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**COMBINED STRENGTH AND ENDURANCE TRAINING:
FUNCTIONAL AND MORPHOLOGICAL ADAPTATIONS
TO TEN WEEKS OF TRAINING**

**J. McCarthy
P. Griffith
W. K. Prusaczyk
H. W. Goforth
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**NAVAL HEALTH RESEARCH CENTER
P.O. BOX 85122
SAN DIEGO, CALIFORNIA 92186-5122**

**NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND**



Combined Strength and Endurance Training: Functional and Morphological Adaptations to Ten Weeks of Training

J. McCarthy, Ph.D.¹, P. Griffith, M.S.², W.K. Prusaczyk, Ph.D.²,
H.W. Goforth, Jr., Ph.D.³, and A. Vailas, Ph.D.¹

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¹ Department of Physical Education and Dance, 2000 Observatory Drive, University of Wisconsin, Madison, Wisconsin 53706

² Geo-Centers, Inc., 10903 Indian Head Highway, Fort Washington, Maryland 20744

³ Naval Health Research Center, P.O. Box 85122, San Diego, California 92186-5122

KEY FINDINGS

- Ten weeks of combined strength and endurance training resulted in significant increases in peak oxygen uptake, muscular strength and power, and muscle hypertrophy.
- Functional and morphological adaptations resulting from combined strength and endurance training are similar to those occurring when either strength or endurance training are performed alone.
- Gains in strength/power development are not impaired by combined strength and endurance training at fast or slow contraction velocities, compared to strength-only training.
- Gains in peak oxygen uptake are not inhibited by combined strength and endurance training, compared to endurance-only training.
- Gains in upper body strength and muscle hypertrophy are not inhibited when a three-day-per-week lower body endurance training program is added.
- The results from combined training studies appear to be influenced by training mode, intensity, volume, frequency, and the method of integration of the two training programs.

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SUMMARY

Problem

Strength and endurance training are often combined by military personnel for tasks requiring multiple physical demands such as endurance, strength, and explosive power. While the literature suggests strength development can be inhibited when endurance and strength training programs are combined, scientific information on their compatibility is limited and inconclusive. Groups such as the U.S. Navy SEALs must also consider combining these two forms of exercise within the limited physical training time available.

Objective

The purpose of this study was to examine the effects of strength and endurance training programs, individually and in combination, on performance changes and associated muscle adaptations.

Approach

Sedentary males (n=30) were randomly assigned to one of three training groups: strength-only (STR), endurance-only (END), or combined strength and endurance (COM). Subjects trained three days per week for ten weeks. Strength training consisted of select upper and lower body resistance exercises. Endurance training consisted of continuous cycling for 50 min. Subjects in COM engaged in both the strength and endurance training programs on the same day. Anthropometric characteristics, strength, and peak oxygen uptake (cycling) were measured; biopsies were taken from the vastus lateralis muscle; and mid-thigh computed tomography (CT) scans were performed before and after training.

Results

Groups STR and COM showed significant ($p < 0.05$) increases in: one-repetition maximum squat (23%, 22%) and bench press (18%, 18%); vertical jump (6%, 9%); lean body weight (3%, 5%); mid-thigh girth (3%, 4%); fast twitch (FT) muscle fiber area (24%, 28%); mean muscle fiber area (21%, 23%); thigh extensor (12%, 14%) and flexor (7%, 6%) areas. All groups exhibited significant increases in peak oxygen uptake following training [END (18%), COM (16%), and STR (9%)].

Conclusions

Combining strength and endurance training programs can produce significant concurrent gains in muscular strength and power, muscle hypertrophy, and peak oxygen uptake.

INTRODUCTION

Typically, physical training programs are designed to maintain, improve, or optimize performance. Strength training programs using high-resistance, low-repetition exercises improve muscular performance by increasing the amount of contractile proteins, muscle fiber area, and maximal force output (Brooks, 1987; MacDougall et al. (Sale, Moroz, Elder, Sutton, and Howard) 1986; Moritani and deVries, 1979). In contrast, endurance training programs, typically involving high-repetition submaximal contractions, increase peak oxygen consumption and enhance endurance (Saltin, and Gollnick, 1983).

Strength and endurance training are often combined by the military to condition personnel for tasks requiring multiple physical demands such as endurance, strength, and explosive power. It is essential for special operations personnel such as the U.S. Navy Sea-Air-Land Personnel (SEALs) to optimally combine these two distinct forms of training within the limited physical training time available.

Despite considerable interest in combined strength and endurance training programs, information on their compatibility is limited and inconclusive. Several studies have shown a significant reduction in muscle strength or explosive power gains during combined training, compared to strength training alone (Demment and Miller, 1987; Dudley and D'Jamil, 1985; Hickson, 1980; Hunter, et al. 1987). In contrast, combined training does not appear to impair endurance development, as measured by peak oxygen uptake (Dudley and D'Jamil, 1985; Hickson, 1980; Sale, MacDougall, Jacobs, and Garner 1990). Recently, attention has been focused on the interference of endurance training with the muscles' ability to generate maximal force and power. While some studies have addressed the general responses of strength development during combined training (Dudley and D'Jamil, 1985; Faulkner, Claflin, and McCully, 1984; and Hunter, et al., 1987), further research is needed to identify the specific physiological mechanisms of endurance training that might impair strength development. This study examined the functional, morphological, and cellular adaptations of a single muscle group (i.e., knee extensors) resulting from combined strength and endurance training, conducted collaterally three times per week, for ten weeks. The combination of non-invasive (physical performance, CT scans) and invasive (muscle biopsy) procedures used in this study was selected to facilitate a comprehensive examination of the effects of combined strength and endurance training.

MATERIALS AND METHODS

Subjects

Thirty males, ages 19 to 35, volunteered to participate in the study. Subjects were screened via medical history questionnaire and physical examination. No subjects exhibited symptoms of cardiopulmonary, metabolic, neuromuscular, or musculoskeletal disorders. No participant had exercised regularly (mean $\leq$ one session per week) for at least three months before entering the study. Subjects were assigned randomly to one of three ten-week training programs: a) strength-only (STR); b) endurance-only (END); or c) combined strength and endurance (COM). All subjects were familiarized with the tests and procedures prior to the pre-training test battery. There were no significant differences among groups (combined mean $\pm$ SD) for age (27 ± 1 yr), height (179.6 ± 0.7 cm), or body weight (82.9 ± 1.4 kg) prior to training.

Training

The extensor muscles of the knee were selected as the muscle group to evaluate, in that this group was exercised in both the endurance (cycle ergometer) and the strength (squats and leg extensions) training programs. To reduce the possibility of chronic glycogen depletion, which has been shown to occur in non-endurance trained subjects with consecutive days of training (Caiozzo, Perrine, and Edgerton, 1981; Costill, Bowers, Branam, and Sparks, 1971), a training frequency of three days per week was selected. Detailed descriptions of each program follow.

Endurance Training. The endurance training program consisted of 50 min of continuous cycling on a cycle ergometer. Following a five-minute warm-up, subjects trained at an intensity eliciting 70% of age-predicted heart rate reserve (HRR) (Karvonen, 1957). During the first week of training, sessions were limited to 30 min of cycling (40% reduction), at 67% of HRR. Heart rate (HR) was monitored by the subject (carotid artery palpation). To adjust for training adaptations in resting HR, training HR was recalculated at two-week intervals throughout the study. For subjects unable to maintain the prescribed workload, power output was reduced by 24.5 Watts (W) for the duration of the training session. These adjustments were performed during the first few weeks of the training to ensure that subjects would complete the workout.

Strength Training. The strength training program included eight exercises, each consisting of one warm-up set and three maximal effort sets (six repetition per set, maximum). The warm-up set was performed using 67% of the maximal effort set weight. During the first week of training, weights were determined by trial and error, and only two of three maximal effort sets (67%) were performed. Training weights were increased throughout the training period to maintain the six repetition maximum (RM) criteria (range = 5 to 7). Rest between maximal effort sets averaged 70 sec (range = 60 to 90 sec). All sets of each exercise were performed before moving to the next exercise. Exercises using free weights

included leg squat, bench press, and standing arm curl. Exercises using plate-loaded machines included leg extension, leg curl, wide grip "lat" pull down, over-head press, and heel raise.

Combined Training. Subjects performed all exercises included in both END and STR programs, with 10 to 20 min rest between each program. The order of STR and END training programs was changed on each training day.

Tests and Measurements. A series of baseline tests and measures were collected prior to training. Muscular strength and power, maximal aerobic power, skinfold thicknesses, and limb girths were measured, and muscle biopsies and CT scans were obtained. All tests and measures were repeated at the conclusion of the ten-week training period.

Anthropometry. Limb girths were measured while subjects stood in a relaxed position with body weight equally distributed on both feet. The circumference of each thigh was measured 18 cm above the superior margin of the patella. The maximum girth of the dominant arm was measured while the elbow was flexed at 90°, and the upper arm was held parallel to the floor with the muscles contracted. Girth measurements were made in duplicate; a third circumference was obtained when duplicate measurements varied by more than 1 cm. Skinfold thicknesses were measured in triplicate at three sites (chest, abdomen, and thigh) using Lange calipers; a fourth measurement was taken if the thicknesses varied more than 1 mm. Body density and percent body fat were calculated using the equations of Jackson and Pollock (1978), and Siri (1956), respectively.

Muscle Performance. Isometric and isokinetic strength tests were performed using a LIDO active isokinetic loading dynamometer (Loredan Biomedical, Inc., Davis, CA). Measurements were made at angular velocities of 0, 96, 192, and 288°·sec⁻¹ (Caisozzo, et al. 1981; Osternig, 1986; Perrine and Edgerton, 1978). Isometric contractions were measured at 30° below horizontal (Dudley and D'Jamil, 1985). Isotonic strength (1 RM squat and bench press) was measured using free weights. Explosive power was measured as the best of four vertical jumps.

Peak Oxygen Uptake. Peak oxygen uptake ($\dot{V}O_{2peak}$) was determined on a Schwinn Biodyne cycle ergometer. Oxygen uptake ($\dot{V}O_2$) was monitored continuously using open-circuit spirometry. Subjects warmed up on the ergometer (2 min at 92 W; 2 min at 147 W), then immediately began a progressive, load-incremented protocol, with workload increasing 24.5 W each minute until volitional exhaustion.

Computed Tomography and Muscle Morphology. The cross-sectional area (CSA) of the knee extensor and flexor muscles was measured from CT scans. Scans were made using a DR3 CT scanner (Siemens, Erlangen, Germany), while subjects lay supine. Radiation exposure was minimized by shielding and low exposure factors (125 kVp, 3 seconds, 180 mA). A single, axial transverse image was obtained for the dominant leg at 18 cm above the superior margin of the patella. Single-blind analyses were performed on the scans; the pre- and post-training scans were

analyzed together to maintain consistency in digitizing the same extensor and flexor muscle compartments. The extensor compartment contained the quadriceps muscle (*rectus femoris*, *vastus lateralis*, *vastus medialis*, and the *vastus intermedius*). The flexor compartment contained the *hamstrings*, *adductor magnus*, *adductor longus*, *sartorius*, and *gracilis*. The CSA was manually digitized using JAVA[®] image processing and analysis system (Jandel Scientific, San Rafael, CA). Subsequently, 16 scans (12%) were re-digitized for extensor and flexor areas. The coefficient of variation was below 1% for each scan.

Muscle Biopsies and Histochemistry. Biopsies were taken from the superficial portion of the *vastus lateralis* muscle, 18 cm above the superior margin of the patella on the dominant leg using a sterile, percutaneous needle biopsy technique (Evans, Phinney, and Young, 1982). Local anaesthesia (1% Lidocaine) was administered subcutaneously without penetrating the muscle fascia. A small incision was made through the skin and underlying fascia for biopsy needle insertion. Once the sample was obtained, it was quickly immersed in isopentane cooled with liquid nitrogen. The frozen biopsies were mounted in a refrigerated (-20°C) cryostat microtome (Reichert Histostat, Germany), cut into 10 μ m sections, and placed on glass coverslips for histochemical analysis. Muscle fibers were classified as slow twitch (ST) or fast twitch (FT) using the myofibrillar adenosine triphosphatase (ATPase) reaction at pH 9.4, after preincubation at pH 10.4 (Dubowitz, 1985; Guth and Samaha, 1969).

Muscle fiber CSAs were measured with a computerized digitizing tablet (Houston Instruments, Austin, TX) using single-blind procedure. Images of the sections were projected with a zoom drawing tube (200x) mounted on a Nikon Optiphot microscope. Centrally located fibers, free of freeze artifacts, circular in shape, and with distinct cell borders, were used for calculations. Fiber type distributions were determined from an average ($\pm$ SD) of 718 ($\pm$ 153) fibers (range, 402 to 1045) per sample. The CSA of 64 (range, 51-100) ST, and 87 (range, 51 to 100) FT fibers were measured from these samples to compute mean cross-sectional areas.

Statistical Analysis

The magnitude of change (post-training score minus pre-training score) among the three groups was compared using a one-way analysis of variance. The level of statistical significance was set at $p < 0.05$. Within groups, pre- and post-training scores were compared using two-tailed Student's t-tests with the Bonferroni correction. Fisher's Least Significant Difference post-hoc test was used to identify significant differences between pairs of groups. The effects of training within each group were assessed using a Dunn's Multiple Comparisons procedure with the Bonferroni correction (Kirk, 1982).

RESULTS

The STR, END, and COM training groups completed an average of 30 of a possible 31 training sessions (97% adherence) during the ten-week period. No subject missed more than two training sessions.

Body weight did not significantly change from pre- to post-training in any groups. Lean body weight increased significantly ($p < 0.05$), and percent fat decreased significantly ($p < 0.05$) in both STR and COM. Fat weight decreased significantly in STR and END, but not in COM (Table 1).

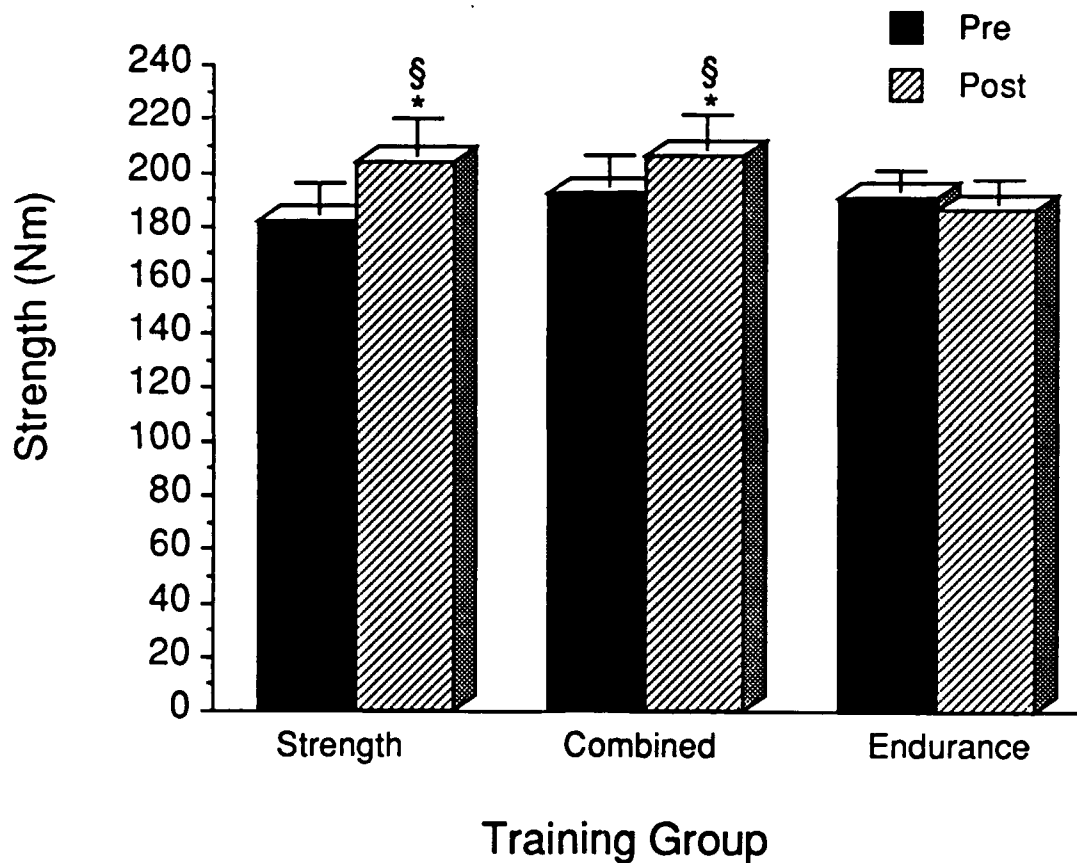
TABLE 1
Physical Characteristics of Subjects
(Mean $\pm$ SEM)

GROUP/VARIABLE	PRE-TRAINING	POST-TRAINING	PRE-TRAINING TO POST- TRAINING DIFFERENCES
Body Weight (kg)			
Strength	82.0 $\pm$ 4.4	82.4 $\pm$ 4.4	0.4 $\pm$ 0.7
Combined	82.1 $\pm$ 4.3	83.7 $\pm$ 4.1	-1.3 $\pm$ 0.5\$
Endurance	84.5 $\pm$ 5.5	83.2 $\pm$ 5.5	1.7 $\pm$ 0.8\$
Lean Body Weight (kg)			
Strength	65.9 $\pm$ 2.1	68.1 $\pm$ 2.3*	2.2 $\pm$ 0.7\$
Combined	65.1 $\pm$ 2.1	68.6 $\pm$ 2.1*	0.3 $\pm$ 0.6\$
Endurance	66.2 $\pm$ 2.6	66.5 $\pm$ 2.5	3.5 $\pm$ 0.4
Fat Weight (kg)			
Strength	16.2 $\pm$ 2.5	14.3 $\pm$ 2.4*	-1.9 $\pm$ 0.5
Combined	16.9 $\pm$ 3.0	15.1 $\pm$ 2.6	-1.6 $\pm$ 0.5
Endurance	18.3 $\pm$ 3.1	16.7 $\pm$ 3.4*	-1.8 $\pm$ 0.7
Percent Fat			
Strength	18.8 $\pm$ 2.0	16.6 $\pm$ 2.0*	-2.2 $\pm$ 0.5
Combined	19.5 $\pm$ 2.8	17.2 $\pm$ 2.4*	-1.8 $\pm$ 0.7
Endurance	20.4 $\pm$ 2.3	18.7 $\pm$ 2.7	-2.3 $\pm$ 0.7
Thigh Girth (cm)			
Strength	52.9 $\pm$ 1.5	54.5 $\pm$ 1.3*	1.6 $\pm$ 0.3\$
Combined	54.3 $\pm$ 1.9	56.3 $\pm$ 1.8*	0.4 $\pm$ 0.4\$
Endurance	54.8 $\pm$ 1.7	55.1 $\pm$ 1.8	2.0 $\pm$ 0.4
Arm Girth (cm)			
Strength	34.1 $\pm$ 1.1	35.1 $\pm$ 1.1*	1.1 $\pm$ 0.2\$
Combined	34.2 $\pm$ 1.3	34.8 $\pm$ 1.2*	-0.2 $\pm$ 0.2\$
Endurance	34.5 $\pm$ 1.1	34.2 $\pm$ 1.2	0.7 $\pm$ 0.2

* Post-training significantly different ($p < 0.05$) than pre-training.

\$ Significantly different ($p < 0.05$) from endurance.

Both STR and COM showed significant ($p < 0.05$) increases in isometric and isotonic strength (Figures 1 and 2a-c), as well as significant ($p < 0.05$) increases in mid-thigh and arm girths and muscle CSA (Table 1). Isometric strength (leg extension) is shown in Figure 1. There was a small (5%) but significant ($p < 0.05$) decrease in isokinetic strength measured at $192^\circ \cdot \text{sec}^{-1}$ for END.



★ = post-training significantly different from pre-training ($p < 0.05$)

§ = significantly different from endurance group ($p < 0.05$)

Figure 1. Isometric Leg Strength (Knee Extension)

CSA of the muscles in the thigh extensor compartment increased significantly ($p < 0.05$) in all groups, although the increase for STR and COM was significantly greater than for END (Table 2). Additionally, significant ($p < 0.05$) increases in CSA were found for the flexor area of the thigh for STR and COM (Table 2).

Histological examination of the muscle biopsies revealed significant ($p < 0.05$) increases in FT fiber CSA for STR and COM, but not for END (Figure 3a). ST fiber CSA increased significantly from baseline ($p < 0.05$) only in STR. No significant differences were found pre- to post-training in FT/ST CSA ratio (Figure 3b) or muscle fiber composition (%ST) (Table 3).

Leg Squat

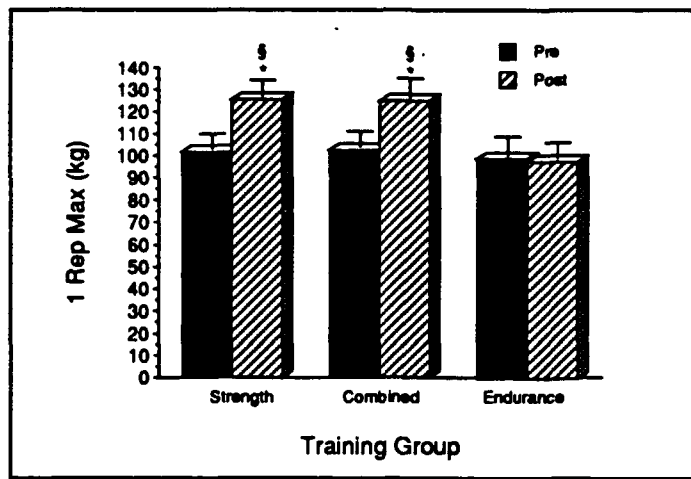


Fig. 2a

* = post-training significantly different from pre-training ($p < 0.05$)
 § = significantly different from endurance group ($p < 0.05$)

Bench Press

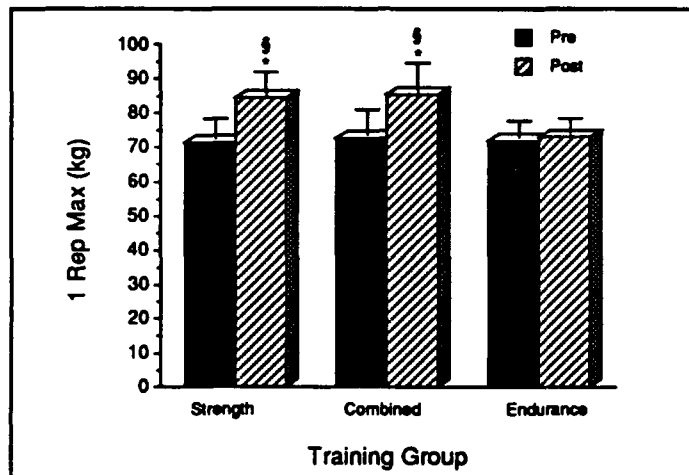


Fig. 2b

* = post-training significantly different from pre-training ($p < 0.05$)
 § = significantly different from endurance group ($p < 0.05$)

Vertical Jump

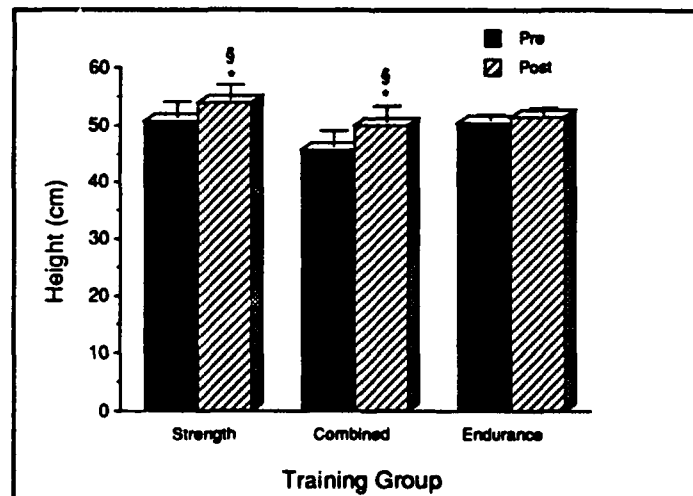


Fig. 2c

* = post-training significantly different from pre-training ($p < 0.05$)
 § = significantly different from endurance group ($p < 0.05$)

Figure 2a-c. Isotonic Exercise

TABLE 2
Thigh Muscle Cross-Sectional Areas
(Mean $\pm$ SEM)

GROUP/VARIABLE	PRE-TEST	POST-TEST	PRE-TRAINING TO POST- TRAINING DIFFERENCES
Extensor Area (cm²)			
Strength	93.6 $\pm$ 3.9	105.0 $\pm$ 4.5*	11.4 $\pm$ 1.7\$
Combined	89.2 $\pm$ 4.9	101.7 $\pm$ 4.5*	2.8 $\pm$ 0.9\$
Endurance	91.7 $\pm$ 4.6	94.5 $\pm$ 4.3*	12.6 $\pm$ 1.5
Flexor Area (cm²)			
Strength	87.1 $\pm$ 5.1	93.4 $\pm$ 5.3*	6.2 $\pm$ 1.4\$
Combined	92.7 $\pm$ 5.4	96.7 $\pm$ 5.8*	-0.1 $\pm$ 1.3\$
Endurance	66.2 $\pm$ 2.6	92.6 $\pm$ 4.8	5.2 $\pm$ 1.6

* Post-training significantly different ($p < 0.05$) than pre-training.

\$ Significantly different ($p < 0.05$) from endurance.

Both absolute ($L \cdot \min^{-1}$) and relative ($ml \cdot kg^{-1} \cdot \min^{-1}$) $\dot{V}O_{2peak}$ increased significantly ($p < 0.05$) from pre- to post-training in all groups (Figure 4). Subjects in END, COM, and STR increased by 18%, 16%, and 9%, respectively.

DISCUSSION

This study employed a combined strength and endurance training program that produced significant increases in both maximal voluntary strength and peak oxygen consumption during a ten-week training program. These functional adaptations were reflected in significant increases in the CSA of flexor and extensor muscles of the thigh, mid-thigh and arm girth, and muscle fiber hypertrophy.

The finding that strength development is not inhibited during combined training contrasts with earlier reports (Dudley, and D'Jamil, 1985; Hickson, 1980; Hunter, et al., 1987). This may be explained in part by differences in training program designs, including: training mode, intensity, duration, volume (number of sets, repetitions, and/or bouts, per training session), frequency (number of sessions per week); subjects' initial fitness levels; and/or method used to integrate the two training programs.

Strength training programs typically involve exercising a muscle group in two or three training sessions per week (Fleck and Kramer, 1987; Pearl and Morgan, 1986); programs exercising the same muscle group more than three times per week have been considered overtraining (Dudley and Fleck, 1987). Symptoms of overtraining, as defined by Dudley and Fleck (1987), include plateauing or decrements of performance despite an adequate training stimulus. One explanation for the effects of overtraining in moderately trained subjects is that consecutive days of endurance training can induce chronic glycogen depletion and result in impaired performance (Costill, Bowers, Branam, and Sparks, 1971).

Fast Twitch Fiber Area

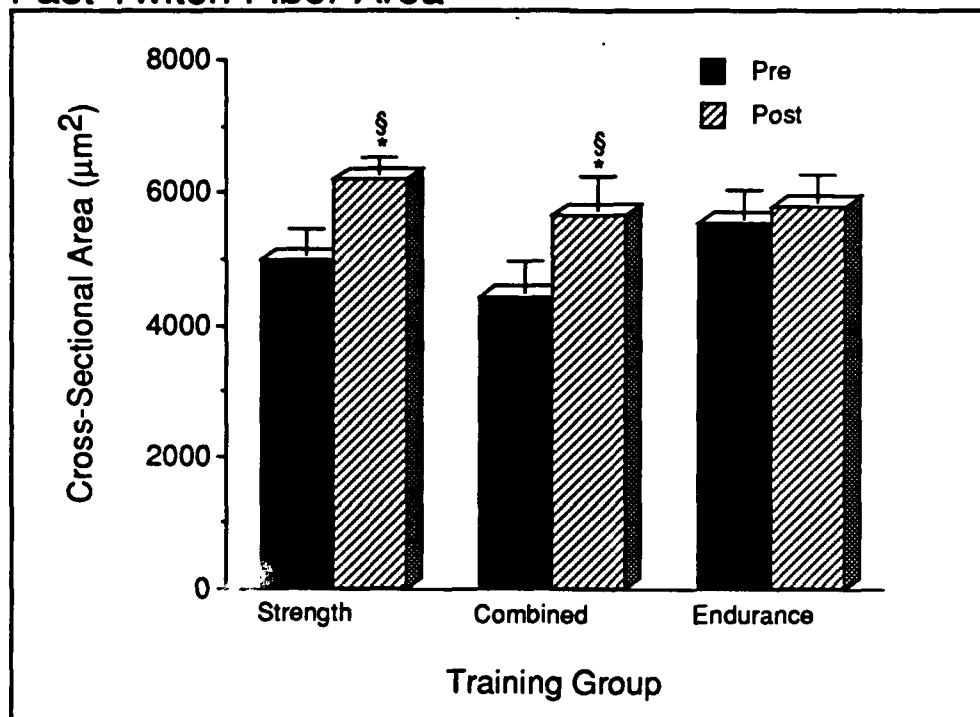


Fig. 3a * = post-training significantly different from pre-training ($p < 0.05$)
§ = significantly different from endurance group ($p < 0.05$)

FT to ST Muscle Fiber Area Ratio

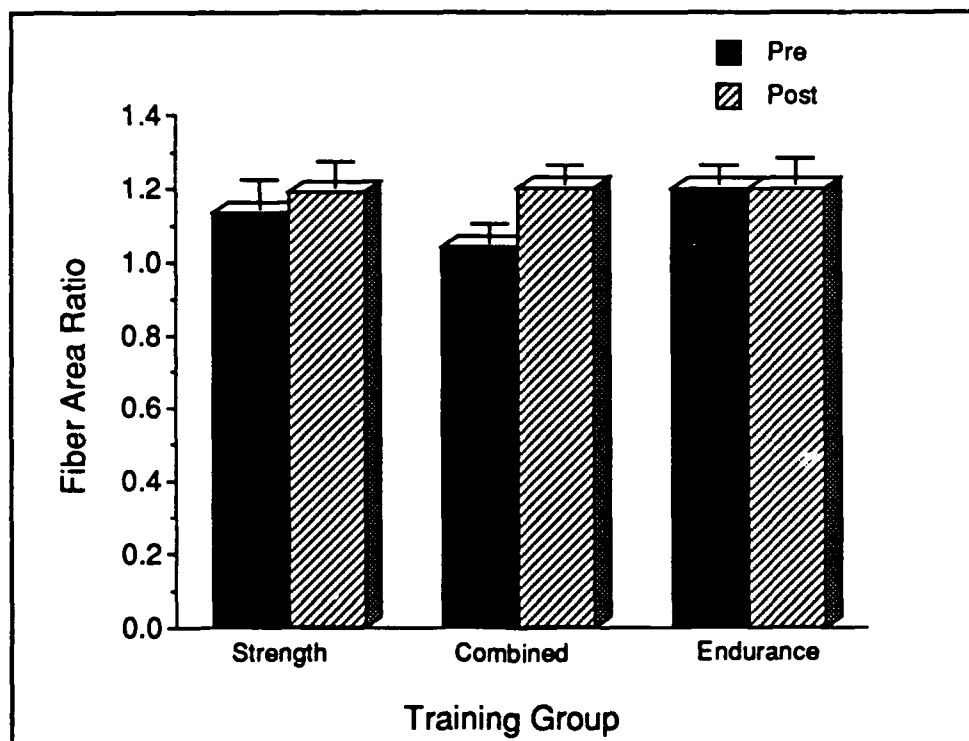


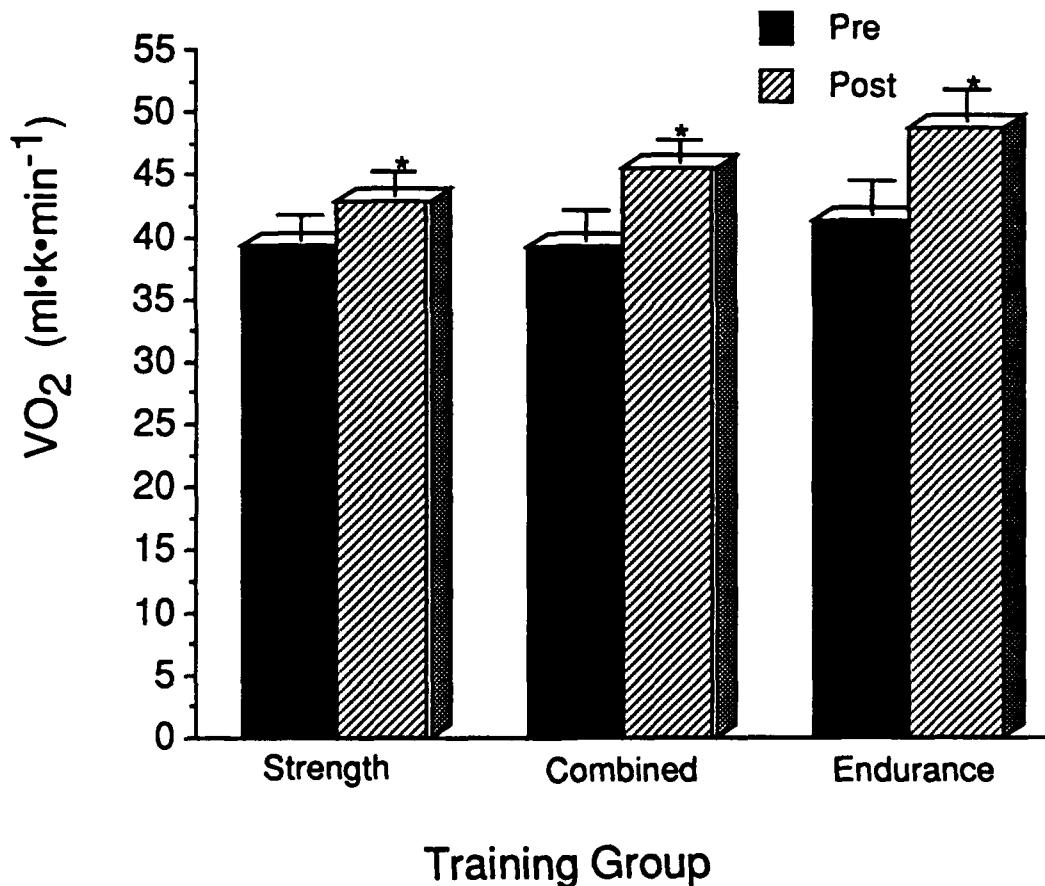
Fig. 3b There were no significant differences ($p < 0.05$) from pre-training to post-training or in comparisons between groups

Figure 3a-b. Fast Twitch Fiber Area, FT to ST Muscle Fiber Area Ratio

TABLE 3
Muscle Fiber Type Composition
(Mean $\pm$ SEM)

GROUP/VARIABLE	PRE-TEST	POST-TEST	PRE-TRAINING TO POST- TRAINING DIFFERENCES
PERCENT SLOW TWITCH FIBERS			
Strength	32.9 $\pm$ 3.5	31.8 $\pm$ 2.7	-1.1 $\pm$ 2.4
Endurance	34.5 $\pm$ 3.2	37.9 $\pm$ 4.6	3.4 $\pm$ 2.9
Combined	37.5 $\pm$ 5.6	39.5 $\pm$ 6.7	2.1 $\pm$ 2.7
PERCENT FAST TWITCH FIBERS			
Strength	67.1 $\pm$ 3.5	68.2 $\pm$ 2.7	1.1 $\pm$ 2.4
Endurance	65.5 $\pm$ 3.2	62.1 $\pm$ 4.6	-3.4 $\pm$ 2.9
Combined	62.5 $\pm$ 5.6	60.5 $\pm$ 6.7	-2.1 $\pm$ 2.7

There were no significant differences pre to post training ($p < 0.0267$).
There were no significant differences in changes between groups ($p < 0.05$).



* = post-training significantly different from pre-training ($p < 0.05$)

§ = significantly different from endurance group ($p < 0.05$)

Figure 4. Maximal Aerobic Power

High frequency and volume of combined training, without adequate nutrition and recovery periods, may contribute to inhibited strength development. In the three studies that reported impairments in strength development (Dudley and D'Jmail, 1985; Hickson, 1980; Hunter et al., 1987), combined training was performed six days per week. Hunter, et al. (1987) and Hickson (1980) employed weight training programs stressing the same muscle group four and five days per week, respectively. When endurance training programs were added, subjects in the combined group engaged in six consecutive days of intense exercise, and experienced significantly less increase in strength development compared to the strength-only group (Hickson, 1980; Hunter, et al., 1987). Conversely, in other studies when subjects performed combined training programs on alternate days, no inhibition on strength development was found (Bell, et al., 1991; Sale, et al., 1990a). Alternating training days may be of importance in combined training programs. In such programs, the exercised muscles may have sufficient time to recover and adapt (e.g., maintain muscle glycogen, hematocrit, resting creatine kinase activity, and resting cortisol levels) (Newsholme, et al, 1991).

Interference with optimal strength or aerobic power development during combined strength and endurance training can occur when opposing physiological stimuli are imposed (Dudley and Fleck, 1988). In the present study, the strength and endurance training protocols were designed to induce gains only in muscular strength and $\dot{V}O_{2peak}$, respectively. However, like Sale et al. (1990a), the physiological demands of the strength and endurance programs resulted in similar, rather than opposite, adaptations. For example, significant hypertrophy of thigh extensor muscles was found in END, and a significant increase (9%) in $\dot{V}O_{2peak}$ occurred in STR. Cycling exercise has been shown to increase leg muscular strength (Faulkner et al., 1984; Fleck and Kramer, 1988) and muscle size (Caiozzo et al., 1981). Thus, the mode of exercise (e.g., cycling, as in this study) may have contributed to muscle hypertrophy in END. Similarly, increases in cycling $\dot{V}O_{2peak}$ have been reported (Davies, 1977; Sale et al., 1990b) resulting from strength training. Sale et al. (1990b) reported an 8% increase in $\dot{V}O_{2peak}$ (on a cycle ergometer) following 22 weeks (3 days per week) of hip/knee extension resistance training; an increase very similar to that found in the present study for STR (9%). Hickson (1980) has demonstrated that $\dot{V}O_{2peak}$, measured on a cycle ergometer, is related to leg muscle size. Therefore, the increase in $\dot{V}O_{2peak}$ in STR may be explained in part by extensor muscle hypertrophy.

Strength training, when combined with endurance training, does not appear to interfere with gains in $\dot{V}O_{2peak}$, and in fact, for cycling exercise, appears to enhance $\dot{V}O_{2peak}$. Similar increases in $\dot{V}O_{2peak}$ were found for both END (18%) and COM (16%), consistent with previous combined training studies (Dudley and D'Jamil, 1985; Hickson, 1980; Hunter et al., 1987; Nelson, Conlee, Arnall, Loy, and Silvester, 1984; Sale et al., 1990b). Despite a potential dual stimulus to

enhanced aerobic power in the COM group above the END group, peak aerobic power did not differ significantly between groups, a finding previously reported by Sale, et. al. (1990a).

The development of upper body strength (non-aerobically trained muscles) was not compromised by the addition of the endurance training program. The strength gains in one-repetition maximum bench press, for both strength and combined training programs, have been reported previously (Hunter et al., 1987).

A brief review of the processes occurring at the cellular level helps elucidate the mechanisms underlying functional adaptations that occur with combined strength and endurance training. Muscle function is related to both muscle fiber size and type (Saltin and Gollnick, 1983). Generally, muscles with a larger proportion of ST fibers are less susceptible to fatigue and facilitate sustained aerobic activity (Saltin and Gollnick, 1983). Conversely, muscles rich in FT fibers can generate more force, especially at rapid contraction velocities (Faulkner, Claflin, and McCully, 1984). Strength training programs, using high-resistance exercises at low-repetitions (such as the present study), can increase muscle fiber area (Moritani and deVries, 1979); however, endurance training programs rarely induce changes in muscle fiber area (Saltin, and Gollnick, 1983). In the current investigation, STR and COM induced hypertrophy of muscle fibers in parallel with isotonic and isometric strength gains.

In conclusion, ten weeks of combined strength (upper and lower body resistance exercise) and endurance (cycling) training three days per week induced concurrent increases in muscular strength, muscle hypertrophy, and $\dot{V}O_{2peak}$ in sedentary adult males. The underlying physiological mechanisms related to strength development indicate that impairment of strength development need not result from combined training. Furthermore, in contrast to previous research, the training protocol employed in this study provides an exercise regimen that induces simultaneous gains in strength and endurance.

CONCLUSION

Research has suggested that the development of muscular strength can be inhibited when endurance and strength training programs are combined. The purpose of this study was to examine the effects of a combined strength and endurance training program on morphological and performance adaptations. Thirty untrained males engaged in one of three training programs: strength-only (STR) (upper and lower body resistance training); endurance-only (END) (50 min of continuous cycling); or combined strength and endurance (COM). Subjects trained three days per week for ten weeks. Anthropometric, strength, and peak oxygen uptake ($\dot{V}O_{2peak}$) measurements, muscle biopsy samples (for muscle fiber analysis), and computed tomography (CT) scans, [for cross sectional area (CSA) of thigh

muscles) were collected pre- and post-training. STR and COM showed significant ($p < 0.05$) increases in strength, power, thigh girth, FT muscle fiber CSA, and thigh extensor and flexor muscle CSA. All groups showed significant increases in $\dot{V}O_{2peak}$. The combined strength and endurance training program used in this study increased $\dot{V}O_{2peak}$ and did not interfere with gains in strength, power, or muscle hypertrophy.

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