significant differences were observed in absolute changes from baseline in weeks 4, 8 and 12. From baseline to week 4, the ALT group experienced a 6.5±6.6 kg increase while the STD group experienced a -1.4±6.2 kg decrease (p= 0.008). The ALT group continued to experience significantly greater increases from baseline at week 8 (9.9±6.8 kg) and week 12 (15.1±8.3 kg) compared to the STD group (week 8, 2.9±5.8 kg; week 12, 9.1±3.7 kg; $p = 0.018$ and 0.041; respectively). In evaluating $1RM_{BP}$ in relationship to body weight, both groups experienced a significant improvement from baseline with the ALT group increasing to a greater degree at 4, 8 and 12 weeks. $1RM_{BP}$ relative to lean mass did not show a time or group effect, but showed a significant interaction which when analyzed post hoc showed again that the ALT group experienced greater increase at all testing points after baseline compared with STD group.

Both groups experienced significant increases in $1RM_{BS}$ which showed continued increase from baseline to 4 weeks, 4 to 8 weeks and 8 to 12 weeks. The ALT group experienced greater increases at both 8 (ALT, 49.7±13.8 kg; STD, 36.9±13.5 kg; $p = 0.040$) and 12 (ALT, 63.8±12.0 kg; STD, 48.5±17.4 kg; $p = 0.026$) weeks compared to the STD group. $1RM_{BS}$ relative to body weight and lean mass showed the same pattern of improvement over time in both groups with the ALT group showing greater increases in $1RM_{BS}$ at both 8 and 12 weeks. The results demonstrated herein lead to rejecting our initial hypotheses stating no significant differences in strength of the bench press and parallel back squat exercises after 12 weeks of training.

Table 6. Strength measures (1RM) at baseline, 4, 8, and 12 weeks of training.

	STD	ALT	COMBINED	P Value
Bench Press 1RM (kg)				
Baseline	104.1 ± 27.6	110.9 ± 20.1	107.5 ± 23.8	T = 0.027
4 Weeks	102.7 ± 29.0	117.5 ± 23.7*	110.1 ± 26.9	G = 0.013
8 Weeks	107.0 ± 25.3	120.8 ± 22.6*	113.9 ± 24.5†‡	T X G = 0.017
12 Weeks	113.2 ± 27.3	126.0 ± 22.8*	119.6 ± 25.4†‡§	
Bench Press to Bodyweight Ratio				
Baseline	1.27 ± 0.22	1.35 ± 0.23	1.31 ± 0.22	T = 0.010
4 Weeks	1.22 ± 0.24	1.42 ± 0.24*	1.32 ± 0.26	G = 0.035
8 Weeks	1.26 ± 0.18	1.45 ± 0.23*	1.36 ± 0.23†‡	T X G = 0.001
12 Weeks	1.33 ± 0.19	1.51 ± 0.22*	1.42 ± 0.22†‡§	
Bench Press to Lean Mass Ratio				
Baseline	1.67 ± 0.27	1.75 ± 0.26	1.71 ± 0.26	T = 0.090
4 Weeks	1.61 ± 0.29	1.84 ± 0.30*	1.73 ± 0.31	G = 0.066
8 Weeks	1.66 ± 0.22	1.88 ± 0.29*	1.77 ± 0.28	T x G = 0.004
12 Weeks	1.75 ± 0.25	1.95 ± 0.29*	1.85 ± 0.28	
Back Squat 1RM (kg)				
Baseline	123.3 ± 39.3	130.1 ± 25.1	126.7 ± 32.3	T = 0.001
4 Weeks	139.6 ± 38.8	152.6 ± 24.8	146.1 ± 32.4†	G = 0.016
8 Weeks	160.2 ± 36.1	179.8 ± 24.5*	170.0 ± 31.7†‡	T X G = 0.006
12 Weeks	171.8 ± 34.5	193.9 ± 24.2*	182.8 ± 31.2†‡§	
Back Squat to Bodyweight Ratio				
Baseline	1.50 ± 0.34	1.59 ± 0.30	1.54 ± 0.32	T = 0.001
4 Weeks	1.66 ± 0.34	1.85 ± 0.27	1.76 ± 0.31†	G = 0.038
8 Weeks	1.90 ± 0.30	2.17 ± 0.25*	2.03 ± 0.30†‡	T X G = 0.001
12 Weeks	2.03 ± 0.30	2.33 ± 0.27*	2.18 ± 0.32†‡§	
Back Squat to Lean Mass Ratio				
Baseline	1.97 ± 0.42	2.05 ± 0.30	2.01 ± 0.36	T = 0.001
4 Weeks	2.19 ± 0.41	2.40 ± 0.27	2.30 ± 0.35†	G = 0.045
8 Weeks	2.49 ± 0.35	2.79 ± 0.26*	2.64 ± 0.34†‡	T X G = 0.001
12 Weeks	2.67 ± 0.36	3.02 ± 0.26*	2.84 ± 0.35†‡§	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. *significantly different from STD. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks.

Power Output

Data from power output assessments are presented in Table 7. There were no significant differences between groups noted in any power variable (PWR_{BP}, PWR_{BS}, or PWR_{VJ}) measurements at baseline. No significant time effect was noted in PWR_{BP}, however, group and interaction effects were both noted. Post hoc analysis revealed significant differences between groups at 8 and 12 weeks with the ALT group showing an overall greater increase over time in PWR_{BP} compared to the STD group. Compared to baseline, the ALT group experienced significantly greater increases in weeks 4 (11.1±46.6 W), 8 (71.4±40.2 W), and 12 (83.0±49.9 W), compared to STD which decreased in week 4 (-19.2±49.3 W, p = 0.155), then increased in weeks 8 (11.3±38.4 W, p = 0.002) and 12 (32.8±53.4 W, p = 0.034). In evaluating power relative to body weight and lean mass, the same pattern emerged with the ALT group showing significant improvements over time while the STD experienced no significant increase. Based on results, the original hypothesis is proven stating intra-set rest intervals would result in significantly greater power output of the bench press exercise after 12 weeks of training.

Both groups showed an increase in PWR_{BS}. A significant interaction was observed with post hoc analysis revealing no significant differences. However, the difference between groups at both 8 and 12 weeks approached significance ($p = 0.084$ and $p = 0.064$, respectively) with the ALT group showing a greater increase. This was also reflected in changes from baseline at 8 (ALT, 151.0±74.0 W; STD, 97.5±60.9 W; $p = 0.085$) and 12 (ALT, 282.1±104.1 W; STD, 204.9±70.2 W; $p = 0.059$). The magnitude of effect was also greater in the ALT group (Table 7). In relationship to body weight, both groups experienced a significant increase over time. Significant differences between groups were noted when evaluating PWR_{BP} relative to body weight. While both groups showed improvement the ALT group showed a greater improvement at 8 weeks with significance almost being reached at 12 weeks ($p = 0.057$). A significant difference was noted at both 8 and 12 weeks between groups with the ALT group showing a greater increase when evaluating PWR_{BS} relative to lean mass. Contrary to the original hypothesis, no significant differences were found in parallel back squat power output leading to rejection of the original hypothesis.

Changes in $APWR_{BP}$ and $APWR_{BS}$ are presented in Figure 3. The ALT group experienced a significantly greater improvement in $APWR_{BP}$, 71.0 W compared to 13.5 W for STD ($p = 0.048$). No significant differences were observed in $APWR_{BS}$ between groups. However, the magnitude of effect size was greater for the ALT group (Table 7). Failure to reject the original hypothesis stating a significant difference in absolute bench press power after 12 weeks of resistance training with a rejection of the hypothesis stating significant difference in absolute parallel back squat power after 12 weeks of training is warranted based on these results.

Increases in PWR_{VJ} were observed in both groups at 4, 8 and 12 weeks with improvement noted from each testing period to the next. A significant difference was observed at 12 weeks with the ALT group showing a greater increase over time compared with the STD group (ALT, 147.7 ± 52.0 W; STD, 91.6 ± 59.8 W; $p = 0.034$). Evaluation of PWR_{VJ} relative to body weight and lean mass showed the same pattern of differences over time and between groups. Based on these results the original hypothesis was proven leading to a failure to reject” our initial hypothesis stating intra-set rest intervals would result in greater power output in the vertical jump after 12 weeks of training.

Table 7. Power measures at baseline, 4, 8, and 12 weeks of training.

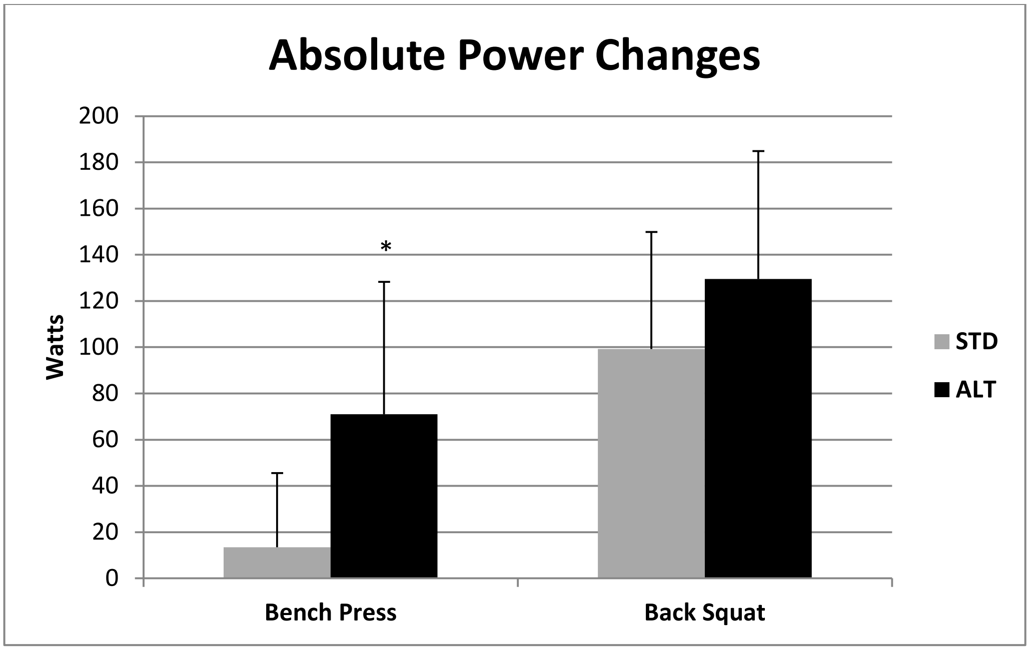
	STD			ALT			COMBINED			P Value
Bench Press Power (W)										
Baseline	560	±	122	575	±	102	568	±	110	T = 0.568
4 Weeks	541	±	105	586	±	123	564	±	114	G = 0.011
8 Weeks	572	±	122	646	±	103*	609	±	116	T X G = 0.020
12 Weeks	593	±	135	658	±	113*	626	±	126	
Bench Press Power to Bodyweight Ratio										
Baseline	6.84	±	0.96	6.99	±	1.10	6.92	±	1.01	T = 0.627
4 Weeks	6.46	±	0.91	7.09	±	1.28	6.78	±	1.13	G = 0.056
8 Weeks	6.77	±	0.92	7.77	±	0.92*	7.27	±	1.03	T X G = 0.003
12 Weeks	6.96	±	0.96	7.90	±	1.24*	7.43	±	1.18	
Bench Press Power to Lean Mass Ratio										
Baseline	9.01	±	1.14	9.07	±	1.21	9.04	±	1.15	T = 0.793
4 Weeks	8.56	±	1.24	9.18	±	1.32	8.87	±	1.29	G = 0.066
8 Weeks	8.88	±	1.11	10.02	±	0.96*	9.45	±	1.17	T X G = 0.006
12 Weeks	9.20	±	1.39	10.21	±	1.17*	9.70	±	1.35	
Back Squat Power (W)◊										
Baseline	625	±	245	632	±	171	628	±	208	T = 0.001
4 Weeks	704	±	233	734	±	179	718	±	205†	G = 0.081
8 Weeks	723	±	227	783	±	188	751	±	206†‡	T X G = 0.053
12 Weeks	830	±	232	914	±	207	870	±	219†‡§	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. *significantly different from STD. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks. ◊ One subject was excluded from analysis of lower body power due to failure to accurately follow protocol during T1 and T3.

Table 7. Continued.

	STD	ALT	COMBINED	P Value
Back Squat Power to Bodyweight Ratio◊				
Baseline	7.57 ± 2.23	7.83 ± 2.33	7.69 ± 2.23	T = 0.001
4 Weeks	8.37 ± 2.14	9.09 ± 2.42	8.71 ± 2.25†	G = 0.101
8 Weeks	8.53 ± 1.94	9.57 ± 2.35*	9.02 ± 2.16†‡	T X G = 0.015
12 Weeks	9.78 ± 2.03	11.11 ± 2.64	10.41 ± 2.38†‡§	
Back Squat Power to Lean Mass Ratio◊				
Baseline	9.96 ± 2.77	10.19 ± 2.62	10.07 ± 2.63	T = 0.001
4 Weeks	11.04 ± 2.57	11.83 ± 2.65	11.41 ± 2.57†	G = 0.068
8 Weeks	11.15 ± 2.31	12.41 ± 2.63*	11.75 ± 2.49†	T X G = 0.017
12 Weeks	12.86 ± 2.49	14.45 ± 2.87*	13.62 ± 2.73†‡§	
Vertical Jump Power (W)◊				
Baseline	1378 ± 237	1389 ± 179	1383 ± 206	T = 0.001
4 Weeks	1418 ± 214	1434 ± 152	1426 ± 183†	G = .205
8 Weeks	1452 ± 210	1470 ± 149	1461 ± 179†‡	T X G = 0.036
12 Weeks	1470 ± 215	1537 ± 150*	1502 ± 185†‡§	
Vertical Jump Power to Bodyweight Ratio (W)◊				
Baseline	17 ± 1	17 ± 2	17 ± 2	T = 0.001
4 Weeks	17 ± 1	18 ± 2	17 ± 2†	G = 0.243
8 Weeks	17 ± 1	18 ± 2	18 ± 2†‡	T X G = 0.001
12 Weeks	17 ± 1	19 ± 2*	18 ± 2†‡§	
Vertical Jump Power to Lean Mass Ratio (W)◊				
Baseline	22 ± 1	22 ± 2	22 ± 2	T = 0.001
4 Weeks	22 ± 1	22 ± 2	23 ± 1†	G = 0.141
8 Weeks	23 ± 1	23 ± 1	23 ± 1†	T X G = 0.004
12 Weeks	23 ± 1	24 ± 1*	24 ± 1†‡§	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. *significantly different from STD. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks. ◊ One subject was excluded from analysis of lower body power due to failure to accurately follow protocol during T1 and T3.



Data are means ± SD. STD, standard group; ALT, alternate group. *significantly different from STD.

Figure 3. Absolute power changes.

Effect Size and Magnitude

The ALT group displayed greater size magnitudes in all performance variables excluding $1RM_{BS}$ compared to the STD group (Table 8). The ALT group magnitude of effect sizes were all moderate or large, while the STD group was found to have small magnitudes as defined by Rhea (60) for highly trained individuals in $1RM_{BP}$, PWR_{BP}, PWR_{VJ}.

Table 8. Effect size and magnitude in strength and power variables.

	STD		ALT	
Bench Press 1RM	0.33	(small)	0.75	(moderate)
Back Squat 1RM	1.22	(large)	2.54	(large)
Bench Press Power	0.27	(small)	0.81	(moderate)
ABS Bench Press Power	0.11	(trivial)	0.69	(moderate)
Back Squat Power	0.84	(moderate)	1.65	(large)
ABS Back Squat Power	0.41	(small)	0.76	(moderate)
Vertical Jump Power	0.39	(small)	0.83	(moderate)

Body Composition

Results of body composition testing over the course of the training period are presented in Table 9. A significant increase in body mass was observed over the course of the 12 week training program. While a time x group interaction was observed, post hoc analysis revealed no significant differences 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 in lean body mass from 8 to 12 weeks. No between group differences were identified. When evaluating percentage change from baseline, a significant time effect was noted ($p = 0.001$) with no significant time x group interaction or group effect. Determination of effect size magnitude showed a small (0.25) and trivial (0.14) for STD and ALT groups, respectively. There were no significant changes in percent body fat as measured by DEXA during the twelve week training. Failure to reject the original hypothesis is warranted based on results demonstrating no significant differences in lean mass gains after 12 weeks of training.

Table 9. Body composition at baseline, 4, 8, and 12 weeks of training.

	STD	ALT	COMBINED	P Value
Weight (kg)				
Baseline	81.7 ± 11.6	82.5 ± 10.0	82.1 ± 10.6	T = 0.001
4 Weeks	83.6 ± 10.0	82.7 ± 9.7	83.2 ± 9.6†	G = 0.898
8 Weeks	84.1 ± 10.7	83.1 ± 9.2	83.6 ± 9.7†	T X G = 0.018
12 Weeks	84.7 ± 10.9	83.6 ± 9.2	84.1 ± 9.9†‡	
Lean Mass (kg)				
Baseline	61.9 ± 8.9	63.3 ± 7.0	62.6 ± 7.9	T = 0.001
4 Weeks	63.2 ± 8.2	63.5 ± 7.3	63.4 ± 7.6†	G = 0.869
8 Weeks	64.0 ± 8.3	64.3 ± 6.9	64.2 ± 7.4†‡	T X G = 0.227
12 Weeks	64.2 ± 8.5	64.3 ± 6.8	64.2 ± 7.5†‡	
Percent Fat (%)				
Baseline	14.3 ± 2.7	12.9 ± 5.5	13.6 ± 4.3	T = 0.126
4 Weeks	15.0 ± 3.3	13.3 ± 5.9	14.1 ± 4.7	G = .445
8 Weeks	14.7 ± 3.5	13.2 ± 5.5	14.0 ± 4.6	T X G = 0.892
12 Weeks	15.1 ± 3.5	13.5 ± 5.6	14.3 ± 4.6	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks.

Myosin Heavy Chain Composition

Studentized t-tests of baseline MHC demonstrated a significantly higher percentage of MHC_{IIX} in the ALT group ($p = 0.023$) compared to STD. No significant differences were observed at baseline in percentage MHC_{IIA} or MHC_{slow}. Results from myosin heavy chain analysis are presented in Table 10. Both groups experienced a significant reduction in MHC_{IIX} after 12 weeks of training, with a concomitant increase in $MHC_{IIA.}$ No interaction or between group effects were noted in either MHC_{IIX} or MHC_{IIA}. Evaluating percentage change from baseline, a significant time effect ($p = 0.001$) was noted with both ALT and STD groups experiencing a decrease in MHC_{IIX}, -37.9±24.1% and -23.4±23.8% respectively, with no differences noted between groups.

A time effect was also noted in percentage change from baseline in MHC$_{IIA}$ for both ALT and STD groups, with both showing an increase 32.0±28.8% and 25.4±29.1% (p = 0.001). Again, no interaction or group effect was noted. A small but significant decrease in percentage MHC$_{slow}$ was observed in both groups. However, when evaluating percent change from baseline, this did not reach significance (p = 0.164). These results are in contrast to the original hypothesis, therefore, the hypothesis is rejected.

Table 10. Myosin heavy chain isoform in percentage total at baseline and 12 weeks of training.

	STD	**ALT**	**COMBINED**	**P Value**
MHC$_{IIX}$				
Baseline	11.1 ± 4.2	16.5 ± 5.7	13.9 ± 5.7	T = 0.020
12 Weeks	7.9 ± 2.5	9.8 ± 4.5	8.9 ± 3.7†	G = 0.649
				T X G = 0.649
MHC$_{IIA}$				
Baseline	35.6 ± 7.7	34.5 ± 7.6	35.0 ± 7.5	T = 0.001
12 Weeks	43.2 ± 7.5	43.9 ± 6.2	43.6 ± 6.7†	G = 0.756
				T X G = 0.756
MHC$_{slow}$				
Baseline	53.3 ± 7.9	49.0 ± 7.6	51.1 ± 7.9	T = 0.002
12 Weeks	48.9 ± 5.9	46.2 ± 7.1	47.5 ± 6.5†	G = 0.568
				T X G = 0.568

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. † significantly different from baseline. ◊ One subject was excluded from analysis due to lack of sufficient sample.

CHAPTER V

SUMMARY

In the current study, we compared the effects of 12 weeks of intra-set rest intervals in a program designed to elicit hypertrophy and traditional hypertrophic training on performance measures and MHC composition. The ability to generate force and power output is a necessary requirement for a number of sports. Manipulation of the variables within a resistance training program in which performance is optimized is important to the strength and conditioning professional, while the adaptations that occur as a result of resistance training are significant to the applied researcher. Results of the current study demonstrate the effectiveness of intra-set rest intervals in programs designed to elicit hypertrophy as evidenced by the greater gains in both strength and power output. The major findings of this study were that after 12 weeks of training 1) intra-set rest intervals resulted in greater increases in strength in the bench press and back squat exercises, 2) intra-set rest intervals resulted in greater power output in the bench press exercise and vertical jump, 3) power output as measured during parallel back squat approached significance compared to traditional hypertrophic training, and 4)when normalized to body weight and lean mass, intra-set rest intervals were superior in increasing power output during parallel back squat, 5) absolute power difference in the bench press was greater in the bench press exercise with the use of intra-set rest intervals. Additionally, similar gains in lean mass were experienced between traditional and intra-set rest which resulted in similar changes in MHC isoforms in both groups.

Macronutrient Intake

It is well established that rates of protein synthesis are elevated following an acute bout of resistance training and the consumption of amino acids (i.e., protein) provides a synergistic effect to this response (13, 53). Therefore, protein requirements for individuals involved in a strength training program are higher than for sedentary individuals (7). Dietary intake was not controlled over the duration of the study, however, a nutrition seminar conducted by a registered dietitian was provided prior to the initiation of training. Additionally, subjects were advised to follow the prescribed dietary guidelines and dietary records were obtained throughout the study. The subjects utilized in the current study reported having been actively performing resistance training 3.5±2.0 days per week for the previous 6.5±4.5 years. Baseline dietary analysis demonstrated protein intake to be within the current guidelines (1.8 $g•kg^{-1}$). However, protein intake increased prior to the second dietary analysis with no further increases observed. Total calories and dietary fat intake did not demonstrate any changes from initial recordings. Carbohydrate intake did progressively decline over the course of the 12 week training period. The loss of calories from carbohydrate intake was made up by the high intake of protein over the duration of the training program.

Training Volume

The use of intra-set rest intervals in a program designed to elicit hypertrophy is a novel aspect of the current study. Few studies have reported on the effects of intra-set rest intervals in long-term training (15, 22, 23, 27, 37, 41, 48, 62) and none of these studies have reported on changes in body composition. In order to effectively compare intra-set rest intervals to traditional hypertrophic training, it was necessary to equate total volume as well as intensity throughout the training as manipulation of these factors have been previously shown to affect training adaptations (16, 29). This was accomplished as no differences in total training volume were observed between groups in main lifts or assistive exercises (Table 4).

Strength

In contrast to our original hypothesis, intra-set rest intervals resulted in greater increases in bench press and parallel back squat strength from baseline compared to traditional resistance training. These differences appeared as early as 4 weeks with the ALT group showing a 6.6 kg increase compared to a decrease of -1.4 kg in the STD group ($p = 0.008$). The trend of greater increases from baseline was also observed at 8 and 12 weeks with the ALT group demonstrating an increase of 9.9 kg and 15.1 kg, respectively; compared to the STD group increase of only 2.9 kg and 9.1 kg ($p = 0.018$ and 0.041, respectively). Similar to bench press strength, intra-set rest intervals resulted in greater increases in parallel back squat strength. By 4 weeks ALT showed an increase over baseline of 22.5 kg compared to 16.3 kg in the STD group ($p = 0.084$), with a significant difference being observed by week 8 (ALT, 49.7 kg; STD, 36.9 kg; $p = 0.040$) and continuing through the conclusion of training (ALT, 63.8 kg; STD, 48.5 kg; $p = 0.026$).

Resistance training for the development of hypertrophy is characterized by the performance of repetitions to the point of fatigue, or failure, as evidenced by the need to decrease the load over consecutive sets. While the comparison of intra-set rest intervals to traditional resistance training to elicit hypertrophy was the primary goal of the current study, the performance of continuous repetitions in hypertrophic training to failure warrants a comparison to those studies in which intra-set rest intervals were used to prevent training to failure. Few studies have determined the effect of training to failure on strength gains in a longitudinal periodized program (22, 27, 41, 62). Results from those studies have shown that performance of repetitions to failure increases (22, 62) or has no effect on strength gains (27, 41). However, no studies have determined that not training to failure provided superior strength gains when compared to training to failure.

Lawton et al. (48) reported greater strength gains in the bench press exercise when performing continuous repetitions compared to intra-set rest intervals in a six week strength training program. Differences between our study and that of Lawton et al. (48) may at least partially explain our divergent findings. First, the intensity in our study corresponded to that used for the development of hypertrophy (65-75%1RM), while the intensity of the study conducted by Lawton et al. (48) corresponded to that used for the development of strength (6RM or 85%1RM). Additionally, the 6RM strength testing procedures performed in the study conducted by Lawton et al. (48) were identical to the performance of continuous repetitions. Greater muscular endurance has been reported in the performance of repetitions to failure (41). As Haff et al. (33) suggested, the results from Lawton et al. (48) on strength improvements in those performing continuous repetitions should be expected after the continued performance of successive 6RM over a six week period when compared to intra-set rest intervals in which repetitions were not performed continuously.

Izquierdo et al. (41) demonstrated similar results comparing resistance training to failure and not to failure. In agreement with Lawton et al.(48) they found training to failure resulted in a greater number of repetitions performed; however, they found no significant difference in strength gains as determined by 1RM strength measures. The study by Izquierdo et al. (41) was unique in design as it allowed for multiple comparisons over a 16 week periodized training period to include a peaking phase. The intensities utilized during the first six week cycle corresponded to the intensities used in the current study. In contrast to the results obtained by Izquierdo et al. (41), in the current study strength gains were greater with the use of intra-set rest intervals after only four weeks in the bench press exercise and approached significance after four weeks in the parallel back squat exercise while reaching significant difference by week 8. While both studies utilized the same relative intensities, it is possible the difference in training experience, as well as rest between sets (1 minute vs. 2 minutes) may account for the differing results. Although Izquierdo et al. (41) reported no difference in strength gains; we demonstrate the efficacy of not only intra-set rest intervals but not training to failure in eliciting strength gains suggesting fatigue is not a necessary stimulus for improved strength.

The rationale for training to failure suggests the performance of repetitions to failure results in a progressive recruitment of muscle fibers in accordance with the size principle as the muscle fatigues (67). Increased recruitment of muscle fibers would result in greater stimulation, particularly in the fast MHC_{IIX} fibers, which may be measured using electromyography (EMG) techniques. While the current study did not measure EMG activity, Burd et al. (14) recently demonstrated peak EMG amplitude occurred at 50% of set completion utilizing loads corresponding to 70% 1RM. Additionally, EMG activity was significantly reduced by the third set, compared to the first. Those results suggest when performing successive repetitions with loads corresponding to hypertrophic training, 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_{IIX}. This is not the case when performing with loads corresponding to a 6RM, as Keogh et al. (43) demonstrated EMG activity increased linearly to the last repetition. While EMG is unable to detect fiber type differences, it is well established fast MHC are recruited last and fatigue very quickly. Intra-set rest intervals in the current study divided the number of repetitions performed in traditional hypertrophic training by 50%. This may have resulted in greater neuromuscular activation over the performance of consecutive sets compared to continuous repetitions. The repetitive maximum activation may have resulted in the greater strength gains as demonstrated in the current study. However, further research is needed to answer this question conclusively.

Power

Our original hypothesis stating intra-set rest intervals would result in greater power output of the upper and lower body musculature after 12 weeks of training was supported in part. Intra-set rest intervals resulted in greater increases in power output over traditional hypertrophic training at the conclusion of the training cycle in both the bench press exercise and vertical jump, with an almost significant difference in parallel back squat. In the bench press, the time course of these changes showed the ALT group increased after only 4 weeks (11.1 W), while the STD group demonstrated a decrease (-19.2 W); although not significant (p = 0.155). By 8 weeks of training a significant difference was achieved with ALT group increasing 71.4 W compared to 11.3 W in STD (p = 0.002). The ALT group demonstrated an 83.0 W increase compared to the relatively moderate increase in the STD group of 33.8 (p = 0.034) over the entire training period. Additionally, when power output was evaluated using the initial load from baseline, the ALT group increased 71.0 W compared to a 13.5 W increase in the STD group (p = 0.046).

Power output of the parallel back squat followed the same trend as that of the bench press exercise demonstrating a 151.0 W increase in the ALT group by week 8 compared to 97.5 W increase in the STD group (p = 0.085). At the conclusion of training the change from baseline in power output of the parallel back squat exercise reached 282.1 W in the ALT group, while the STD group only achieved a 204.9 W increase (p = 0.059). We suggest our original hypothesis was supported only in part due to the fact the power difference in the parallel back squat exercise only approached significance. However, the effect size in the ALT group was large compared to the moderate effect size in the STD group according to the magnitude of effect size developed by Rhea (60). When power output was evaluated using baseline loads, there was no significant difference between the ALT and STD groups (129.5 W and 99.3 W; respectively). Again, the magnitude of effect size was moderate for the ALT group and only small in the STD group.

In contrast to the trends observed in both bench press and parallel back squat exercises, the difference between the two training paradigms in power output of the vertical jump took the full 12 week training phase to manifest. Once demonstrated, the difference in change from baseline and magnitude of effect size were both greater in the ALT group where an improvement of 147.7 W was produced compared to 91.6 W in the STD group ($p = 0.034$).

Haff et al. (34) originally proposed that intra-set rest intervals (termed cluster training in the original study) would allow each prescribed repetition of a set to be performed with the highest quality. Previous studies in isolated frog muscle have shown that a decrease in force is closely correlated with an increase in muscle metabolites, primarily H^+ and adenine diphosphate (ADP) (19). Similar studies have demonstrated comparable results in humans (74). In contrast to these results, Sahlin and Ren (63) demonstrated that force is not limited by high H^+ concentration, but the ability to maintain an isometric contraction, or endurance, is diminished possibly due to impaired capacity to resphosphorylate ADP. Recent investigations have demonstrated acidosis is not responsible for the decrease in force or velocity observed over the performance of continuous contractions. For a review see Allen et al. (3) A number of investigations have suggested the accumulation of inorganic phosphate (P_i) may affect velocity of shortening. Increases in P_i occur during muscle contraction, mainly from the breakdown of PCr. Models of cross bridge cycling propose P_i is released in the transition from low force weakly attached states to high force strongly attached states (3). Westerblad et al. suggested this implies that the transition to the high force states is hindered by increased levels of P_i (75). However, research examining the effects of Pi on velocity of shortening are limited (18, 20, 56).

Still another possible metabolite contributing to the decreased velocity of shortening over the performance of repeated contractions is ADP. Increases in $[ADP]_i$ have been suggested to occur during repeated contractions, coincident with PCr depletion (64). Westerblad et al. (76) demonstrated that in the fatigued state, the velocity of shortening was slower following a longer tetanus compared to a shorter contraction. The authors suggested this was due to transient increases in ADP. Partial recovery occurred in a matter of seconds thought to be due to rapid removal of ADP by enzyme action or diffusion. While the exact cause of reduced velocity of shortening is still debated (75), the current study suggests the use of intra-set rest intervals allows for a superior ability to generate power. It is therefore possible, intra-set rest intervals allowed for a partial reduction of either P_i or ADP by enzyme action or diffusion. Furthermore, the intra-set rest interval 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 (63). The truncated number of repetitions performed per set, 5 in the current study, would utilize less PCr and result in less metabolite accumulation than more traditional hypertrophic training. While not recorded, it was observed the time to complete the 5 repetitions performed by the ALT group to be approximately 10-15 seconds, while it took almost twice the time for the STD group to complete the desired number of repetitions (20-25 seconds).

Support for the superiority of intra-set rest intervals 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 to the performance of continuous repetitions has been demonstrated (49), as well as higher peak velocity in the power clean utilizing intra-set rest intervals (34). While these results support the use of intra-set rest intervals in chronic training, long term studies have demonstrated a tendency toward greater gains in power output of the lower body musculature (27, 37), as well as significantly greater gains in power output of the lower body musculature compared to the performance of continuous repetitions in athletes (41). The results of intra-set rest intervals on upper body power output is controversial, with some reporting no difference (23, 27, 41, 48) and one reporting less (22) 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 the current study and those reporting no difference or less improvement in power output of the bench press exercise may at least partially explain the divergent findings. The intensity used in the current study corresponded to loads for the development of hypertrophy (65-75%). The optimal load for the development of power has been widely studied, however, it has been demonstrated peak power occurs between 40-60% 1RM in the bench press utilizing a Smith machine (69) which was the apparatus used in the currents study. Loads in the current study were greater than those prescribed for bench press power; however, they fall closer to the desired range than intensities used in previous investigations in which no difference or less improvement was observed. Previous studies utilized loads corresponding to a 6RM or approximately 85% 1RM.

The only study to date that has utilized loads similar to the current study was conducted by Izquierdo et al.(41); however, the authors failed to demonstrate differences in power output in the initial phase of training utilizing loads corresponding to10 RM (~75% 1RM) for the bench press. While intra-set rest intervals were not the comparative goal in the study by Izquierdo et al. (41), intra-set rest intervals were utilized to prevent training to failure. Differences between the current study and that by Izquierdo et al. (41) may at least partially explain the different findings. Greater improvements in power output were not completely realized in the current study until 8 weeks of training. The initial phase in which intensity of the two studies was similar lasted only 6 weeks. Therefore, the differences in power output may not have had an opportunity to be realized. Additionally, assessment of power output by Izquierdo et al. (41) involved only the concentric action beginning from a stop position, compared to our determination which allowed a descent phase corresponding to an eccentric component.

In agreement with previous studies, we demonstrated intra-set rest intervals to be superior in the development of lower body power output compared to the performance of intra-set rest intervals. While back squat power only approached significance, the magnitude of effect size was greater for intra-set rest intervals, and when evaluated relative to lean mass significance was reached. Additionally, power output as determined by vertical jump was also greater using intra-set rest intervals. Folland et al. (27) were the first to report a tendency towards greater velocity strength gains using intra-set rest intervals in lower body exercises. Additionally, Hansen et al. (37) recently compared traditional vs. intra-set rest intervals (cluster training) on strength and power of the lower body musculature in elite rugby union players. During the first six weeks intensities corresponded to 80-95% 1RM while the last two weeks utilized heavy load jump squats (80-95% 1RM) and light to moderate ballistic jump squats performed at 0-20% 1RM. Clean pull and power clean intensities ranged from 80-95% 1RM. Intra-set rest intervals were only used in strength and power training involving squat and clean movements. Calculations of magnitude-based inference demonstrated a likely positive effect of intra-set rest intervals in peak power and peak velocity at 40 kg, and peak velocity at bodyweight during the jump squat. The authors concluded traditional style training resulted in greater strength improvements while some evidence suggests a possible benefit for intra-set rest intervals in lower body power development.

It has been demonstrated peak power occurs between 50-70% in the parallel back squat exercises utilizing a Smith machine (69). The loads in the current study fall within this range (65-75%). Izquierdo et al. (41) have been the only group to demonstrate significantly greater gains in lower body power output after long term training. Unique in design, the study by Izquierdo et al. allowed multiple comparisons in a 16 week training period corresponding to three micro-cycles using intensities associated with the development of hypertrophy, strength and power. During the first 6 weeks, 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 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 as there were no differences in training intervention during the last 5 weeks. Based on the current results and those from other studies, adaptations may have occurred during the initial few weeks of training and not been realized until the end of training.

Abdessemed et al. (1) compared the effects of different intra-set rest intervals utilizing 70% 1RM loads. The authors utilized 10 sets of 6 repetitions with the corresponding load with 1, 3 and 5 minutes rest. Results demonstrated no difference in power output between 3 and 5 minute intra-set rest intervals, while 1 minute intra-set rest interval was associated with reduced mean power output. While these results favor greater rest periods in intra-set rest intervals, they did not compare these to the traditional hypertrophic training model. The use of 1 minute intra-set rest interval in the current study provides for greater increases in power output compared to traditional hypertrophic training. Abdessemed et al. (1) have demonstrated an even greater power output can be obtained by increasing the intra-set rest interval time. However, from a practical standpoint, the use of 1 minute intra-set rest interval in the current study allowed the training time to be similar in length, whereas while greater intra-set rest interval length may provide superior results, the time to complete the training would be sufficiently extended. The length of time is of importance when designing resistance training programs, particularly to the collegiate strength and conditioning professional as time with athletes may be limited by rules and regulations.

Hypertrophy

As previously stated, few studies have reported on the effects of intra-set rest intervals in long-term training (15, 22, 23, 27, 37, 41, 48, 62) and none of these studies have reported on changes in body composition. In support of our original hypothesis, training with traditional and intra-set rest intervals resulted in similar increases in lean mass over the duration of the 12 week training program. Increases in lean mass were observed in week 4 (0.73 kg) and week 8 (1.5 kg); with no significant increase observed over the final 4 weeks (1.6 kg). In the current study, rest intervals were short and congruent with current recommendations for the development of hypertrophy (6). The use of shorter rest intervals using moderate intensities has been associated with greater acute elevations in growth hormone when compared to longer rest periods using higher intensity loads (47). However, Ahtiainen et al. (2) demonstrated that hormonal and hypertrophic response did not vary when short (2 minutes) or long (5 minutes) rest intervals were utilized in a chronic training program when volume was equated. There were no differences in total volume over the 12 week training period in either the multi-joint upper or lower body major lifts or single joint assistive lift exercises ($p > 0.05$). These data support the previous work by Ahtiainen et al. (2) demonstrating similar hypertrophic response regardless of rest intervals when volume and intensity are equated.

Contrary to our original hypothesis, no significant differences were observed between groups in changes in myosin heavy chain isoforms after 12 weeks of resistance training. Both groups experienced a significant increase in MHC_{IIA} with a concomitant reduction in MHC_{IIX}. Furthermore, a small decrease in MHC_{slow} was also observed, although when evaluating percentage change from baseline this did not reach significance. It is well established; 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_{IIX} fibers with a concomitant increase in $MH_{IIA/X}$ and MHC_{IIA} fibers (16, 28, 59). However, Liu et al. (50) 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_{slow} to MHC_{IIA}. While the training protocol in the current study did not explicitly include ballistic movements, the use of intra-set rest intervals has been shown to result in greater velocity of contraction compared to traditional resistance training (34, 36).

The differences in intensity and length of time of the current protocol and that of Liu et al. (50) may at least partially explain our divergent findings. Liu et al. (50) utilized 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 the current study was twice that of the study by Liu et al. (17), 12 weeks vs. 6 weeks, respectively. Both protocols fall within the time course of adaptations as have been previously reported, occurring in as little as 4 weeks in males (70). However, Claflin et al. (17) recently suggested that an alternative explanation must be responsible for the enhanced fiber function as a result of high-velocity training as that group 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. While Claflin et al. (17) did not directly assess changes in MHC_{IIA} and MHC_{IIX}, the results from the current study and that of Claflin et al. (17)

suggest that the increased performance evidenced as a result of high-velocity contractions may in fact result from neural adaptations (55) rather than physiological adaptations.

Practical Applications

The results from the current study support the use of intra-set rest intervals during training for muscle hypertrophy. Intra-set rest intervals resulted in greater gains in strength and power output when compared to traditional hypertrophic training. Furthermore, intra-set rest intervals produced similar gains in lean mass over the course of the training period. The length of time prescribed in the current study for intra-set rest 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 the incorporation of intra-set rest intervals in the hypertrophic phase of a traditional or non-traditional 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.

Conclusions

The purpose of this dissertation study was to determine the effects of intra-set rest intervals on performance measures and MHC adaptations after a 12 week resistance training program designed to elicit hypertrophy. The results obtained herein suggest intra-set rest intervals are superior to traditional resistance training for hypertrophy as evidenced by the greater gains in both strength and power output of the upper and lower body musculature when intra-set rest intervals were utilized. Furthermore, intra-set rest intervals resulted in the same physiological adaptation in MHC and body composition, further demonstrating the advantage of using intra-set rest intervals in hypertrophic training.

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APPENDIX A

CONSENT FORM

CONSENT FORM
Effects of Altering Rest to Work Ratio in a Hypertrophic Training Program

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. If you decide to participate in this study, this form will also be used to record your consent.

You have been asked to participate in a research project studying the effect of altering the rest to work ratio in a standard hypertrophic resistance training protocol. The purpose of this study is to determine if altering the rest to work ratio as well as sets and repetitions impacts strength, power, and muscle mass. You were selected to be a possible participant because you informed the researchers you were a healthy male between the ages of 20 and 40 and have been resistance training for at least 2 years and have informed researchers that you:

1. Do not have any metabolic disorders including known electrolyte abnormalities; heart disease, arrhythmias, diabetes, thyroid disease, or hypogonadism;
2. Do not have a history of hypertension, hepatorenal, musculoskeletal, autoimmune, or neurologic disease;
3. Do not have any bleeding disorders
4. Are not taking thyroid, anti-hyperlipidemic, hypoglycemic, anti-hypertensive, anti-inflammatory (these include any corticosteroids, i.e. cortisone, or any over the counter non steroidal anti-inflammatory medications which includes medications containing aspirin, ibuprofen contained in Advil and Motrin, or naproxen contained in Aleve) or androgenic medications;
5. Have not taken ergogenic levels of nutritional supplements that may affect muscle mass (e.g., creatine, HMB), insulin-like substances, or anabolic/catabolic hormone levels (DHEA, etc.) within six months prior to the start of the study and/or creatine naïve ideally.

This study is being sponsored/funded by the National Strength and Conditioning Association.

What will I be asked to do?

If you agree to participate in this study, you will be asked to record all food ingestion on food record forms for four days (4-d) for the entire duration of the study. You will be asked to attend a familiarization session in which you will be shown exercises that you will be asked to complete during testing and training.

Baseline Testing

You will be weighed, have your body composition measured using dual energy x-ray absorptiometry, and have your one repetition maximum determined on a smith machine for both the back squat and bench press. You may then be asked to participate in a pilot study looking at the muscle activity during two different training sessions. If you are asked to participate in pilot testing, you will return to the laboratory after strength testing and perform the back squat and bench press at a percentage of your maximum while having your muscle activity recorded via electrodes placed on your skin. One week later you will be asked to return to the laboratory and do the same workout again with a different set and repetition scheme.

After pilot testing, you will be asked to participate in strength and power testing as well as body weight and body composition testing. Testing will take place over two days and will be separated by at least 48 hours. You will also be asked to provide a muscle sample from your leg muscle for us to determine your fiber composition. Muscle biopsies will be obtained using the Bergstroem technique (2 biopsies during the study), which involves a ¼ incision on the skin and the use of a 5mm biopsy needle. Local anesthetic will be used prior to incision and biopsy. Percutaneous muscle biopsies (50-70 mg) will be obtained from the middle portion of the vastus lateralis muscle (thigh muscle covering the outermost portion of the front of the leg) of one leg at the midpoint between the knee and hip joint at a depth between 1 and 2 cm. For the remaining biopsy, attempts will be made to extract tissue from approximately the same depth and area as the initial biopsy by using the pre-biopsy scar, depth markings on the needle, and a successive incision that will be made approximately 0.5 cm to the former from medial to lateral. All these procedures will be conducted again at the conclusion of the training program. Prior to beginning training, you will also have a small amount of blood drawn (approximately 20 ml).

Training Program

You will then be asked to participate in a training program designed to increase lean mass. You will be asked to train four times a week for 12 weeks. Your training sessions will be supervised by trained personnel. You will have your body composition, strength and power tested every fourth week of the study for a total of 4 times (including pre and post). You will also be asked to drink a nutritional supplement that is commercially available at the end of every workout.

You will also have a small amount of blood drawn from your arm (approximately 20 ml) three times during the 3rd, 7th, and 11th week corresponding to 24, 48 and 72 hours after your last workout to test for markers of muscle damage. Training will last approximately 1 hour 4 times per week. The total time involved in this study is approximately 14 weeks.

What are the risks involved in this study?

The risks associated with this study are you will be in contact with a very low level of radiation during body composition testing. This is a standard procedure for the measurement of body composition and the level of radiation is similar to that experienced in a flight from Houston to Dallas on a commercial airline. The exercise tests that will be performed may cause symptoms of fatigue, shortness of breath, and/or muscular fatigue/discomfort. The exercise tests may also cause short-term muscle soreness and moderate fatigue for several days following the tests. The exercise tests will be performed by trained personnel and monitored to ensure appropriate compliance. Risks associated with blood sampling include minor discomfort at puncture site and possible bruising. There is a slight risk of contracting an infection, however, only trained phlebotomist will be performing blood sampling using previously approved sterilization procedures.

The biopsy procedure carries the risk of the following complications which include sores (100%), infection (<1%), and permanent numbness (<<1%). Additional risks include discomfort, bleeding and possible scarring at biopsy site. If problems occur as a result of biopsy procedure please contact Jonathan Oliver (214)649-3887 24 hours a day.

What are the possible benefits of this study?

The possible benefits of participation are you will receive a comprehensive body composition analysis, dietary analysis, as well as an assessment of your current strength and power based on standard athletic testing procedures. You will also receive information regarding your current muscle status and composition as well as a training program known to increase muscle size.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University being affected.

Will I be compensated?

You will receive $25 for each biopsy obtained. Disbursement will occur at the conclusion of individual testing.

Who will know about my participation in this research study?

This study is confidential. The records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only researchers within the Exercise and Sports Nutrition Laboratory will have access to the records.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Jonathan Oliver, (214)649-3887, joliver@hlkn.tamu.edu .

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979)458-4067 or irb@tamu.edu.

Signature

Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in this study.

Signature of Participant: ________________________________ Date: _____________

Printed Name: ____

Signature of Person Obtaining Consent: ______________________Date: _____________

Printed Name: ____

APPENDIX B

PERSONAL INFORMATION WORKSHEET

PERSONAL INFORMATION WORKSHEET

Texas A&M University
EXERCISE & SPORT NUTRITION LABORATORY

Personal Information

Name:
____

Address:
____

City: ______________ State: ______ Zip Code ______ SS# ________________

Home Phone: (___) ________________ Work Phone: (___) ________________

Beeper: (___) ________________ Cell Phone: (___) ________________

Fax: (___) ____________ E-mail address:______________________

Birth date: _____ / _____ / ______ Age: ______ Height: __________ Weight: __________

Exercise History/Activity Questionnaire

1. Describe your typical occupational activities.

2. Describe your typical recreational activities

3. Describe any exercise training that you routinely participate.

4. How many days per week do you exercise/participate in these activities?

5. How many hours per week do you train?

6. How long (years/months) have you been consistently training?

APPENDIX C

MEDICAL HISTORY QUESTIONNAIRE

MEDICAL HISTORY QUESTIONNAIRE

Texas A&M UNIVERSITY

EXERCISE & SPORT NUTRITION LABORATORY

Medical History Inventory

Directions. The purpose of this questionnaire is to enable the staff of the Exercise and Sport Sciences Laboratory to evaluate your health and fitness status. Please answer the following questions to the best of your knowledge. All information given is **CONFIDENTIAL** as described in the **Informed Consent Statement.**

Name:______________________________ Age _____Date of Birth_______________

Name and Address of Your
Physician:____

MEDICAL HISTORY

Do you have or have you ever had any of the following conditions? (Please write the date when you had the condition in the blank).

____Heart murmur, clicks, or other cardiac findings?
____Asthma/breathingdifficulty?
____ Frequent extra, skipped, or rapid heartbeats?
____Chest Pain of Angina (with or without exertion)?
____High cholesterol?
____Diagnosed high blood pressure?
____Heart attack or any cardiac surgery?
____Leg cramps (during exercise)?
____Chronic swollen ankles?
____Varicose veins?
____Frequent dizziness/fainting?
____Muscle or joint problems?
____High blood sugar/diabetes?
____Thyroid Disease?
____Low testosterone/hypogonadism?
____Glaucoma?
____Bleeding Disorders

____Bronchitis/Chest Cold?
____Cancer, Melanoma, or Suspected Skin Lesions?
____Stroke or Blood Clots?
____Emphysema/lung disease?
____Epilepsy/seizures?
____Rheumatic fever?
____Scarlet fever?
____Ulcers?
____Pneumonia?
____Anemias?
____Liver or kidney disease?
____Autoimmune disease?
____Nerve disease?
____Psychological Disorders?

Do you have or have you been diagnosed with any other medical condition not listed?

____

____

Please provide any additional comments/explanations of your current or past medical history.

____

____

Please list any recent surgery (i.e., type, dates etc.).

____

____

List all prescribed/non-prescription medications and nutritional supplements you have taken in the last 3 months.

____

____

What was the date of your last complete medical exam?

____

____

Do you know of any medical problem that might make it dangerous or unwise for you to participate in this study? (including strength and maximal exercise tests) ____ If yes, please explain: _________________

____

____

Recommendation for Participation (for ESNL use only):

_____ No exclusion criteria presented. Subject is ***cleared*** to participate in the study.
_____ Exclusion criteria is/are present. Subject is ***not cleared*** to participate in the study.

Signed: ____________________________________ Date: _______________________

APPENDIX D

POWER TESTING FORM

TIMEPOINT: (circle)

Name: ______________________ **1 2 3 4**

NOTE: USE FEET AND HAND PLACEMENT TAKEN AT T1 FROM STRENGTH FORM

Procedure: Have subject perform warm up and vertical jump test. Followed by 3 sets 5 reps 40-50% 1RM, then test 3 sets for maximum power with 2 min rest between. If 3rd average power greater than set 1 and 2, another set is allowed.

BS1RM (lbs)	400
40% (lbs)	160
50% (lbs)	200
60% (lbs)	240
60% (kgs)	109
T1 BS1RM	245
60% ABS	145
60% ABS (kgs)	66

Relative (60% 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)					
average velocity (m/s)					
peak power (watts)					
peak velocity (m/s)					

Absolute (60% T1 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)					
average velocity (m/s)					
peak power (watts)					
peak velocity (m/s)					

BP1RM (lbs)	220
40% (lbs)	90
50% (lbs)	110
60% (lbs)	130
60% (kgs)	59
T1 BP1RM	205
60% ABS	125
60% ABS (kgs)	57

Relative (60% 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)					
average velocity (m/s)					
peak power (watts)					
peak velocity (m/s)					

Absolute (60% T1 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)					
average velocity (m/s)					
peak power (watts)					
peak velocity (m/s)					

APPENDIX E

STRENGTH TESTING FORM

Name: ____

Squat feet placement (measured at T1 only)

left foot heel (measured from right) 16.5

right foot heel (measured from right) 16.5

left foot outside (measured from top) 35.5

right foot outside (measured from top) 10

90 degrees 13

Bench hand placement (measured at T1 only)

distance between hands 24

	T1	**T2**	**T3**	**T4**
Date:	__________	__________	__________	__________

Estimate 1RMBS	405
Estimate 1RMBP	265
Estimate 1RMLP	0

Back Squat

Reps	Resistance	%Old 1RM	Achvd Reps
5	162	40%	__________
5	203	50%	__________
5	243	60%	__________
(2-3)	284	70%	__________
(2-3)	324	80%	__________
1	365	90%	__________
1	385	95%	__________

Leg Press

Reps	Resistance	%Old 1RM	Achvd Reps
5	0	40%	__________
5	0	50%	__________
5	0	60%	__________
(2-3)	0	70%	__________
(2-3)	0	80%	__________
1	0	90%	__________
1	0	95%	__________

Bench Press

Reps	Resistance	%Old 1RM	Achvd Reps
5	106	40%	__________
5	133	50%	__________
5	159	60%	__________
(2-3)	186	70%	__________
(2-3)	212	80%	__________
1	239	90%	__________
1	252	95%	__________

APPENDIX F

VERTICAL JUMP FORM

TIMEPOINT: (circle)

Name: ______________________________ **1 2 3 4**

Procedure: Have subject perform warm up and vertical jump test. Three attempts, if third is better than first and second, then they get another go. Max of 5 jumps.

Weight (lbs) ____________

Weight (kgs) ____________

Reach Height (in) ____________

Jump Height (in)

1st Attempt ____________

2nd Attempt ____________

3rd Attempt ____________

4th Attempt ____________

5th Attempt ____________

Best Jump (Jump height - Reach height)

____

VITA

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