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LEG RESISTANCE TRAINING: EFFECTS UPON VO₂peak AND SKELETAL MUSCLE MYOPLASTICITY.

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ABSTRACT

LEG RESISTANCE TRAINING: EFFECTS ON CARDIOVASCULAR FITNESS (VO₂ peak) AND SKELETAL MUSCLE MYOPLASTICITY. **Reggie O’Hara, Munna Khan, Roberta Pohlman, and James Schlub. JEPonline.** 2004;7(5):26-43. The central focus of this review was to determine whether concurrent heavy loaded leg strength exercises and reduced aerobic loading influence VO₂ max or predicted VO₂ max when measured on a cycle ergometer or treadmill or both. Our review indicates that measurement of VO₂ max, time to exhaustion, and the type of physical training program employed may influence endurance capacity on a cycle ergometer or treadmill or both. Heavy resistance training (80% of 1 RM) can induce shifts in myosin heavy chain (MHC) isoforms from type IIb (glycolytic) to type IIa (mixture-oxidative/non-oxidative) in trained peripheral muscle. The precise mechanisms causing these increases in aerobic capacity still remain unresolved in the literature. These peripheral adaptations may be attributed to concurrent heavy loaded-high volume (3 sets of 12 to 16 repetitions performed to volitional fatigue) leg resistance training and reduced volume aerobic

loading. The mechanisms responsible for this change may be associated with the cross sectional area of the trained musculature. For example, if the cross sectional area of oxidative and glycolytic skeletal muscle increases, even in the same percentages of the original muscle mass, then any work rate will represent a lesser percentage of that muscle's maximal capacity to complete both oxidative and non-oxidative work.

Key Words: VO_2 max, peripheral adaptation, central adaptation, leg strength, and resistance training.

INTRODUCTION

Researchers suggest that increased leg strength, independent of cardiovascular training, may augment VO_2 peak and aerobic endurance performance. Increased leg strength may also improve cycling and running time to exhaustion, and amplify a subject's VO_2 max on a cycle ergometer and treadmill (10-36). Various researchers have examined the effects of intensive leg resistance training and its ability to increase aerobic capacity when measured on a cycle ergometer or treadmill (9,10,15-17,21, 26,28,31,34,36).

Skeletal muscle plasticity is defined and characterized by dynamic functional and structural remodeling of the muscle fiber (biochemistry and size). Alterations may occur due to removal of force loads (space travel, hind limb suspension, and bedrest) or to increased weight-bearing loads. Again, significant changes in skeletal muscle fiber biochemistry may occur as a result of high load and high volume resistance training and low volume aerobic loading, thereby enhancing oxidative capacity in certain population subsets. However, the precise contributory mechanisms are not definitive (25).

Some researchers (13,17) hypothesize that increases in VO_2 max, measured on a cycle ergometer, may be due to enlarged skeletal muscle mass and enhanced oxidative capacity in the resistance trained leg musculature. One group of researchers (22) determined the effects of three distinctive resistance-training programs on cardiovascular endurance and discovered that high repetitions (2 sets of 22 to 26 reps) and low resistance (60 % of 1 RM) considerably increased time to exhaustion and maximal power output. The physiological adaptations in the high repetitions group included increased lactate tolerance, improvements in the non-oxidative and oxidative energy systems, or simply an increased tolerance of very high intensity work (22). Combined aerobic and resistance training programs can also increase aerobic power and duration of short-term, high-intensity, running and cycling (10,24).

High intensity resistance training may also augment VO_2 peak and capillary blood supply to skeletal muscles. Hepple et al (15) recruited elderly men (65 to 74 yr) to participate in a nine-week resistance training study. The group of ten subjects performed three sets of four exercises for each leg separately at an intensity that would elicit volitional fatigue within 6 to 12 repetitions. Each of four resistance exercises was completed on a universal strength-training machine. The group of trainees increased peak VO_2 and the number of capillaries per muscle perimeter length increased, which subsequently paralleled changes in their VO_2 peak. Not only can the physiological changes in the above noted studies occur in the elderly population, but comparable physiological changes may also occur in the inactive younger population. Interestingly, the elderly men in this study did participate in low-intensity periodic physical activity (i.e., tennis, golf, and walking), but still managed to increase several cardiovascular (CV) fitness parameters through intensive leg resistance training.

One group of investigator's (36) examined the effect of six-months of high and low intensity leg resistance exercises on aerobic capacity amongst a group of older (60 to 80 yr) men and women. They observed that subjects who increased leg strength were able to exercise at a higher relative intensity and for a sustained duration. The probability of younger subjects increasing aerobic capacity by enhancing leg strength, however, is unlikely. Younger subjects may already have normal leg strength, unlike the elderly subject's used this study (36). Therefore, the effects of concentrated leg resistance training in a group of younger subjects may not significantly increase aerobic capacity. In contrast, Hickson et al (17) showed that 18 to 27 year-olds increased

leg strength by 40 percent and endurance time to exhaustion increased while cycling (47%) and running on a treadmill (12%), after 10-weeks of near maximal leg resistance training.

Several other researchers (13,27,31) found that aerobic training coupled with high volume multi-joint resistance training in the legs and upper body musculature produced promising results in aerobic endurance and VO_2 max. Therefore, at least in some exercise training protocols, the leg strengthening emphasis has improved aerobic capacity. For example, O'Hara, et al (25) recruited a small convenience sample of (n=14) previously trained Air Force men who showed significant increases in predicted maximal aerobic capacity when tested on a cycle ergometer after six and 12 weeks of training. Each subject performed a high number of repetitions (n=12 to 16) until volitional fatigue and recovered one to two minutes between each set of leg resistance exercises. After 12-weeks of heavy leg resistance training the group's mean predicted aerobic fitness increased from 27.6 ml/kg/min to 34.7 ml/kg/min. This was a significant change, especially considering the fact that this group of men had previously been participating in two or more years of aerobic conditioning but were still unable to increase their fitness level on a cycle ergometer. The authors suggested that skeletal muscle morphology change might explain the increases in predicted aerobic capacity, such as improvement in muscular recruitment patterns and strength levels in the trained leg musculature. Additionally, increases noted in participants cycling comfort may also have been attributed to enhanced leg resistance volume and loading and muscular efficiency. The neuromuscular response to chronic resistance training and ensuing alterations in motor unit recruitment patterns may also be another causal link to a subject's enhanced endurance and aerobic capacity.

Conley and Rozenek (8) reported that high volume resistance training, consisting primarily of multi-joint exercise movements of the leg musculature increases aerobic metabolism between 8 to 10 %. The exact physiological mechanisms responsible for this change could be attributed to permutations of skeletal muscle's improvement in oxygen delivery and utilization, peripheral vascular or cardiac. Nonetheless, the precise physiological mechanisms linked to improvements in aerobic metabolism, due to a resistance-training regimen, are unknown.

Only a relative handful of researchers (3,16-18,36) have specifically examined the effects of intensive leg strengthening combined with aerobic training on VO_2 max, short and long-term aerobic endurance, and aerobic power. The proposed peripheral mechanisms behind improvements in VO_2 peak and endurance performance could be attributed to improvement in muscular recruitment patterns and leg strength, which may influence blood lactate turnover rates, or threshold. Increased cycling comfort, resulting from increased leg resistance training volume and load, may also lower exercise heart rate response directly (31).

METHODS

This review focuses on the physiological effects of enhanced quadriceps strength on maximal oxygen uptake and predicted oxidative and endurance capacity. The secondary focus of this review is to examine the specific resistance lifting loads and volumes necessary to elicit mechanisms of change in trained leg skeletal myofibrils that may contribute to a participant's improved aerobic capacity. The two areas of focus these investigators are attempting to address are controversial amongst researchers and remain unresolved in the scientific literature. Therefore, these investigators have attempted to answer the following questions:
When measured on a cycle ergometer or treadmill or both, could concurrent heavy loaded leg resistance training, and reduced volume aerobic loading increase predicted or maximal peak VO_2 or both?
If so, what are the peripheral mechanisms responsible for augmentations in oxidative capacity?

Research Articles Selection

The investigators performed a search of the literature, dating as early as 1969 to 2003, using The United States Air Force Medical Service Virtual Library. The following descriptive words were entered into the search: (a) VO_2 max; (b) leg strength; (c) power output; (d) cycle testing; (e) treadmill testing; (f) anaerobic power; (g)

aerobic training (h) resistance training (i) peripheral adaptation and (j) central adaptation. Sixty-two articles were located and these authors selected 34 articles that specifically addressed the proposed research questions.

Skeletal Muscle Plasticity

Performing high-intensity progressive resistance training with near maximal workloads can increase fast-twitch muscle fiber size. Subsequently, reductions in mitochondria density may result (35). However, according to *Brooks et al.* (6), the volume of the mitochondrial mass remains unchanged. Resistance training with heavy workloads can also reduce skeletal muscle capillary density, but the capillary-to-fiber ratio also remains unchanged.

In contrast, a high repetition progressive resistance-training regimen, typically used by bodybuilders, may actually increase the number of capillaries per muscle fiber and increase the capability of skeletal muscle to sustain a given amount of force for extended periods (5). Subsequently, the skeletal muscle strength-endurance capacity may increase. This enhancement of muscular strength and endurance may also increase the muscle's function to maintain a level of muscular force for prolonged durations, which may contribute to increased thigh and leg cycling comfort.

For the purposes of studying exercise heart rate responses to leg training on a cycle ergometer, Saltin and Hermanssen (29) randomly divided subjects into two groups. Group one trained only one leg on a cycle ergometer, while group two served as an untrained control. This group of investigators discovered that group one had a lower heart rate response during testing of the trained leg versus the untrained leg, when compared to their pre-test VO_2 max values. The trained leg (group 1) had a reduced exercise heart rate response. The lowered heart rate response is attributed to small nerve endings located in the trained thigh musculature. According to Saltin and Hermanssen (29), these small nerve endings in skeletal muscle perceive the metabolic milieu inside the muscle. Subsequently, this influences the exercising subject's heart rate response through links to the cardiac control center in the brain.

Saltin, et al (30) determined peripheral and central adaptations of one-legged aerobic and anaerobic exercise on a cycle ergometer. A group of healthy male subjects ($n=13$) consisting of medical or fine arts students [mean age 21.7 yr.; height (ht) 181 (cm); weight (wt) 71.1 (kg)] participated in four weeks of cycle ergometer training four to five times weekly. Subjects were homogenous in training status and VO_2 max. Therefore, they were able to randomly select and place subjects in one of three training groups. The groups and their training models are depicted in Table 1.

Table 1. Saltin et al. (30) Study Results.

<i>Group</i>	<i>Training Program</i>
1 ($n=5$)	One-legged aerobic endurance (AE) training (continuous ergometer cycling for 30 to 50 minutes) and the other leg with sprint (S) training (repeated maximum efforts for 30 to 40 seconds followed by 1.5 minute recovery periods).
2 ($n= 5$)	One-legged S training and the other leg remained untrained.
3 ($n=3$)	One-legged AE training and the other leg remained untrained.

Saltin, et al (30) reported that group one increased VO_2 max in each leg from a baseline value of 2.81 L/min by 11 % and 20 % in the S and AE trained leg musculature, respectively. In Group 2, VO_2 max increased from a baseline of 2.81 L/min, in the S trained leg by 15 % while the untrained leg increased less than 3 %. Baseline VO_2 max for group three was 2.4 L /min and 2.5 L /min for both legs. Following the AE training, a 24 % increase of VO_2 max resulted, while the untrained leg exhibited a 6 % increase in VO_2 max. The differences between AE and S trained legs were not significant. However, the researchers observed that a close relationship exists between peripheral and central circulation adaptability in regulating heart rate response.

Of particular interest to this group of researchers (30) were the similar adaptations among subjects in all three training groups. For example, group one subjects' participated in aerobic training almost twice as much as subjects in groups two and three. However, submaximal heart rate response and VO_2 max in the legs of subjects in groups one and three (leg endurance group) were similar to subjects in groups one and two (leg sprint group). These same researchers stated the following: "*In animals and perhaps in man too, cardio-acceleration can be elicited both by cortical influence on the vasomotor center and by afferent inflow of impulses from exercising muscles. Considering the marked local response one could speculate whether the change in submaximal heart rate is related to a less active peripheral drive.*" (30).

In this study, Saltin, et al (30), concluded that the lowered heart rate response, due to leg training, enhanced filling time in the myocardium, which increased end diastolic and stroke volume (SV). Therefore, training induced changes, including resistance training, may exert a favorable influence on certain cardiovascular adaptations, such as a reduced exercise heart rate response to known work rates. The study by Saltin, et al (30), further indicates that peripheral changes (legs), not just central (myocardium) changes, may affect certain controlling mechanisms in skeletal muscles.

In order to determine mechanisms of change in skeletal muscles, Staron et al (34) conducted a study on human skeletal muscle fiber type adaptability to various strength workloads. The investigators collected muscle biopsies from the vastus lateralis of 20 subjects who were divided into three groups: untrained (n=5); weight lifters (n=7); and distance runners (n=8). The weight lifters (consisted of two competitive power lifters and one competitive bodybuilder and four non-competitive, but well-trained lifter's) and distance runners (average marathon time = 159 min) who had participated in training four to six times weekly for a minimum of three years. The distance runners did not include any form of lower body strength training into their routines. The untrained controls were sedentary and had not participated in any regimented physical activity programs. These same researchers (34) were also interested in the ability of skeletal muscle to change its fiber type composition of weight lifters based upon the specific type of resistance training routine they engaged in. They discovered that the volume-percent of mitochondria in Type IIB skeletal muscle fibers of weight lifters and runners were similar. However, Type IIB skeletal fibers in the untrained controls were drastically higher. Subjects who participate in high-intensity resistance training, which may require near-maximal musculature contractions, will primarily recruit fast-glycolytic Type IIB skeletal muscle fibers. However, after obtaining muscle biopsies from the vastus lateralis muscle (upper thigh) of the subjects, researchers discovered that a larger percentage (32% vs. controls) of fast oxidative glycolytic (FOG) Type IIA skeletal myofibrils occupied that muscle. Additionally, the conversion of Type IIB to Type IIA could be due to a cumulative effect of strength training that results in greater recruitment of Type IIA versus Type IIB muscle fibers. Furthermore, resistance training may also enhance the oxidative (aerobic) production of adenosine triphosphate (ATP) and therefore, short-term endurance capacity increased without a complementary increase in VO_2 max.

Staron, et al (34), found that skeletal muscle fiber Types I, IIA, and Type IIB have a higher volume percent of mitochondria in both distance runners and weight lifters when compared to the untrained-controls. Nonetheless, well-trained runners routinely have a greater density and volume of mitochondria in Type I skeletal muscle fibers, when compared to weight lifters. The muscle biopsies taken from this group of weight lifters indicates that weight lifters rely more on Type IIA skeletal muscle fibers, which may contribute to an increase in their oxidative capacity without a concomitant increase in VO_2 max.

Staron and colleagues (34) suggest that the collective effect of weight training actually incorporates a greater recruitment of Type II a skeletal muscle fibers, in comparison to either Type I or IIB skeletal muscle fibers. Weight training can also enhance the oxidative capacity of skeletal muscle fibers and subsequently increase short-term endurance capacity, without producing any significant increases in maximal oxidative capacity. Staron, et al (33) observed the effects of heavy-resistance training on skeletal muscle adaptations in 13 men (age=23.5 \pm 1.5 yr., ht=1.77 \pm 0.88 m) and 8 women (age=20.6 \pm 1.5 yr., ht=1.80 \pm 0.05 m) who had never

participated in a heavy resistance-training program. The control group consisted of 12 subjects, 7 men (age 20.7 ± 1.4 yr., ht 1.80 (m) ± 0.09) and 5 women (age 20.6 ± 1.6 yr., ht 1.61 (m) ± 0.01) who were not participating in the heavy resistance training program, nor any outside physical training routine. The subjects, enrolled in this training study (33), performed squats, leg press, and leg extension exercises until volitional muscle fatigue, twice weekly for 8-weeks. Subjects performed two-warm-up sets followed by three- sets of 6 to 8 repetitions on Monday and 10 to 12 repetitions on Wednesday, with a two- minute recovery between sets of each exercise.

The investigators extracted (80-160 mg) muscle biopsies from the superficial portion of the vastus lateralis muscle, located in the thigh musculature. The muscle biopsies were extracted at the beginning of this 8-week training program and every 2-weeks thereafter from all subjects in the training and control groups. Muscle samples were analyzed for fiber type composition, cross-sectional area, and myosin heavy chain content (MHC).

The investigators observed that men and women who completed the heavy leg resistance training exercises increased absolute and relative dynamic strength after 4-weeks of training. They also observed significant reductions in percentages of Type IIb skeletal muscle fibers (from 21 ± 8.3 % week 1 to 8.9 ± 8.2 % week 9) after only two weeks of training in women and 4-weeks in men. A non-significant increase in percentage of Type IIa (from 31.4 ± 7.9 % week 1 to 38.2 ± 10.6 % week 9) skeletal muscle fibers and a significant increase in the percentage of Type I skeletal muscle fibers was observed in the quadriceps femoris, after only 4-weeks of physical training in all female subjects.

Increases in percentage of Type I skeletal muscle fibers in the quadriceps region were found to be transient and decreased to non-significant levels between six and eight weeks of training. Fox, Bowers, and Foss (p.114) (12), cite that “*Fast-twitch type IIa skeletal muscle fibers also have a high density of mitochondria and a substantial presence of capillaries and myoglobin to support the oxidative aspects of their metabolic function.*”

The structural design of fast oxidative glycolytic (FOG) (Type IIa) skeletal muscle fibers allows them to be moderately resilient to muscular fatigue. The FOG muscle fibers are also rich in mitochondria and oxidative enzymes. In addition, the FOG fibers have the ability to use metabolites from blood to sustain the metabolic activity required during muscular contraction. Therefore, the FOG fibers are developed to produce force for long periods without increasing glycogenolysis (6).

Brooks, et al (6), also suggests a skeletal muscle undergoing chronic physical stress with high-loading requirements may shift contractile protein phenotype to a more economical cross-bridge cycling system (i.e., the cross-bridges cycle at a slower rate in maintaining the force of sustained contraction). The change in cross-bridge cycling rates could be an important physiological phenomenon if one considers the concentric skeletal muscle shortening elicited when a subject attempts to pedal at a constant work rate on a cycle ergometer. Hickson, et al (16), observed that during sub-maximal cycle ergometer exercise ($85\% VO_2$ max, 60 rpm), the peak tension occurring with each pedal thrust equated to approximately 50 to 60 percent of maximal force exerted on the cycle ergometer pedals. This force per pedal thrust implied that activation of motor units in the quadriceps does not occur at the same time or phase of cycling accompanied by a significant recruitment of fast twitch skeletal muscle fibers. As a result, of resistance training, subjects participating in this training study increased maximal force by 30 percent in the thigh musculature. These investigators also observed that peak tension decreased from 50 to 60 percent of maximal force applied to the pedals, before subjects participated in this study, to 30 to 45 percent after their participation. The reduction exhibited in peak tension implied that during each pedal thrust an ensuing increase in recruitment of slow twitch skeletal muscle fibers resulted, accompanied by a diminished recruitment of fast twitch muscle fibers in the thigh musculature. Because of the reduced reliance on fast-twitch fiber recruitment with each pedal thrust, there would also be a reduced rate of adenosine triphosphate (ATP) consumption per muscle fiber unit of contractile force and a subsequent sparing of skeletal muscle glycogen.

Willoughby and Pelsue (38) determined steady state myosin heavy chain (MHC) isoforms (Types I, IIa, and IIx) mRNA abundance in skeletal muscle after 8-weeks of high intensity resistance training. Twelve untrained males (age = 19.88 ± 0.53 yrs.; ht= 180.13 ± 3 (cm); and bodyweight 74.63 ± 7.92 (kg)) were randomly assigned to either a control group (C), or a resistance-trained group (RT). The RT group performed three sets of 6 to 8 repetitions of bilateral leg presses three times weekly (Monday, Wednesday, and Friday) using 85 to 90 percent of their 1-RM, coupled with a 90 second recovery between each set. Other than pre and post-testing, the C group did not participate in resistance training during the 8-week study. The RT group increased thigh volume, muscular strength, and myofibrillar protein content in skeletal muscle after 8-weeks of leg resistance training and the C group made no significant changes. Researchers observed significant increases in the RT groups Type I MHC mRNA ($42.50\% \pm 8.32$ to $49.51\% \pm 9.77$) and Type II a ($37.28\% \pm 7.89$ to $42.81\% \pm 6.95$) after 8-weeks of training. However, there was a decrease in the percentage of Type X mRNA ($20.17\% \pm 2.44$ to 7.67 ± 3.63) on the trained leg musculature. The high-intensity resistance-training program employed in this physical training study required large contractile efforts of the subject's leg musculature, coupled by slow velocity movement speeds. These investigators suspect that high-intensity resistance-training requiring large contractile efforts and slow movement speeds reduces activation of Type II b skeletal muscle fibers during the exercise bout, in comparison to high activation of Type I and II a skeletal fibers. Based on the study results, these researchers believe that the principle of training specificity and resistance training intensity (workload) play an important function in the differential expression of Type I, II a, and II x MHC genes on individual skeletal myofibrils.

Brooks (6), found that high-intensity, slow-speed training using isokinetic loading, is associated with increases in intramuscular glycogen, creatine phosphate (CP), adenosine triphosphate (ATP), adenosine diphosphate (ADP), creatine phosphorylase, phosphofructokinase (PFK), and Krebs cycle enzyme activity. In contrast, lifting at faster velocities/speeds does not induce the same physiological adaptations, when compared to slower lifting speeds.

Adams, et al (1), tested the effects of 19-weeks of heavy resistance training on thigh skeletal muscle myosin heavy chain (MHC) composition in 17 healthy males (age= 36 ± 2 yr.; ht= 178 ± 1 (cm); and wt= 89 ± 3 (kg)). Eight subjects performed concentric lifts, five performed a combination of concentric and eccentric lifts, and four subjects served as controls. The subjects performed three sets of 6 to 12 repetitions of leg press and knee extensions until volitional fatigue twice weekly. The researchers obtained skeletal muscle biopsies before and after training in each trained subjects' right musculus vastus lateralis. In order to simplify management of raw data, the researchers combined all training groups results. After 19 weeks of training, the researchers observed that the subjects' (n=13) Type II b MHC fiber composition decreased from $19 \pm 4\%$ to $7 \pm 1\%$ and percentage of Type II b skeletal muscle fibers also decreased from $18 \pm 3\%$ to $1 \pm 1\%$. In contrast, Type II a skeletal muscle fibers increased from $47 \pm 3\%$ to $60 \pm 2\%$ and percentage of type II a skeletal muscle fibers increased from $46 \pm 4\%$ to $60 \pm 3\%$. The control group made no significant change in either percent of MHC or percent of skeletal muscle fiber. The resistance trained groups' percentages of Type I skeletal muscle fiber and Type I MHC composition was unchanged after training. These investigators found that heavy resistance training by the subjects significantly altered both MHC composition and genetic expression of skeletal muscle. More importantly, marked reductions in percentages of Type IIb muscle fibers, coupled by a concomitant increase in Type II a skeletal muscle fibers resulted.

Bishop, et al (5) and Tesch (35), reported that a high repetition progressive resistance-training regimen, routinely employed by bodybuilders, may increase left-ventricular volume and enhance the number of capillaries per skeletal muscle fiber, in comparison to someone who performs Olympic style weight training. The increased capillary density in skeletal muscle will augment "transit times," improving the exchange of gases and nutrients between the blood and muscle cell (Brooks, Fahey, White & Baldwin, 2000) (6). This high volume of resistance training will also increase skeletal muscle myoglobin stores and oxidative enzyme activities.

Hickson and colleagues (16) conducted a study to determine if heavy resistance training could increase cardiovascular endurance, and maximal aerobic capacity and whether participant's maximal treadmill or cycle scores are correlated to augmented leg strength. They recruited nine men age 18 to 27 yr. (average age=23 yrs.) to participate in a 10-week high-intensity leg-strengthening program, five times weekly. The training program was designed to increase quadriceps strength and to determine if heavy resistance training could increase cardiovascular endurance, and VO_2 max. The investigators also determined whether the differences observed during cycling and treadmill VO_2 max scores in the same subjects correlated to increased leg strength. The subjects recruited for this study did not train for six months before enrolling, and most were considered recreational athletes (i.e., soccer, basketball etc.). Three times weekly, each subject performed parallel squats (5 sets of 5 repetitions), leg extensions (3 sets of 5 repetitions), and leg flexions (3 sets of 5 repetitions). The other two days of training, the subjects performed leg presses (3 sets of 5 repetitions) and calf-raises (3 sets of 20 repetitions). The subject recovered three minutes between each set of resistance exercises and a qualified instructor supervised all resistance-training sessions. All leg-strengthening exercises were performed with the maximal amount of weight that could be lifted. The starting weight for the subjects was set at only 80 percent of their one-repetition maximum. As subjects' strength levels increased, additional resistance was added to maintain the same relative resistance for the required repetitions. Post-training, subjects significantly increased endurance time to exhaustion while cycling (47%) and running (12%) at 100 percent of their pre-training VO_2 maximum. A small increase in VO_2 max resulted (4%, $p < 0.05$) during cycling ($3.40 \text{ l} \cdot \text{min}^{-1}$ to $3.54 \text{ l} \cdot \text{min}^{-1}$) post training. However, there were no significant changes in VO_2 max after expressing the values in relative terms ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). The heavy workloads employed in this leg-resistance training program had no effect on maximal VO_2 when subjects ran on the treadmill and absolute differences between the two modalities of exercise were the same before and after training. Pre-training blood lactate concentrations on the cycle (pre: 11.2 mmol/L; post: 10.0 mmol/L) and treadmill (pre: 9.3 mmol/L; post: 10.3 mmol/L) were not significantly different after training.

The intensive leg-strengthening program incorporated into the Hickson study (17) increased leg strength significantly in all three maximum strength tests, which included parallel squats, knee flexions, and knee extensions. After three weeks of resistance training, mean strength in the parallel squats increased 19 percent, 27 percent after six weeks, and 38 percent after 10-weeks. Knee flexion strength also increased 42 percent and knee extension strength increased by 50 percent. These investigators suggested that increases in muscular strength and/or muscle girth are positively associated with increased endurance capacity, but not with increases in VO_2 max. Furthermore, the increase in cycle time to exhaustion was four times greater, in comparison to run time to exhaustion on the treadmill. These researchers indicate that in order to determine endurance capacity, due to heavy resistance training, the muscles that are directly involved in the training routine must also be the prime muscle group engaged in the activity during post testing.

The subjects who participated in this reported study (16) recovered longer (3 minutes) between sets of prescribed leg resistance exercises and they performed a restricted number of repetitions (5 repetitions) for each leg exercise. In contrast, Schlub et al (10) and O'Hara *et. al* (25) recruited a small convenience sample of ($n=14$) previously trained men who showed significant increases in estimated predicted aerobic capacity when they were tested on a cycle ergometer, after six and 12-weeks of training. Each subject performed a high number of repetitions ($n=12$ to 16) until volitional fatigue and recovered one to two minutes between each set of leg resistance exercises.

Schlub and colleagues hypothesized that the physiological mechanisms explaining increases in VO_2 max and aerobic endurance could be attributed to increased concentrations of ATP and CP at rest and improved enzymatic capacity to quickly re-synthesize ATP from immediate energy sources. The neuromuscular response to chronic resistance training and ensuing alterations in motor unit recruitment patterns may be another causal link to a subject's enhanced endurance and aerobic capacity.

Hurley, et al (18), tested the affects of 16-weeks of Nautilus strength training on VO_2 max and hemodynamic responses to submaximal treadmill physical training. Participants' VO_2 responses and heart rates were also measured during one strength training session, in order to establish acute physiological effects due to training. Two groups (training (T) and control (C)) of healthy untrained men (mean age= 44 ± 1 yr.; age range=40-55 yr) performed one set of 14 resistance exercises for eight to 12 times per set. The exercises consisted of hip and back, leg extension, leg pres, leg curl, arm cross, decline press, behind neck pull-down, omni triceps, and omni biceps. The control group consisted of 10 healthy, untrained men (mean age=52 ± 2 yr., age range=40-64 yr.). Both the T and C groups' VO_2 max, cardiac output during submaximal treadmill exercise, and body composition, were tested before and after 16-weeks of training. These researchers found that VO_2 max, hemodynamic responses to submaximal exercise, percent body fat, and body weight remained unchanged in both groups. However, fat-free weight did significantly increase (66.9 ± 2.6 (kg) vs. 68.8 ± 2.7 (kg); $p < 0.05$). Although these investigators showed that a resistance-training routine did not improve VO_2 max, they included only one set of a total body resistance program. They also excluded heavy resistance training of the leg musculature and they did not incorporate aerobic training into the routine. Hurley and co-workers [18] also attributes lack of improvement in VO_2 max to the relatively low training intensity (45% VO_2 max) coupled with only one set per exercise in the resistance part of the program.

Izquierdo, et al (19), examined the effects of a 16-week progressive resistance training program on serum hormone concentrations, quadriceps femoris muscle group cross sectional area, maximum half squat, maximal workload attained during progressive cycling, and blood lactate accumulation. Eleven middle-aged men (Group 1, mean age = 46 yr.) and 11 older men (Group 2, mean age = 64 yr.) participated in this 16-week training study. Both groups participated in a supervised resistance training routine twice weekly, performing two exercises for the leg extensor muscles (bilateral leg press & knee extension exercises). The groups performed the bench press and four to five exercises for the major muscle groups which integrated, chest press, lateral pull-down, and/or shoulder press for upper body, abdominal crunches and/or rotary torso, and the standing leg curl and/or abductor /adductor exercises. After the first eight weeks of training, no significant changes occurred in any of the physiological parameters which included, serum hormone concentrations, cross sectional areas of the quadriceps femoris muscle group, maximal half squat, maximal workload obtained during progressive cycling, and blood lactate accumulation during progressive cycling). However, the researchers did observe that the resistance-training program elicited increases in maximal and submaximal aerobic endurance on a cycle ergometer after the first eight weeks of training.

RESULTS

This review was written to answer the following questions: When measured on a cycle ergometer or treadmill or both, could concurrent heavy loaded leg resistance training and reduced volume aerobic loading increase predicted or maximal aerobic power or both? If so, what might be the mechanisms responsible for augmentations in aerobic power?

Many studies reviewed attempted to discern the influence of progressive resistance training on altering leg skeletal muscle structure and function. Additionally, studies were designed to identify whether a heavy loaded leg resistance training routine, coupled by reduced volume aerobic loading, could augment aerobic capacity. Table 1 summarizes the 20 studies and provides the accompanying results and includes the particular training protocols employed, gender, ages, and maximal aerobic capacity results. After careful examination of the literature the authors discovered that high-intensity workloads involving slow movement speeds, which cause a subject to reach volitional fatigue, may reduce activation of type II b (glycolytic) skeletal muscle fibers in the vastus lateralis muscle and increase capillary numbers and citrate synthase (CS) activity (13). For example, Wang, Hikida, Staron, and Simoneau (37), observed that heavy resistance training causes recruitment of motor units not typically used when performing normal daily activities, such as type II b. In contrast when one

participates in chronic heavy loaded resistance training type II b muscle fibers are recruited and can begin turning off the myosin heavy chain (MHC) II b gene and turning on the MHC II a gene.

Table 2. Results of the global studies.

SN	Study	N; Gender	Age Group	Training	VO ₂ max Protocol	Pre VO ₂ Max mL/kg/min ¹	Post VO ₂ Max mL/kg/min	Effect (p-value) p ≤ 0.05	Control Yes/ No
1	Frontera, Meredith, O'Reilly, and Evan, 1990.	12 M	60-72	Warm up 10 min, 3 time/wk, 12 wk	Thigh-Knee m/c	26.9 ± 0.8	28.3 ± 1.1	P>0.05	No
2-3*	Hickson, Rosenkoetter, and Brown MM, 1980.	9 M	18-27	Training, 5 days/wk 10 wk	² Bicycle ³ Treadmill	44.0 ± 2.3 47.8 ± 1.5	44.6 ± 2.4 48.8 ± 2.0	P> 0.05 P> 0.05	No No
4-5*	Hickson RC, Dvorak BA, Gorostiaga EM, Kurowski TT and Foster C, 1988.	6 M 2 F	29-39	Weight training 3 days/wk 10 wk	⁴ Cycle ⁵ Treadmill	54.4 ± 1.8 60.2 ± 2.2	54.8 ± 1.7 60.0 ± 2.0	P> 0.05 P> 0.05	No Yes
6-7*	Hepple RT, Mackinnon SLM, Goodman JM, Thomas, and Plyley MJ, 1997.	20 M	65-74	RT- 9 wk, AT-18 wk 30 min 3 days/wk 18 wk	Cycle ⁶ 6RT ⁷ AT	27.7± 1.4 25.3 ± 1.3	30.1 ± 1.2 31.0 ± 1.1	P> 0.05 P< 0.01	Yes Yes
8-10*	Mccarthy, Agre, Graf, Pozniak and Vilas, 1995.	30 M	25-29	50min each Training, 3 days/wk, 10 wk	Treadmill ⁸ Strength ⁹ Endurance ¹⁰ Combined	39.3 ± 2.1 41.4 ± 2.6 39.3 ± 2.4	42.9 ± 1.9 48.7 ± 2.6 45.5 ± 1.8	P<0.016 P<0.016 P<0.016	Yes Yes Yes
11-12*	Hurley, Seals, Ehsani, Cartier, Dalsky, et. al, 1980.	13 M	40-55	Exercise Training, 16 wk	Treadmill Train. Gp. Contr. Gp.	36.1 ± 1.4 30.1 ± 1.8	37.8 ± 1.3 31.4 ± 2.1	P > 0.05 P > 0.05	No No
13-14*	Coggan, Spina, King, Rogers, et. al, 1992.	17 M 13 F	60-70	45 min/day, 4 days /wk, 12 month	Treadmill ¹³ Men ¹⁴ women	27.0 ± 2.7 22.3 ± 2.8	34.8 ± 4.0 28.2 ± 2.7	P<0.001 P<0.001	Yes Yes
15	Bell, Petersen, Wessel, et. al 1991.	16 M 15 F	20-29	45min 3days/wk 12 wk	Ergometer	51.7 ± 5.1	55.7 ± 4.8	P< 0.05	Yes
16-17*	Marcinik, Potts, Schlabach, Will, et. al, 1991.	18 M	25-35	Training, 4- min to unable	Treadmill ¹⁶ Train. Gp. ¹⁷ Cont. Gp.	38.8 ± 7.0 39.7 ± 2.7	39.7 ± 7.8 39.7 ± 4.2	P>0.001 P>0.001	Yes Yes
18-20*	Kraemer, Patton, Gordon, Harman, et. al, 1995.	35 M	17-29	S, E, C Training, 3 days/wk 12 wk	Treadmill ¹⁸ Strength ¹⁹ Endurance ²⁰ Combined	53.47 ± 4.95 52.45 ± 5.95 58.88 ± 5.95	53.02 ± 4.34 58.65 ± 6.87 63.41 ± 8.02	P> 0.05 P< 0.05 P< 0.05	Yes Yes Yes

SN = Study Serial number

Figure 1 depicts the percent change in maximal aerobic capacity based on the testing modality employed by researchers after participants had engaged in either a resistance training program, aerobic program, or concurrent aerobic and resistance training.

Increases on aerobic fitness status may be attributed to peripheral changes (legs and thighs) verses central (myocardium) changes in certain physical activities. The peripheral changes may also be related with neuromuscular adaptations, resulting in improved muscular recruitment patterns. For example, a subject's ability to recruit Type II a skeletal muscle fibers when cycling at high work rates, may contribute to enhanced cycling time to exhaustion and result in minor improvements in VO₂ peak. The cumulative effects of strength training also seems important on converting skeletal muscles percentages from Type II b to Type II a and enhancing the activation of skeletal motor units

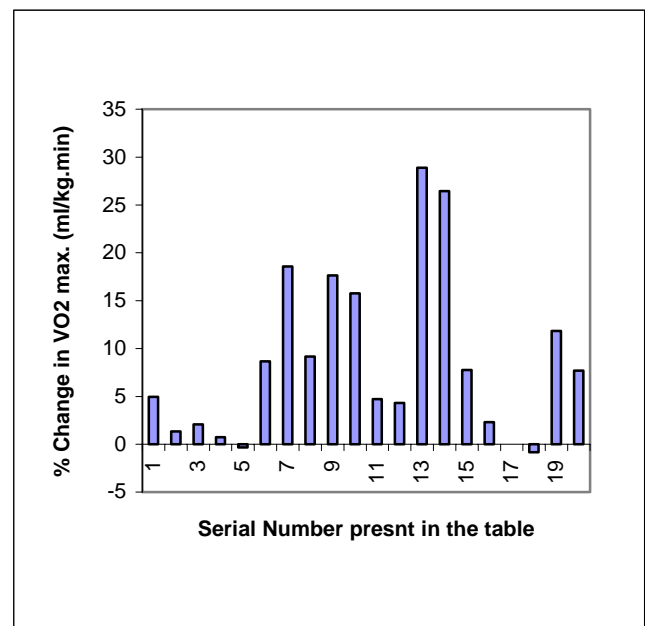


Figure 1. Percent change of VO₂max during the different types of exercises.

located within the trained musculature. The economical cross-bridge cycling system may also contribute to improved endurance performance because the cross bridges of the protein filaments cycle at faster rates allowing the subject to generate a sustained muscular force (6). One's ability to maintain concentric muscular contractions may play a part in amplifying endurance performance, especially in activities such as steep grade running or heavy loaded cycling.

Increases in CS activity may also be associated with the intensive leg resistance- training program, which may result in localized adaptation in the trained musculature (7,13,20,32). Frontera and co-workers (13) observed a positive correlation between CS activity in the vastus lateralis muscles and leg cycle $VO_2\max$, after combining before and after training data ($r=0.56$, $p=0.04$). A subject's ability to enhance $VO_2\max$ on the cycle ergometer could be associated with increased capillaries per muscle fiber, facilitating greater oxygen utilization. The trained thigh's ability to maximize oxidation of fats and spare muscle glycogen, due to increases in lipolytic enzyme activity, may also enhance endurance time to exhaustion.

Marcinik *et. al* (23) reported that a high intensity resistance-training program did not result in statistically significant changes in bodyweight (BW), body fat percentage (BF%), or fat free weight (FFW) after 12-weeks of training, as depicted in Figure 2. The participants training routine included leg extensions, leg curls, squats, bent-knee crunches, bench press, hip flexor, lat pull-downs, arm curls, and a 30-second recovery between exercises. One might surmise that a resistance training program which required subjects to complete three circuits of a variety of exercises three times weekly would enhance FFW and aid in reducing body fat percentage and thus, improve participants maximal aerobic capacity. However, in this study participant's cycling time to exhaustion was significantly increased (pre = 26.3 ± 5.2 min; post = 35.1 ± 6.8 min) and was highly correlated to increased peak torque production and 1 RM leg strength. Marcinik and colleagues concurred with Hickson *et. al* (16) who hypothesized that improved cycling time to exhaustion might be highly influenced by leg strength possibly due to enhanced rate of slow twitch fiber recruitment and reduced rate of fast twitch recruitment in the resistance trained quadriceps musculature.

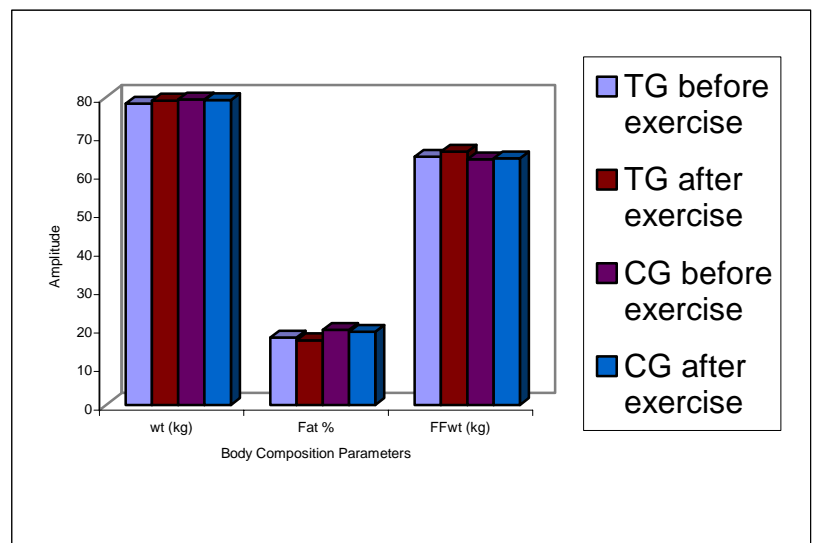


Figure 2. Results from Marcinik *et al.*, 1991.

DISCUSSION

The purpose of this review was to integrate an assortment of articles focusing on the effects of enhanced quadriceps strength on maximal oxygen uptake or predicted oxidative and endurance capacity or both, measured on a treadmill and cycle ergometer. Several researchers' (7,13,16,17) observed that higher volume and increased resistance loading can minimally improve $VO_2\max$ but significantly improve running and cycling endurance performance and cycling time to exhaustion. However, we were unable to locate any articles that elucidated on whether predicted aerobic capacity measured on the cycle ergometer or treadmill is reflected in more accurate tests, which use indirect spirometry to measure $VO_2\max$. We were able to locate one peer-reviewed published abstract (31), whereby a group of researchers examined the effects of reduced aerobic

loading and heavy leg resistance training on predicted aerobic capacity. The researchers (31) who conducted this study had a relatively small cohort of trained men ($n=14$) and they did not perform any pre to post maximal leg strength tests to determine changes in absolute leg strength, nor did they measure VO_2 max to make comparisons between subjects predicted and maximal fitness status.

The assessment and strengthening of the quadriceps femoris cross-sectional area seems prudent when determining one's success on a cycle ergometer. In fact, the vastus medialis and lateralis muscles comprise the quadriceps femoris and are the most activated muscles during cycling. The average peak activation of the vastus medialis is 54 percent and the quadriceps femoris is 50 percent, respectively. Additionally, increases in cycle work rate drastically augment the average maximum activation of the quadriceps muscles (35). Therefore, recommending that a subject participate in a concentrated quadriceps resistance training regimen could be prudent to increasing peak VO_2 when measured on the cycle ergometer.

Increased thigh and leg strength may be an influential constituent for improving cycling performance, according to a study conducted by Bijker, de Groot, and Hollander (4). These investigators tested the differences on leg muscle activity during running and cycling and whether differences in delta efficiency activity existed between the two modes of exercise. Eleven healthy subjects (7 men and 4 women) (mean age 23.7 ± 4 yr., height 1.79 ± 0.10 (cm); and weight 69.3 ± 7.9 (kg)) participated in this study. The investigators used electromyography (EMG) to determine muscle activity noninvasively. EMG is used during exercise when measuring increases and decreases in muscle force. Clear relationships between average EMG skeletal muscle activity exists between concentric exercise and energy expenditure. Mean EMG activity, therefore, can be an accurate method of determining possible differences in the actions of leg muscle activity during cycling and running. Surface electrodes were applied to three superficial leg muscles (gastrocnemius [lateral head], vastus lateralis, and biceps femoris) with an inter electrode distance of at least two centimeters. The researchers observed that during running, the biceps femoris and vastus lateralis muscles showed no relationship between the average EMG activity and the increased external mechanical power output. The metabolic costs of concentric skeletal muscle contractions are much greater than eccentric muscle contractions. The results of this study presently support the idea that concentric muscle actions are much more prevalent in cycling verses running. For running, only the correlation coefficient of the gastrocnemius muscles was significantly different from zero. The average efficiency during running was 42 percent, which was significantly greater than cycling where average efficiency was 25 percent.

The greater efficiency during running relates to the muscle actions. For example, when running up shallow inclines, eccentric muscle actions predominate. However, when running up much steeper inclines, concentric muscle actions dominate. Greater efficiency during running relates to the active stretch induced when landing, which permits the storage of elastic energy that may be reused during the push-off (concentric) phase of running. In contrast, when attempting to run up steeper inclines, the work produced by the leg musculature to overcome the external force (grade) is dissipated and elastic energy stored in the working muscle is lost. During cycling the primary muscle actions are concentric and do not vary (4).

Bishop, et al (5), tested the effects of 12-weeks of resistance training on aerobic endurance performance in a group of 18 to 42 year old trained cyclists. The 21 cyclists were randomly assigned to resistance training (RT; $n=14$) or control group (C; $n=7$). The RT group performed three sets 8 parallel squats (set 1: 15 repetitions with 50% of 1-RM; set 2: 8 repetitions with 70% of 1-RM; set 3: 5 repetitions with 80 % of 1-RM) twice weekly to failure of lifting form. A three-minute recovery bout between each set of squats occurred. The researchers reported that 12-weeks of high resistance and low repetition training considerably increased 1-RM squat strength by 35.9 percent in the RT group and 3.7 percent in the C group. Improvement in squat strength after 6-weeks was also greater in the RT verses the C group. Non-significant changes resulted in groups for peak VO_2 ($ml/kgO_2/min$ and $L/O_2/min$), lactate threshold, and muscle fiber type (i.e., changes in type I or II fiber diameter) These researchers suggest that total volume of resistance training, not necessarily leg strength

improvement is more important in improving cycling time to exhaustion and altering muscle fiber characteristics. Based on the findings, the authors' did suggest that a non-significant improvement in VO_2 peak in the present study could stem from the lack of movement specificity because the subjects were restricted to just one leg exercise (parallel squat). The increased leg strength in 1-RM squat was confined to just one leg resistance exercise and therefore, was not transferred to endurance-cycling performance.

Unlike Bishop, et al Hickson, et al (5,17), observed significant increases in leg strength (1-RM), cycling endurance time to exhaustion, and small increases in VO_2 max after completing 10-weeks of high resistance and low repetition training. However, Hickson, et al (17) included multiple leg exercises, unlike Bishop et al. (5). For instance, subjects enrolled in the Hickson [16] study were required to complete three sets of five repetitions of knee extensions, leg presses, parallel squats, and calf raises with as much weight as possible. Hickson, et al (16), also observed that heavy resistance training of the leg musculature aided in short-term (4 to 8 min) aerobic endurance capacity during cycling and increased cycling time to exhaustion at 80 percent of VO_2 max from 71 to 85 minutes. Subjects enrolled in this study performed five sets of five repetitions of knee extensions, parallel squats, knee flexions, and toe rises. The incorporation of multiple joint movement leg exercises may have transferred to improved cycling performance. In fact, these investigators (16) observed that the eight subjects enhanced their capacity to cycle or run to exhaustion after 10-weeks of concentrated leg exercises.

Sale (26), wrote a review on the effects of resistance training on neural adaptation. He reported that resistance-training can augment changes within the nervous system, which allows a subject to more fully activate prime mover muscles recruited for a specific movement pattern. The prime mover muscles are also better able to activate synergistic and antagonistic muscles, thereby creating greater net force in the movement direction. Resistance training enhances the function of the nervous system to fully activate the amount of force generated by a particular muscle group. A subject's ability to activate a larger cross-sectional area of skeletal muscle could prove to be an important adaptation for improving submaximal and maximal cycle ergometry fitness. Based on several surface electromyographic (EMG) studies, Sale [26] also reports that the relative roles of variation in motor unit firing rates and muscle recruitment can affect the ease with which a muscle group fully activates. For example, when comparing small muscles in the hand to much larger muscles in the legs (soleus, tibialis anterior, and extensor digitorum brevis), untrained subjects experience no difficulty recruiting all motor units in the hand for a 50 percent maximal voluntary contraction (MVC). In contrast, non-resistance trained subjects will have difficulty in both recruiting and maintaining optimal firing rates in the highest threshold units of certain muscles in the legs (soleus, tibialis anterior, and extensor digitorum longus). Furthermore, the non-resistance trained subjects may also experience problems in keeping the highest threshold motor units active in sustained MVCs. The change in motor unit firing rates, may also allow higher threshold motor units to fire continuously for longer durations before they fire intermittently or cease to fire.

Hagerman (14) tested the effects of 16-weeks of high-intensity (85-90% of 1-RM) resistance leg exercises on VO_2 peak, capillary density, 1-RM leg strength, and blood lipids. Two groups of physically active elderly men participated twice weekly in a resistance training program. The resistance-training (RT) group ($n=12$; age= 63.7 ± 5.0 yr.) and untrained (UT) group ($n=10$; age= 66.2 ± 6.5 yr.) did exhibit some type cardiovascular abnormality. A physician examined this group of subjects and defined them as fit to participate in a high-resistance protocol. Although the subjects were physically active, none had ever participated in a heavy resistance-training program. Elderly men who participate in a heavy resistance-training program may not only tolerate equivalent workloads compared to younger subjects, but they also exhibit comparable muscular changes. The RT group in this study completed a warm-up session followed by one set of 10 repetitions at 50 percent of 1-RM. The warm-up set was followed by 3 sets of 6 to 8 repetitions performed at 85 to 90 percent of 1-RM of the following exercises: half squat, double leg press, and double leg extensions. A two-minute recovery period occurred between each set of exercises. The 16-week leg resistance program significantly increased the percentage of Type II skeletal muscle fibers in the legs, 1-RM strength improved from baseline

to post training in the double leg extension (50.5 %), half squat (83.5%), and leg press (72.3%). Capillary density remained unchanged and peak VO_2 and working capacity were significantly improved in the RT group. However, subjects' cardiac mass and volume remain unchanged in both RT and UT groups. These results seem to suggest that this group of resistance-trained men did not make any notable central adaptations, but rather peripheral adaptations in the leg musculature. An increase in the number of capillaries per skeletal muscle fiber occurred after resistance training, but the 19 percent increase in capillarization was still non-significant in the RT group. Based on the findings, the authors suggest that the heavy resistance-training program acts as an aerobic stimulus, which contributed to improvements in VO_2 peak in the RT group of physically active elderly men. This outcome is in agreement with several other researchers (5, 7, 15) who showed comparable results in similarly aged men after participating in heavy loaded leg resistance training.

CONCLUSIONS

Our review indicates that measurement of VO_2 max, time to exhaustion, and the type of physical training program employed may influence endurance capacity on a cycle ergometer or treadmill or both. For example, very heavy resistance training (80% of 1-RM) can educe shifts in myosin heavy chain (MHC) isoforms from type IIb (glycolytic) to type IIa (mixture-oxidative/non-oxidative) in trained peripheri. However, the precise physiological mechanisms attributed to these increases in aerobic capacity, still remains unresolved in the literature.

When VO_2 max is predicted utilizing a cycle ergometer, peripheral adaptations may favorably impact predicted aerobic fitness status. These peripheral adaptations may be attributed to concurrent heavy loaded-high volume (3 sets of 12 to 16 repetitions performed to volitional fatigue) leg resistance training and reduced volume aerobic loading. A group of researchers [31] reported that increased cycling comfort (resulting from increased leg strength) might lower exercise heart rate responses during a sub-maximal cycle test. These same researchers claimed that mechanisms responsible for this change may be associated with the cross sectional area of the trained musculature. If oxidative and non-oxidative skeletal muscle tissue increases, even in the same percentages of the original muscle mass, then any work rate will represent a lesser percentage of that muscle's maximal capacity to complete both aerobic and anaerobic work. Therefore, workload will be perceived as less stressful, subsequently, lowering exercise heart rate and allowing one to exercise for extended durations without fatiguing. However, these researchers (31) did not administer a maximal leg strength test to support their proposed hypothesis. Nonetheless, this was the only study we identified that specifically addressed the effects of reduced aerobic and increased leg resistance loading on predicting VO_2 max on a cycle ergometer.

Will measurement of predicted VO_2 max on a cycle ergometer or treadmill or both, be affected by heavy loaded leg strength exercises and reduced aerobic loading? This question remains unanswered in the literature. Most of the studies we located only examined if and how heavy loaded and high volume leg strength training altered VO_2 max, time to exhaustion, and aerobic endurance. We surmise, based on our extensive search of the literature, that additional research is required to determine whether predicted aerobic capacity measured on a cycle ergometer or treadmill or both, is reflected in more accurate tests (indirect spirometry) that measure VO_2 max. Future researchers should also focus their efforts on determining the effects of diverse physical training protocols on predictive and maximal VO_2 tests that are administered on a cycle ergometer and treadmill. Although aerobic training should, theoretically, enhance a subject's aerobic capacity, others may benefit by performing heavily loaded leg strengthening and reduced aerobic loading exercises.

An additional question that should be addressed in future studies, relates to predictive aerobic tests. Could high volume and heavy loaded leg resistance exercises increase predicted aerobic capacity when measured on a cycle ergometer? If so, will a subject's VO_2 max score on the cycle ergometer be influenced to the same degree as his predicted score? Does the predictive or maximal test or both measure central or peripheral adaptation in the trained skeletal muscle mass? These investigators hypothesize that certain physical training protocols emphasizing heavy loaded leg strength and reduced aerobic loading exercises, may exert a strong influence on

lowering submaximal exercise heart rate responses on certain exercise testing modes (i.e., cycle ergometer, treadmill hill protocol). The lowered exercise heart rates to known work rates may be positively correlated to increased leg strength and muscle mass verses to cardiovascular fitness (central mechanisms). The carry over effect to maximal testing, using the same exercise-testing mode, could be insignificant, however. Therefore, future research in this area is warranted.

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