

Effects of Different Weight Training Exercise/Rest Intervals on Strength, Power, and High Intensity Exercise Endurance

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Reference Data

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ABSTRACT

This study investigated the effects of a high volume 5-wk weight training program and different exercise/rest intervals on measures of power, high intensity exercise endurance (HIEE), and maximum strength. Subjects, 33 weight trained men (M age 20.4 ± 3.5 yrs), were divided into 3 equal groups. The groups used the same exercises and set-and-repetition scheme. Rest intervals were 3 min for Gp 1, 1.5 min for Gp 2, and 0.5 min for Gp 3. Pre/post changes were analyzed using $G \times T$ ANOVA. Peak power, average peak power, and average total work, as measured during 15 five-sec cycle max-effort rides and the 1-RM squat, increased significantly ($N = 33$, $p < 0.05$). The vertical jump and vertical jump power index did not show a statistically significant change. The 1-RM squat increased significantly more in Gp 1 (7%) than in Gp 3 (2%). Data suggest that, except for maximum strength, adaptations to short-term, high-volume training may not be dependent on the length of rest intervals.

Key Words: exertion, squat, total work

Introduction

Increasing endurance is generally deemed an important consideration in the development of training programs for strength/power sports such as football. Although other factors such as speed of movement, maximum strength, and maximum power output appear to be more important, the ability to sustain high intensity exercise must also be considered when evaluating and developing the performance characteristics of strength/power athletes (1).

High intensity exercise endurance (HIEE) concerns the ability to sustain or repeat maximum or

near maximum power output, largely through anaerobic mechanisms (1, 14). Weight training (≤ 12 reps per set) has been shown to generally increase various modes of exercise endurance (8, 9, 14, 20), especially as the intensity of the exercise increases (8, 19). Therefore a typical weight training protocol may have its greatest effects on HIEE (8, 14). Studies and reviews suggest that higher repetitions per set (8 to 12 reps per set) and multiple sets generally do more for HIEE and body composition than fewer reps per set, or using only one set per exercise (3, 4, 14, 19). Thus high volume weight training protocols produce greater gains in HIEE than low volume protocols.

Short rest periods between sets have also been believed to enhance HIEE (3, 19, 23). This belief has led many strength and conditioning specialists to suggest the use of short rest periods when trying to improve HIEE. Thus short rest period priority weight training programs, or circuit weight training that employs short rest periods, have been developed (19). Typically these programs have been used during the preparation phase of a periodized training program or during other short periods of training such as football winter workouts (19, 22). However, no studies have examined the effects on HIEE of different rest periods between sets.

The purpose of this study was to examine the effects of rest interval manipulation on weight-training-induced alterations on measures of body composition, maximum strength, vertical jump height (VJ), a vertical jump power index (VJPI), and measures of cycle power and high intensity exercise endurance over a 5-week period.

Methods

The volunteer subjects were 33 moderately trained college age men (20.4 ± 3.5 yrs, 80.2 ± 12.0 kg). Each had to be able to squat at least 1.3 times body mass and had to be already participating in a weight training program. The subjects were assigned to 3 groups, 11 in each, with no initial differences between groups in the means for any variable. Group 1 used a 180-sec

rest period between sets, Group 2 used a 90-sec rest period, and Group 3 used a 30-sec rest period.

Training was conducted 4 days a week for 5 weeks. The exercises consisted of major lifts focusing on increasing leg and hip strength and power. Major exercises, those involving large muscle mass, were performed for 5 sets of 10 reps after light and moderate warm-up sets. Assistance exercises, those involving small muscle mass, were performed for 3 sets of 10 reps. This protocol (see below) was employed because of its similarity to many programs used during the preparation period of the training for various sports and winter workouts for football.

- Sunday and Wednesday
 - Squats*
 - Push press*
 - Bench press
 - Straight-leg deadlifts
 - Crunches
- Monday and Thursday
 - Clean pulls from midthigh*
 - Power snatch*
 - Shoulder shrugs
 - Bentover rows
 - Crunches

5 weeks: sets of 10 repetitions

*Major exercises

- 1 × 10 Low (40–45% 1-RM)
- 1 × 10 Med (45–50% 1-RM)
- 5 × 10 High (5 × 10-RM)

Assistance exercises

- 3 × 10-RM

In view of each subject was a large clock with a sweep hand to help him maintain the appropriate rest period. Two investigators were present at every training session to assure compliance with the rest period protocols. Target sets were performed with the same weight for each set. Increases in training weight were adjusted carefully to ensure that the subjects could complete the required sets and repetitions. If a subject was perceived to be using too little weight, adjustments were made. Each subject maintained a training log indicating the repetitions made and the weight used per set. The logs were used to calculate the training intensity (average mass used), relative intensity (% of initial 1-RM), and volume load (repetitions × mass lifted).

Body mass was measured on a medical scale to the nearest 0.1 kg. Body composition measurements were skinfolds and girths. Skinfolds were taken from the right side at the triceps, subscapular, abdominal, suprailiac, and thigh. Girth measurements were taken at the chest (mid and full inspiration), waist, right upper arm (relaxed and flexed/contracted), and right thigh. Skinfolds and girths were taken by an experienced tester at the same anatomical point for pre- and postmeasurements (19).

Vertical jump height (VJ) was measured using a VJ board marked in centimeters (19). A vertical jump power index (VJPI) was calculated using the Lewis formula ($2.21 \times \text{body mass} \times \sqrt{\text{VJm}}$) (19). The VJPI can be converted to an estimated power output (EVJP) by multiplying the VJPI by the approximate acceleration of gravity ($9.8 \times \text{VJPI} = \text{EVJP}$). The 1-RM parallel squat was tested using the procedures described by Stone and O'Bryant (19).

Power and measures of high intensity exercise endurance were tested on a cycle ergometer (Monark 680) fitted with electromagnetic switches and interfaced with an Apple GS II computer. Power and work analyzation samples were collected every half pedal crank revolution with a sample resolution of 4 ms. Pilot studies have shown the test-retest reliability for work and power to be $R > 0.90$ for this system. The subjects performed 15 five-sec rides with 50 sec between rides. Resistance for the test was set at $0.1 \text{ kg} \times \text{body mass}$. The subjects were encouraged to make an all-out maximum effort on each ride. This test of power and HIEE was chosen because of its similarity to sports such as football, in which this type of high intensity intermittent activity is common. The cycle tests were analyzed for peak power (PP), average peak power (APP 15), average power (AP), total work (TW), and average total work performed (ATW 15). These variables are defined as follows:

- Peak power: highest power at any ride
- Average peak power: sum of peak powers divided by 15 (peak power averaged across 15 rides)
- Average power: average power output at each ride
- Total work: amount of work accomplished at each ride
- Average total work: sum of work at each ride divided by 15 (total work averaged across 15 rides).

The highest value for PP, AP, and TW typically occurred during the second ride.

All subjects were familiarized with the tests approximately 1 week before the experiment began. Tests were performed at Week 0 (T1) and at the end of 5 weeks (T2). Data were analyzed with a $G \times T$ (group × trials) ANOVA. Interactions were analyzed on pre/post change scores using a t test. Pearson product moment correlations were performed; the alpha level was $p \leq 0.05$. Estimates of statistical power suggest that the subject number was adequate (2).

Results

The 1-RM squat increased significantly across time for the combined groups. There was a significant interaction for the 1-RM squat showing that Gp 1 increased more (7%) than Gp 3 (2%) across the 5 weeks (Table 1).

Table 1
Performance Variables ($M \pm SD$)

Groups		Squat (kg)		V jump (cm)		VJPI ($\text{kgm} \cdot \text{sec}^{-1}$)		EVJP (W)	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
1	Pre	124	27	51	8	129	14	1264	137
	Post	133	29	53	8	133	22	1303	215
2	Pre	120	23	57	10	132	23	1294	225
	Post	127	22	58	8	133	20	1303	196
3	Pre	125	24	56	7	134	21	1313	205
	Post	128	24	56	8	132	21	1294	205

Note. Signif. time effect, $p \leq 0.05$, for the squat; signif. interaction, $p \leq 0.05$, for the squat (Gp 1 > Gp 3). VJPI: vertical jump power index; EVJP: estim. vert. jump power.

Table 2
Cycle Performance Variables ($M \pm SD$)

Groups		Peak power (W)		Avg power (W)		Avg tot. work (J)	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
1	Pre	1016	220	906	190	4022	866
	Post	1071	207	950	162	4327	755
2	Pre	1113	183	956	165	4163	744
	Post	1143	165	992	145	4424	661
3	Pre	1045	218	911	225	4003	1002
	Post	1170	154	1006	122	4479	658

Note. Signif. time effect, $p < 0.05$, for all variables.

VJ and VJPI did not increase significantly across time or in any group (Table 1).

The pre/post cycle variable curves for each group were parallel. Analysis of PP, AP, and TW in Ride 2 compared to Rides 14 and 15 showed significant decreases. However, the changes in PP, AP, and TW from Ride 2 to Rides 14 and 15 did not differ significantly between groups.

Peak power, APP 15, and ATW 15 increased significantly across time for the combined groups. No interactions occurred (Table 2). Peak power, AP, and TW accomplished for each of the 15 cycle rides are shown in Figures 1, 2, and 3, respectively ($N = 33$). Correlations between the 1-RM squat and peak power, APP 15, and ATW 15 were all statistically significant and are shown in Table 3.

Training variables are shown in Table 4. Training intensity, relative intensity, and volume load increased significantly over time. The relative training intensity (% 1-RM) was significantly greater for Gp 1 than for Gp 3 each week. No significant differences in body

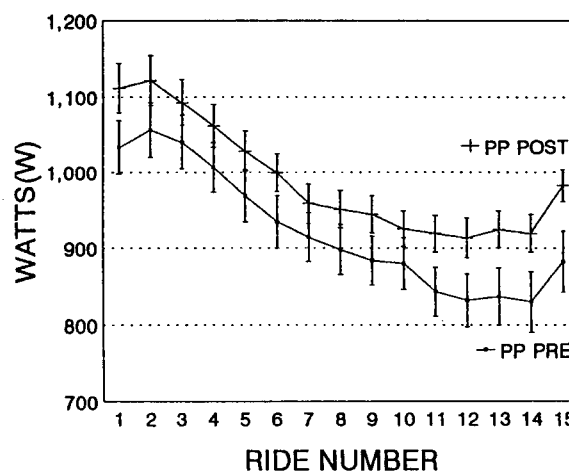


Figure 1. Peak power changes across rides, $M \pm SEM$.

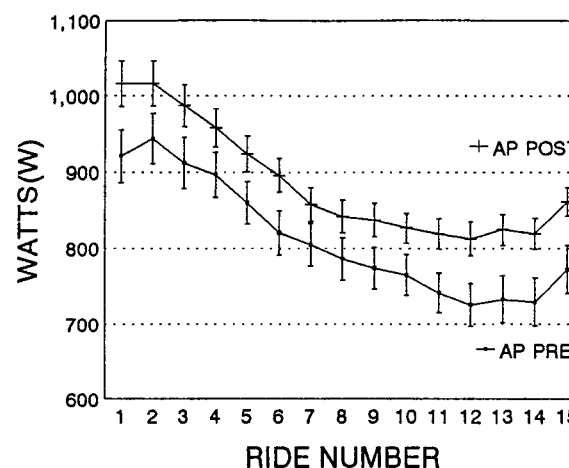


Figure 2. Average power changes across rides, $M \pm SEM$.

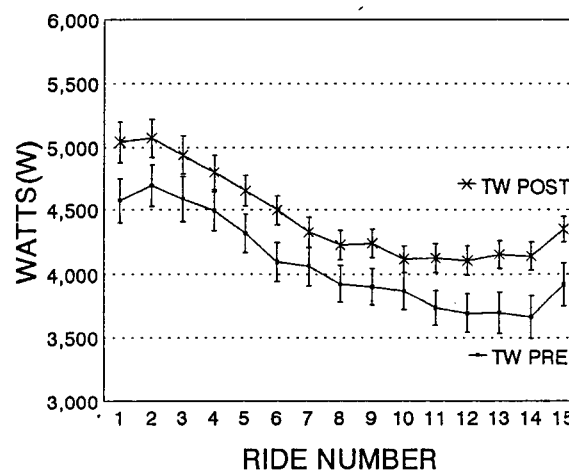


Figure 3. Total work across rides, $M \pm SEM$.

Table 3
Correlations Between 1-RM Squat & Cycle Variables

	Peak power	APP 15	ATW 15
Pre	0.62	0.67	0.64
Post	0.74	0.72	0.75

Note. All correlations signif. at $p \leq 0.05$.

APP 15: sum of peak powers for all 15 rides; ATW 15: sum of avg work for all 15 rides.

Table 4
Squat Training Intensity, Relative Intensity, & Volume Load

Week		Gp 1		Gp 2		Gp 3	
		M	SD	M	SD	M	SD
1	Intensity	73	17	62	11	59	17
	Rel. inten	58	5	52	4	47	6
	Vol. load	3622	837	3089	572	2875	614
2	Intensity	73	18	64	11	59	11
	Rel. inten	58	6	54	5	47	2
	Vol. load	3643	902	3210	561	2956	565
3	Intensity	76	19	69	13	61	11
	Rel. inten	60	6	58	6	49	2
	Vol. load	3779	971	3456	622	3057	537
4	Intensity	77	17	71	12	64	13
	Rel. inten	63	7	60	7	51	4
	Vol. load	3850	865	3561	635	3189	639
5	Intensity	80	17	72	12	66	15
	Rel. inten	64	9	61	9	53	5
	Vol. load	3974	851	3620	631	3313	741

Note. Signif. time effect, all variables; signific. rel. intensity group effect, Gp 1 > Gp 3.

mass, individual skinfolds, or girths were noted between groups (Table 5). A 5% nonsignificant decrease in sum of skinfolds was noted across time ($N = 33$, $p < 0.06$).

Discussion

Generally it has been recognized that to maximize increases in strength through weight training, one needs sufficient rest between sets (3, 4, 19). Even though the protocol for this study was not optimal for increasing maximum strength, the resulting data support the concept that longer rest periods are more likely to lead to greater increases in maximum strength than shorter rest periods (Table 1). Reviews of the literature (3, 4, 19) have repeatedly pointed out the importance of intensity and relative intensity of training in eliciting increases in performance, especially as it concerns maximum strength; total work accomplished appears to be secondary.

Table 5
Body Mass & Body Composition

Groups		Body mass (kg)		Sum of skinfolds (mm)	
		M	SD	M	SD
1	Pre	82.2	14.5	93.5	47.5
	Post	82.7	15.0	90.8	44.7
2	Pre	78.2	8.7	88.3	34.1
	Post	78.4	8.0	82.3	33.4
3	Pre	80.2	12.8	89.7	38.9
	Post	79.6	13.0	85.0	38.4

Although the program was not optimum for maximum strength increases, the longer rest periods for Gp 1 allowed that group to use greater intensities and significantly greater relative intensities (% initial 1-RM) compared to Gp 3. Since Gp 2 used intensities and relative intensities between those of Groups 1 and 3, their maximum strength gains were also between those of the other two groups. The data in Table 4 suggest there is a rest period continuum, with strength gains increasing as rest periods are lengthened, which in turn is related to the relative training intensity.

Recovery of ATP requires 3 to 5 min, and CP recovery occurs within 8 min (6, 10) and likely influences subsequent exercise intensity. High intensity exercise results in lactic acid (H^+ and La^-) accumulation and can disturb the concentration difference between Na^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , and other anions such as proteins and phosphate ions (strong ion difference), resulting in a lowered intracellular pH (11, 13). These disturbances can contribute to muscle fatigue (11, 13). Shorter rest periods of 1 min or less between sets can produce marked increases in serum lactate, indicating a lowered intra- and extracellular pH and an ion disturbance (5, 12). The time needed for cellular lactate ion and H^+ efflux has been shown to be 4 to 10 min (7, 18). Because of the high intensity exercise afforded by multiple sets of 10 reps, a 30-sec rest period may not be long enough to neutralize the intracellular effects of ion and pH disturbance. The optimum rest period length, yet to be determined, likely depends on the type of exercise, number of repetitions per set, and other factors.

Previous research (19) has shown that strength training can improve VJ and VJPI. Thus it is somewhat surprising that no significant difference occurred in VJ or VJPI in the present study. There may be two reasons for this: (a) the subjects were moderately trained and, as a group, already had a higher than average initial VJ and VJPI (based on results from our lab); (b) the program was designed to increase HIEE, not maximum strength, VJ, or VJPI, thus improvement would not have been marked.

Weight training caused a significant increase in cycle peak power (6.6%), APP 15 (6.0%), and ATW 15 accomplished over the 15 rides (8.5%), independent of rest period length. There was no apparent relationship between changes in maximum strength (1-RM squat) and changes in peak cycle power, APP 15, and ATW 15 as a function of group. This does not mean maximum strength was not a factor; there were relatively strong correlations ($N = 33$) between the 1-RM squat and cycle variables. These correlations also showed an increase across time, suggesting that the relationships were stronger at T2 than T1 (Table 3).

Medbø and Burgers (16) provide evidence that both peak power and anaerobic capacity can be enhanced in the same training program. In this study both peak power and measures of cycle HIEE (APP 15 and ATW 15) increased. Exposure to high lactates can improve buffering capacity and result in greater anaerobic capacity (16, 18). Increased buffering/anaerobic capacity could improve HIEE (14).

Increases in lactate concentrations as a result of weight training exercise depend on the size of the muscle mass involved, number of repetitions per set, relative intensity of exercise, and rest interval between sets (12, 15, 17, 21). Although not measured in the present study, previous work with similar weight training protocols has produced blood lactate concentrations of 5–7 mMol $\cdot$ L⁻¹ for long rest periods between sets (3 min), and 9–14 mMol $\cdot$ L⁻¹ for short rest periods between sets (≤ 1 min) (12, 15, 21). Based on the possibility of increased buffering and anaerobic capacities as a result of exposure to high lactates, we might expect shorter rest periods to better enhance measures of cycle HIEE. However, this was not the case, suggesting the following possibilities:

1. Higher blood lactates from shorter rest periods are not necessary to produce increased buffering capacity/anaerobic capacity. Thus the lactate concentrations afforded by the 3-min rest periods were sufficient for adaptation.

2. The higher training intensities associated with longer rest periods offset the higher lactates associated with short rest periods. This agrees with the observations of Medbø and Burger (16) that different intensities of sprint training can produce similar increases in anaerobic capacity in 6 weeks, and that the anaerobic capacity is closely related to the peak rate of energy release. Additionally, Wilmore et al. (23) suggest that, given enough weight training volume, the intensity of exercise is the most important factor in improving both strength and endurance.

3. Five weeks is not long enough to produce group differences in lactate buffering/anaerobic capacity or measures of HIEE.

4. Other mechanisms such as neural factors, maximum strength, or increased muscle glycogen stores are more important in enhancing measures of cycle HIEE compared to changes in buffering/anaerobic capacity as a result of weight training (14).

Reviews of the literature suggest that high repetitions per set produce greater gains in HIEE than do low repetitions per set (3, 4, 19). McGee et al. (14) have shown that compared to low volume loads, large volume loads (volume load = repetitions $\times$ mass) consisting of multiple sets have a greater effect in increasing both specific and nonspecific HIEE. The present study suggests that rest period length is not strongly related to increasing measures of cycle HIEE over 5 weeks, and that the intensity of the exercise may influence measures of HIEE as well as maximum strength.

The results of the present study, and those of McGee et al., suggest that the best way to increase HIEE while maintaining or increasing maximum strength through weight training may be to add sets (as long as the training intensity is maintained or increased) rather than to shorten the rest periods. It should also be noted that the present study may have yielded a different result if the measurement of HIEE had been a continuous test to exhaustion rather than an intermittent test. However, the ideal rest period for optimum changes in any performance variable has not yet been determined.

Reviews of the literature suggest that weight training of sufficient volume can reduce % fat and total fat and can increase lean body mass (3, 19). Although not significant ($p = 0.06$) in this study, the trend for changes in skinfolds was in the anticipated direction (Table 5).

Practical Applications

Greater increases in peak power or HIEE related variables such as total work accomplished might have occurred if the test variables had been more mechanically specific to the training mode (i.e., weight training exercise). However, previous research suggests that weight training using moderately trained subjects does have a considerable transfer of training effect to cycle ergometry (14). Furthermore, transfer of training effect to nonspecific testing modes is an important factor since different types of athletes use weight training to improve their performance.

Figures 1, 2, and 3 show the changes in cycle ergometry variables (PP, AP, and TW) over all 15 rides from T1 to T2 ($N = 33$). These figures are essentially parallel lines and show that peak power, average power, and total work accomplished were enhanced at each of the 15 posttraining rides. This is important in that it suggests more power is available even after considerable fatigue is evident. Assuming for example that weight training would transfer to football performance in a manner similar to that noted with cycle ergometry in the present study, the data suggest that power may be available on the 15th play.

The present study indicates that, during a 5-week high-volume weight training program designed to improve endurance, the length of rest period intervals does not influence measures of HIEE among moderately trained subjects. On this basis it appears that

shorter rest periods may speed up workouts. However, short rest periods (30 sec) can reduce gains in maximum strength, and likely power as well. In our study the 2 subjects in Gp 3 with the best 1-RM squats and VJs showed 10-kg decreases and 1-cm losses, respectively, over the 5-week period. This type of change was not noted in any subject in the other two groups.

The information provided in the present study suggests that weight training programs with short rest periods, such as circuit training, are not optimal for producing increases in all three variables (1-RM strength, power, and HIEE). Thus, during high volume programs, intensity of exercise can be optimized by allowing longer rest periods of 1.5 to 3 min. Additional sets per exercise may be a better way to enhance endurance. This will allow greater gains, or better maintenance of maximum strength and power, while optimizing gains in HIEE.

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