Journal of Strength and Conditioning Research, 2004, 18(3), 513–517

THE EFFECT OF HIGH-LOAD VS. HIGH-REPETITION TRAINING ON ENDURANCE PERFORMANCE

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ABSTRACT. Ebben, W.P., A.G. Kindler, K.A. Chirdon, N.C. Jenkins, A.J. Polichnowski, and A.V. Ng. The effect of high-load vs. high-repetition training on endurance performance. *J. Strength Cond. Res. 18(3):513–517. 2004.*—The purpose of this study was to compare the effects of high-load (H-load) periodized resistance training and high-repetition (H-rep) reverse step loading periodized resistance training on endurance performance. Twenty-six female university rowers (age = 20 ± 1 year) were randomly assigned to H-load (5 novice, 8 varsity) or H-rep (7 novice, 6 varsity) groups. Subjects were pre- and posttested using a 2,000-m rowing ergometer test. Outcome variables included $\dot{V}O_2$ peak, time to test completion, total power, average power per stroke, total number of strokes, stroke rate, and body mass. Subjects trained for 8 weeks using identical exercises. Varsity rowers who performed H-load training demonstrated greater improvement compared with those who performed H-rep training. Novice rowers who performed H-rep training demonstrated greater improvement compared with those who performed H-load training. High-load periodized training appears to be more effective for athletes with advanced training status, and H-rep reverse step loading periodized training is more effective for those who are relatively untrained.

KEY WORDS. aerobic, strength, crew, rowing, periodization

INTRODUCTION

Improved endurance performance apparently requires increased aerobic capacity and strength. For anaerobic sports, the role of high-load (H-load) resistance training for improving strength and athletic performance is well established. Some evidence suggests that H-load resistance training may improve aerobic performance as well (11–13, 15, 23, 24). However, high-repetition (H-rep) resistance training may be best for muscle endurance (1, 2) and aerobic or endurance sports (4). Questions remain about whether H-load or H-rep resistance training is the best method of training for endurance sports, with few studies comparing the benefits of these types of training for female athletes or rowing (3, 7, 22).

High-load resistance training is useful for improving endurance performance. In training studies using 3 sets of 5 repetition maximum (RM) or 3 sets of 6RM, H-load resistance training improved cycle ergometer performance and leg strength with no change in muscle cross-sectional area or $\dot{V}O_2$ (11) and running economy (15), respectively.

Running economy, muscular power, and 5-km running performance can also be enhanced with the addition of explosive strength training, sprint training, and plyometrics, with no concurrent change in $\dot{V}O_2$max (24). Resistance training with loads of 85–100% of 1RM performed with rapid actions improves endurance performance (23). It is possible that H-load resistance training and high-speed muscle actions each play a role in endurance performance (11, 13, 15, 23, 24). While evidence suggests that H-load resistance training improves endurance performance, questions remain about the potential effectiveness of H-rep resistance training.

Research evaluating the effect of H-rep resistance training is limited. Reverse step loading, characterized by decreasing loads and increasing repetitions throughout the periodized program, has been recommended for endurance athletes (2). Other sources recommend training with sets of 12–40 repetitions for improving muscular endurance (1, 2).

Successful rowing performance requires high aerobic capacity (5, 8, 9, 19, 29) and strength (14, 25, 27). Both strength and aerobic capacity of rowers can be improved when resistance training is performed concurrently with conditioning (3). Research evaluating resistance training for rowers has compared traditional resistance training protocols to other training methods, such as partner resistance exercises or modified proprioceptive neuromuscular facilitation trunk strengthening patterns, focusing on their effect on functional rowing performance (7, 22). No significant differences were observed between training groups in either study (7, 22). No previous research has compared the effectiveness of H-load versus H-rep resistance training for endurance sports such as rowing. The purpose of this study was to compare the effects of a periodized H-load resistance training program and an H-rep reverse step loading periodized resistance training program on 2,000-meter rowing ergometer performance measures of female collegiate rowers. This study also evaluated the response of varsity and novice rowers to each program design variation.

METHODS

Experimental Approach to The Problem

This study was designed to determine the effects of 8 weeks of high-load traditionally periodized training compared with a reverse step loading periodized resistance training program. Independent variables in this study included sets, repetition scheme, load (volume) and organization of the sets, repetition, and volume over time (3). Time to test completion was the primary sport-specific performance variable. We measured strength associated variables, total power and average power per stroke, total number of strokes, and stroke rate to gain insight into how performance may have changed as the result of a particular resistance protocol. Because aerobic capacity is

Table 1. Resistance training exercises performed by all subjects.

Monday	Wednesday	Friday
Power pull	Dumbbell squat jumps	Power pull
Squat	Walking lunge	Deadlift
Seated row	Horizontal dumbbell row	Horizontal + 20 degrees dumbbell row
Stiff leg dead lift	Shoulder raises–3 planes	Single leg deadlift
Resisted back extension with twist	Push press	Bench press
Lat pull-down	Resisted lateral flexion	Resisted back extension

an important performance determinant in rowing we also measured $\dot{V}O_2$ peak. All dependent variables were assessed prior to and after the training protocols.

Subjects

Subjects included 26 female rowers who were part of the Marquette University crew team. Historically, these rowers have placed in the top 2 to 83 percent in meets with national class or international participation. During the 2002 spring season, these athletes recorded an average top 45% finish, averaging boats and all competitions. Thirty-one novice and varsity female university rowers (age = 20 ± 1 year) were originally randomly assigned in a balanced (i.e., ~equal novice and varsity) fashion to H-load or H-rep groups. Not all subjects completed all (i.e., pre- and post-) testing or training procedures because of illness, injury, or non-compliance. Thus, 13 rowers were in each of the H-load (5 novice, 8 varsity) and H-rep (7 novice, 6 varsity) training groups.

Mean age was 20 ± 1.0 years, mean height was 170 ± 6.0 cm, and mean weight was 71 ± 7.0 kg. There were no group differences in age, height, or body mass between rowers in H-load and H-rep groups. Compared with varsity rowers, novice rowers were younger (novice = 18 ± 1.0 years; varsity = 21 ± 1.0 years; $p < 0.001$). All rowers gave signed approved informed consent prior to the study. Research approval was obtained from the Marquette University Office of Research Compliance. All subjects were experienced in performing resistance training using exercises similar to those used in the training study and had previously performed a combination of H-load and H-rep resistance training microcycled on a weekly basis. All subjects performed rowing ergometer training prior to and during the study as part of their normal off-season training.

Training Protocols

As described above, subjects were randomly assigned to either an H-load or an H-rep resistance training protocol. All subjects performed identical resistance training exercises as described in Table 1. The H-load training group performed a traditionally periodized program with sets and repetitions ranging from 3 sets of 12 repetitions during week 1, to 3 sets of 5 repetitions by week 8. The H-rep training group performed a reverse step loading periodized program (4) with a set and repetition scheme ranging from 2 sets of 15 repetitions during week 1, to 2 sets of 32 repetitions by week 8. Table 2 outlines the periodized program for each group. Total training volume was greater for the H-rep group because of the high repetitions associated with this type of training. The average training volume for the 8-week training cycle was 105,003 kg for the H-rep subjects and 84,744 kg for the H-load subjects. All subjects trained 3 times a week for the first 6 weeks and twice a week for the last 2 weeks. The reduced training volume during the final 2 weeks served as an unloading phase, which is thought to be especially important for the H-rep reverse step loading group. Subjects trained at approximately 80 and 100% of their RM, depending on the training day and exercises. Subjects continued with their dry-land conditioning, in preparation for their competitive season, throughout the course of the study.

Table 2. Periodized programs for the H-load and H-rep groups.*

Week	Reps	Sets	Exercises
High load group (traditional periodization)			
1	12	3	6
2	12	3	6
3	10	3	6
4	10	3	6
5	8	3	6
6	7	3	6
7	6	3	6
8	5	3	6
High repetition group (reverse step loading periodization)			
1	15	2	6
2	20	2	6
3	20	2	6
4	22	2	6
5	25	2	6
6	28	2	6
7	30	2	6
8	32	2	6

* H-load = high load traditional periodization; H-rep = high repetition reverse step loading; reps = repetitions.

Testing Protocols

Subjects were tested pre- and posttraining on a Concept II rowing ergometer (Morrisville, VT) using a 2,000-meter rowing test (10, 26). In a recent independent study we have shown high reliability for the Concept II ergometer over the same time period as this study ($N = 6$) for strength and power variables (intraclass correlation coefficient [ICC] range = 0.89–0.99), similar to what has been reported previously (26). After a 5-minute warm up, subjects were instructed to row a 2,000-m time trial at "race pace." All subjects were given verbal encouragement. $\dot{V}O_2$ was measured continuously during the test by automated open circuit spirometry (SensorMedics, Yorba Linda, CA) calibrated prior to testing with gases of known concentration. Peak $\dot{V}O_2$ was the highest $\dot{V}O_2$ for any 30-s time interval. Time to test completion, total power, average power per stroke, total number of strokes, stroke rate, peak heart rate, and RQ were also measured or calculated during the test.

Table 3. Baseline pretraining performance characteristics of 13 high load (H-load) and 13 high repetition (H-rep) trained female rowers during a 2,000-m rowing ergometer performance test. Data are mean ± *SD*.*

	H-loadN	H-loadV	H-repN	H-repV	Protocol P	Ability P	P×A P
Time (s)	502 ± 28	477 ± 20	513 ± 25	475 ± 19	0.66	0.002	0.45
Power (w)	40,977 ± 6,034	46,281 ± 7,220	37,089 ± 4,683	47,485 ± 5,165	0.58	0.003	0.29
Strokes	230 ± 22	223 ± 21	222 ± 17	226 ± 17	0.74	0.82	0.48
Stroke rate	28 ± 2	28 ± 3	26 ± 2	29 ± 2	0.57	0.14	0.28
Power per stroke (w)	179 ± 29	208 ± 25	167 ± 22	211 ± 25	0.68	0.002	0.46
$\dot{V}O_2$ pk ($ml \cdot kg^{-1} \cdot min^{-1}$)	41 ± 5	44 ± 5	38 ± 2	44 ± 3	0.45	0.006	0.47
RQ pk	1.02 ± 0.04	1.02 ± 0.03	1.03 ± 0.01	1.01 ± 0.02	0.82	0.51	0.38
Heart rate pk ($b \cdot min^{-1}$)	187 ± 6	190 ± 6	192 ± 5	189 ± 13	0.57	0.93	0.35

* Strokes = total number of strokes; Stroke rate = strokes per minute; pk = peak; H-loadN = high load trained novice; H-loadV = high load trained varsity; H-repN = high repetition trained novice; H-repV = high-repetition trained varsity; Protocol P = protocol main effect probability; Ability P = ability main effect probability; P×A P = Protocol by ability interaction probability.

Table 4. Posttraining performance change (post- minus pretraining) characteristics of 13 high load (H-load) and 13 high repetition (H-rep) trained female rowers during a 2,000-m rowing ergometer performance test. Data are mean ± *SD*.*

	H-loadN	H-loadV	H-repN	H-repV	Protocol P	Ability P	P×A P
Time (s)	−10 ± 6	−7 ± 8	−15 ± 6	−4 ± 6	0.74	0.02	0.10
Power (w)	4,315 ± 4,134	2,099 ± 3,945	2,796 ± 3,371	1,112 ± 3,319	0.42	0.21	0.86
Strokes	11 ± 17	0 ± 14	−3 ± 16	0 ± 15	0.27	0.57	0.32
Stroke rate	2 ± 2	1 ± 2	0 ± 2	0 ± 2	0.19	0.29	0.47
Power per stroke (w)	11 ± 4	10 ± 10	16 ± 7	5 ± 8	0.96	0.09	0.15
$\dot{V}O_2$ pk ($ml \cdot kg^{-1} \cdot min^{-1}$)	−3 ± 3	−1 ± 3	−1 ± 3	−2 ± 4	0.75	0.52	0.35
RQ pk	0.01 ± 0.03	0.00 ± 0.04	−0.02 ± 0.06	0.01 ± 0.04	0.59	0.56	0.27
Heart rate pk ($b \cdot min^{-1}$)	2 ± 4	1 ± 6	−1 ± 2	2 ± 4	0.74	0.64	0.36

* Strokes = total number of strokes; Stroke rate = strokes per minute; pk = peak; H-loadN = high load trained novice; H-loadV = high load trained varsity; H-repN = high repetition trained novice; H-repV = high-repetition trained varsity; Protocol P = protocol main effect probability; Ability P = ability main effect probability; P×A P = Protocol by ability interaction probability.

Statistical Analyses

Baseline pretraining performance characteristics were analyzed by 2-factor (protocol, ability) analysis of variance (ANOVA). Changes as the result of training (time) within groups were analyzed by paired *t*-tests. Changes in performance after training between groups were first computed as posttraining minus the baseline values for each dependent variable. These delta values were then analyzed by 2-factor (protocol, ability) ANOVA. Data are presented as mean ± *SD*. Significance was provisionally set at $p \leq 0.05$; however, data are also discussed based on exact *p* values.

RESULTS

Results are described as baseline pre- and posttraining test measures of performance time, power, stroke performance, and $\dot{V}O_2$ peak. Pre- and posttest results are described in tables 3 and 4, respectively, and figure 1.

The pretest showed no difference in 2,000 m performance time between H-load and H-rep groups. As expected, the novice rowers were slower than the varsity rowers (novice = 509 ± 26 s, varsity = 476 ± 19 s, $p = 0.002$).

There was no difference in pretest power output (W) between H-load and H-rep training groups. There were no differences in any group in the total number of strokes or the stroke rate during the performance test. The average power per stroke was similar for the H-load and H-rep training groups. However, compared with the varsity rowers, the novice rowers produced less power (novice = 38,709 ± 5,405 W; varsity = 46,797 ± 6,222 W; $p = 0.003$)

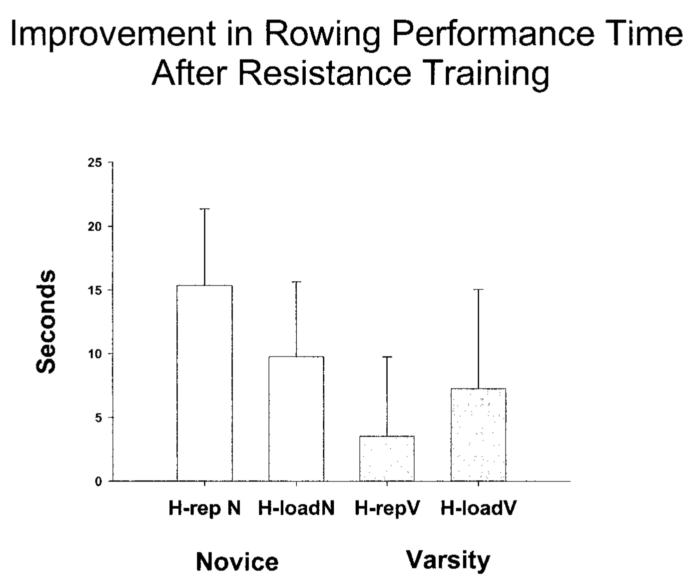

FIGURE 1. Improvement in rowing performance time (baseline pretraining minus posttraining measures) after H-rep and H-load training in novice and varsity rowers. H-repN = high-repetition–trained novice; H-repV = high-repetition–trained varsity; H-loadN = high-load–trained novice; H-loadV = high-load–trained varsity. All training groups had significantly faster posttraining times. Data are mean ± *SD*. The training protocol by ability interaction was $p = 0.1$.

and less power per stroke (novice = 172 ± 25 W per stroke; varsity = 209 ± 24 W per stroke; $p = 0.002$), which was consistent with performance time. Thus, varsity rowers had faster ergometer times and greater power, but similar number of strokes compared with the novice rowers.

There was no initial difference in $\dot{V}O_2$ peak between the H-load and H-rep training groups, nor were there differences in the RQ peak or heart rate peak during the performance tests. However, the novice rowers had a significantly lower $\dot{V}O_2$ peak than the varsity rowers (novice = 39.3 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$; varsity = 44.4 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$; $p = 0.006$).

Both H-load and H-rep groups improved their performance times after training ($p < 0.001$). The novice rowers had a greater increase in performance (i.e., decreased time) than the varsity rowers. The protocol by ability (i.e., novice or varsity) interaction suggested a greater positive effect of H-rep training on the novice rowers and H-load training on the varsity rowers.

All rowers increased their posttest power output compared to pretest measures ($p = 0.003$) with no group differences. There was no change in total strokes ($p = 0.82$) or stroke rate ($p = 0.22$) after training in any group compared to pretest performance measures. However, the average power per stroke was increased significantly in all rowers regardless of training protocol. There was a tendency for increased power per stroke for the novice rowers.

The $\dot{V}O_2$ peak significantly improved in all rowers ($p < 0.001$) after training, but there were no significant group differences between training protocol or ability. The RQ peak did not change overall from pretest to posttest. The peak heart rate attained during the posttest performance increased slightly (~ 1 $b \cdot min^{-1}$) though significantly ($p < 0.001$) with no group differences.

DISCUSSION

To our knowledge, this is the first training study to compare H-rep and H-load resistance training and its effect on endurance performance. Findings demonstrate that H-load is as effective as H-rep resistance training in improving rowing performance in female rowers. In addition, H-load resistance training was more effective for the more highly trained (e.g., varsity), and H-rep resistance training was more effective for the less highly trained (e.g., novice) rowers.

The H-load and H-rep training groups started from a similar pretraining performance baseline. Both H-load and H-rep training resulted in improved performance. Previous studies have demonstrated improved endurance performance times (13, 16, 24, 25), as well as improved strength in endurance tests (14), as a result of high-load resistance training programs. Not surprisingly, improved strength results in improved rowing performance time, as both are correlated (14, 18). In this study, the novice rowers improved to a greater degree and responded more to the H-rep training compared to H-load training. This finding offers some support to previous recommendations for H-rep resistance training for improving muscular or athletic endurance (1, 2, 4). On the other hand, varsity rowers tended towards greater improvement in rowing time with H-load training. These findings are consistent with the theory that pretraining status dictates the magnitude of potential adaptation (17, 21) and that periodized training with adequate loads may result in optimal adaptations for those with a higher pretraining status (16).

Improved rowing performance was likely the result of increased power per stroke in both the H-load and H-rep training groups. Stroke frequency remained unchanged from pre- to posttest and was not altered by training. Since the rowers attempted to perform the pre- and posttests at a cadence similar to training and competitive rowing, it appears that increased power associated with resistance training was not accrued at the expense of stroke frequency and rowing specificity.

Predictably, novice rowers had slower performance times, produced less power, and were less aerobically fit ($\dot{V}O_2$ peak) than varsity rowers. Rowing ergometer tests have been preferred over treadmills to measure $\dot{V}O_2$ in rowers because of specificity, and greater maximal $\dot{V}O_2$ has been measured in rowers on rowing ergometers compared to treadmills (26, 28). In addition, both graded and 6-minute rowing ergometer tests (similar to those performed in the present study) have been shown to produce similar peak $\dot{V}O_2$ (20). Despite previous findings (28, 33), true maximal oxygen uptake values may not have been measured in the present study as evidenced by the relatively low peak RQ (< 1.1) and heart rates (~190 $b \cdot min^{-1}$) recorded. Discrepancies with previous studies may be due to differences in the experience of the athletes studied. Regardless of whether or not maximal $\dot{V}O_2$ changed with training, peak $\dot{V}O_2$ did increase with concurrent resistance training, as previously reported (3). The ability to perform at a higher $\dot{V}O_2$ can be associated with improved performance. Thus, an increased $\dot{V}O_2$ peak may also contribute to the increase in rowing performance. Because peak $\dot{V}O_2$ increased to a similar degree after training and group differences still persisted, the increase in peak $\dot{V}O_2$ cannot explain all the differences in performance associated with H-rep or H-load. It is interesting to note that previous studies by Johnston et al. (15) and Paavolainen et al. (24) showed improved aerobic performance with no increase in $\dot{V}O_2$ max, demonstrating that an increased maximal oxygen uptake may not be a prerequisite for increased endurance performance.

Most evidence suggests that resistance training adaptations are similar between genders and are typified by muscle fiber hypertrophy, an increase in the percentage of type II fibers, and a decrease in IIb fibers (30, 31). Like men, women are capable of increased dynamic strength after 4 to 8 weeks of resistance training (30). However, it is difficult to generalize the findings of the present study to men because, compared with male subjects, female subjects have previously demonstrated some differences in the time course adaptation of muscle fibers, such as fast fiber hypertrophy rates that are 2 times greater than slow fibers (32). Additionally, female type I fibers are largest, compared to males whose type IIa fibers are largest, before resistance training (6). It is difficult to interpret how these gender specific differences in the time course of adaptations may have differentially affected the test groups in this study.

Finally, consistent with the findings of Johnston et al. (15), there was no statistically significant change in body mass for either training group, further demonstrating that resistance training does not result in significant weight gain for women.

PRACTICAL APPLICATIONS

Periodized resistance training improves endurance performance in women crew athletes. Athletes with higher pretraining status may experience greater benefit in endurance performance from periodized H-load resistance training. Athletes with lower pretraining status may benefit more from H-rep resistance training.

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Acknowledgments

This article is dedicated to Alan Kindler, Marquette University rowing coach, who died on September 6, 2002, at the age of 29. He redefined *strength* for all of us.

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