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Interference of Strength Development by Simultaneously Training for Strength and Endurance*

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Summary. The purpose of this study was to determine how individuals adapt to a combination of strength and endurance training as compared to the adaptations produced by either strength or endurance training separately. There were three exercise groups: a strength group (S) that exercised 30–40 $\min \cdot day^{-1}$, 5 $days \cdot week^{-1}$, an endurance group (E) that exercised 40 $\min \cdot day^{-1}$, 6 $days \cdot week^{-1}$; and an S and E group that performed the same daily exercise regimens as the S and E groups. After 10 weeks of training, $\dot{V}O_{2\,max}$ increased approx. 25% when measured during bicycle exercise and 20% when measured during treadmill exercise in both E, and S and E groups. No increase in $\dot{V}O_{2\,max}$ was observed in the S group. There was a consistent rate of development of leg-strength by the S group throughout the training, whereas the E group did not show any appreciable gains in strength. The rate of strength improvement by the S and E group was similar to the S group for the first 7 weeks of training, but subsequently leveled off and declined during the 9th and 10th weeks. These findings demonstrate that simultaneously training for S and E will result in a reduced capacity to develop strength, but will not affect the magnitude of increase in $\dot{V}O_{2\,max}$.

Key words: Maximum oxygen uptake – Weight training – Heavy resistance training

The adaptation to exercise is related to the type of training stimulus. For example, heavy resistance, low-repetition strength exercise, such as weight training, results in increases in strength and in muscle cell hypertrophy (Gollnick et al. 1972; Thorstensson et al. 1976) with little or no increases in maximum oxygen uptake capacity (Allen et al. 1976; Gettman et al. 1978; Wilmore et al.

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1978). In contrast, light resistance, high-repetition endurance exercise, such as running, swimming, and cycling, results in increases in muscle mitochondria, muscle myoglobin, maximum oxygen uptake, and the capacity to perform prolonged work without an accompanying increase in strength or muscle hypertrophy (Åstrand and Rodahl 1970; Holloszy and Booth 1976). At present it is not yet known if it is possible to adapt to these extreme forms of exercise in the same individuals simultaneously. Therefore, the present study was undertaken to determine how selected adaptations to a combination of strength and endurance training compared with those produced by either strength or endurance training separately.

Methods

Subjects

The subjects were divided into three exercise groups. These groups performed either strength training (S), endurance training (E), or strength and endurance training (S and E). Eight subjects, seven males and one female aged between 18 and 27 (mean = 22) volunteered for strength training. For the endurance training, eight subjects, five males, and three females between the ages 19 and 36 (mean = 25) volunteered. There were seven subjects, five males, and two females aged between 18 and 37 (mean = 26) in the strength and endurance training group. Several of the subjects were active in recreational sports but none had been training on a regular basis for at least 3 months prior to the start of the exercise programs.

Strength Training Program

The exercise program consisted of weight training 5 days per week for 10 weeks, and was designed exclusively to increase leg strength. On 3 days per week the subjects performed the following: parallel squats, five sets of five repetitions; knee flexions, three sets of five repetitions; and knee extensions, three sets of five repetitions. On alternate days they performed the following: leg presses, three sets of five repetitions; and calf raises, three sets of 20 repetitions. All exercises were performed with as much weight as possible; initially the subjects exercised at approx. 80% of maximum weight. As strength increased, additional weight was added to maintain maximal resistance for the required repetitions. The sets were separated by 3-min recovery periods. The parallel squats and calf raises were performed using olympic-style weights; the flexions, extensions, and presses on a Universal Gym. The subjects also did deadlifts and sit-ups on days 2 and 4 to strengthen their back and abdominal muscles, so as to avoid injury. All training sessions were supervised.

Endurance Training Program

The subjects were required to exercise 6 days per week for 10 weeks. The program consisted of interval training on an ergometer 3 days per week and of continuous running on the alternate days. The interval training consisted of six 5-min sessions of bicycling at a work rate that approached the subjects' $\dot{V}O_{2\,max}$. The intervals were separated by 2 min of rest. As the subjects' power output increased during the training, the work rate on the bicycle also was increased to approach their $\dot{V}O_{2\,max}$. The running program consisted of continuous running as fast as possible for 30 min/day during the 1st week, 35 min/day during the 2nd week, and 40 min/day thereafter.

Strength and Endurance Training Program

The subjects in this group underwent the same exercise regimens at the same intensities as performed by the strength group and as performed by the endurance group. There were usually at least 2 h of rest or inactivity separating the two types of training, although one subject performed the second regimen after only a 15–30 min rest.

Measurement of Strength

Leg strength was assessed by determining the maximum amount of weight that could be lifted for one repetition in a parallel squat. This measurement was selected because the emphasis of the strength training program was on the quadriceps muscles and to permit comparisons with the endurance group whose training emphasis was also placed on the lower extremities. The subjects were familiarized with all procedures prior to testing. The criterion for determining strength was the inability to continue to perform a single repetition against increasing resistances. These determinations were made before the start of training and at weekly intervals during the 10 weeks of training in the strength and in the strength and endurance training groups. The subjects in the endurance group were tested before and after 10 weeks of training. All tests were conducted by the same investigator. Leg extensions were used in place of the squats for the weekly measurements of strength in one subject (S and E) group because of minor hamstring muscle problems.

Measurement of $\dot{V}O_{2\,max}$

Maximum oxygen uptake was measured during work on a bicycle ergometer and a treadmill. The subjects were familiarized with bicycling and treadmill running in advance of the testing. For the initial $\dot{V}O_{2\,max}$ tests the subjects performed exercise bouts of 4–8 min duration against progressively increasing workloads. In general, for the bicycle tests the work rates were increased at 1-min intervals with the amount varying according to the subjects' exercise capacity, while for the treadmill tests speed and/or grade were increased at 1-min intervals with the amount of work also varying according to each subjects' exercise capacity. There was a minimum of two tests per subject on the bicycle and on the treadmill. The criterion that $\dot{V}O_{2\,max}$ showed no further increase ("leveling off") or a decrease with increasing workloads was used to establish maximum values in all subjects in the pretraining tests. Average heart rates of at least 185 bpm and an average respiratory quotient at $\dot{V}O_{2\,max}$ of at least 1.10 were observed on all tests and served as additional criteria. These same criteria remained constant throughout the program. The subjects who were in the endurance and who were in the strength and endurance groups were tested in a similar manner after 5 and 10 weeks of training. The strength group was retested only after 10 weeks of training.

During the exercise tests, the subjects' expired air was continuously analyzed for volume, O_2, and CO_2 concentration with a Beckman Metabolic Measurement System that has been described in detail previously (Wilmore et al. 1976).

Girth and Skinfold Measurements

Thigh girth on each leg was measured with a cloth tape at the midpoint from the greater trochanter to the superior border of the patella. Skinfolds were measured with Lange skinfold calipers at the following sites: triceps, subscapula, superiliac, pectoralis (chest) or posterior thigh (females) and anterior thigh. Percent fat was calculated according to the procedures described by Yuhasz (1965).

Statistical Procedures

The time course data were evaluated using multivariate analysis of covariance (or variance) with repeated measures ("profile analysis") (Morrison 1976). Significant multivariate effects were followed by examination of appropriate univariate analysis of variance procedures. These analyses were performed with the REGM program designed by Wilkinson (1975). Other data were analyzed with the use of paired *t*-tests.

Results

Body Composition

Statistical trends within each group were the same whether all subjects or just the males alone were considered. Thus, the responses to these programs were identical in the males and females and they were grouped accordingly. Body weight increased in the S group, decreased in the E group, and did not change in the S and E group (Table 1). Thigh circumference increased with strength and strength and endurance training but remained unaffected by endurance training. Relative body fat decreased significantly in the E, and S and E groups. Between group differences were not statistically significant for any measurement.

Strength Development

There were no statistically significant differences in strength between the groups prior to the start of training. Average strength in the S, and S and E groups increased at approximately the same rate throughout the first 7 weeks of training (Fig. 1), and continued to increase in the S group throughout the entire 10 weeks of training. The average improvement in the S group was 42 kg, 44% above the starting values. In contrast, strength increments in the S and E group leveled off between the 7th and 8th weeks and surprisingly decreased during the 9th and 10th weeks of training. The peak improvement observed in the 7th week was approximately 30 kg, 34% above pretraining levels while the magnitude of

Table 1. Effects of the three types of training programs on body weight, thigh girth, and percent fat

Group	Body weight (kg)		Thigh girth[a] (cm)		Percent fat	
	Before training	After training	Before training	After training	Before training	After training
Strength (8)	75.8 ± 3.4	77.7 ± 3.3[b]	53.3 ± 1.2	55.6 ± 1.1[b]	14.5 ± 1.4	13.7 ± 1.1
Endurance (8)	77.0 ± 4.9	74.8 ± 4.2[c]	54.4 ± 1.5	54.3 ± 1.0	17.8 ± 2.5	14.2 ± 1.6[c]
Strength and Endurance (7)	82.2 ± 7.3	81.4 ± 6.9	54.7 ± 1.4	56.4 ± 1.7[c]	15.3 ± 2.8	13.0 ± 2.2[c]

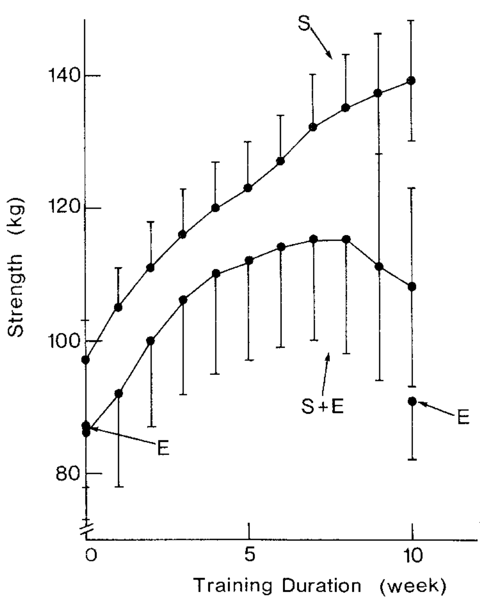
Values are means ± SE. Number of subjects are given in parentheses
[a] Average thigh girth for both legs
[b] Before vs. after Training, $p < 0.01$
[c] Before vs. after Tarining, $p < 0.05$
Percent fat means are for six subjects in the S and E group

improvement observed after 10 weeks of training was 22 kg, 25% higher than starting levels. The losses in strength were observed in all S and E subjects during the course of the 10-week program. Group mean differences by week were significantly different from the 7th through the 10th week of training, thus indicating different responses by the S, and S and E groups over this period. Mean values between the S, and S and E groups at each week of training also approached statistical significance by the 10th week of training (Fig. 1). The endurance-trained subjects did not significantly increase their strength after 10 weeks of training.

The amount of weight lifted in the squats during the course of training showed a similar pattern to the gain and subsequent loss in strength by the S and E group. The average training weights lifted for each repetition was 69 kg in the 1st week of training, 95 kg in the 7th week, and 91 kg in the 10th week. At the same time, the average training weights in the S group also paralleled their development of strength. They averaged 75 kg in the 1st week, 105 kg in the 7th week, and 114 kg in the 10th week of training.

Maximum Oxygen Uptake

There were no statistically significant differences between the E group and the S and E group on the rate of increase in $\dot{V}O_{2\,max}$. As shown in Table 2, after



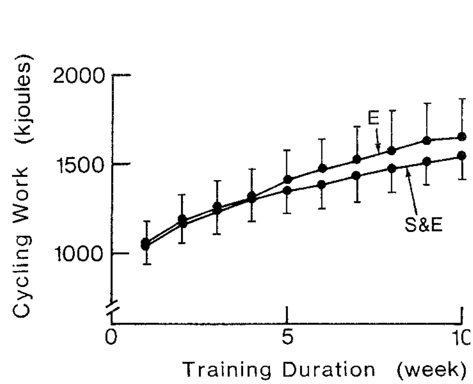


Fig. 1. Strength changes in response to the three types of training. Measurements were made on a weekly basis in the strength (S) and strength and endurance (S and E) groups. The endurance (E) group was tested before and after 10 weeks of training

Fig. 2. Increases in average total bicycle work per week during the 10 weeks of training in the endurance (E) and strength and endurance (S and E) groups

Table 2. Effects of the three types of training programs on $\dot{V}O_{2max}$

Training Group	Bicycle			Treadmill		
	Before training	After 5 weeks	After 10 weeks	Before training	After 5 weeks	After 10 weeks
Strength (8)						
$l \cdot min^{-1}$	3.30 ± 0.28	–	3.43 ± 0.29^a	3.54 ± 0.24	–	3.68 ± 0.28
$ml \cdot kg^{-1} \cdot min^{-1}$	43.8 ± 2.6	–	43.9 ± 2.6	46.7 ± 1.9	–	47.4 ± 2.3
Endurance (8)						
$l \cdot min^{-1}$	3.10 ± 0.31	3.49 ± 0.34^a	3.82 ± 0.35^a	3.39 ± 0.29	3.65 ± 0.31^a	3.96 ± 0.32^a
$ml \cdot kg^{-1} \cdot min^{-1}$	40.1 ± 2.7	46.6 ± 3.1^a	50.9 ± 3.4^a	44.2 ± 2.4	48.5 ± 2.6^a	52.8 ± 3.0^a
Strength and endurance (7)						
$l \cdot min^{-1}$	3.14 ± 0.34	3.51 ± 0.34^a	3.72 ± 0.38^a	3.42 ± 0.33	3.77 ± 0.36^a	4.00 ± 0.37^a
$ml \cdot kg^{-1} \cdot min^{-1}$	38.1 ± 2.7	42.6 ± 2.3^a	47.1 ± 1.7^a	41.6 ± 2.7	46.3 ± 2.5^a	49.0 ± 2.4^a

Values are means ± SE. Number of subjects are given in parentheses
[a] Significantly different from before training, $p < 0.01$

10 weeks of training the average increases in $\dot{V}O_{2\,max}$ in $l \cdot min^{-1}$ were 23% in the E group and 18% in the S and E group during bicycle testing and 17% in both groups during the treadmill testing. The average increases in $ml \cdot kg^{-1} \cdot min^{-1}$ also were similar in both groups averaging 27% and 19% during the bicycle and treadmill testing, respectively, in the E group and 24% and 18%, respectively, in the S and E group. Average total cycling work performed during the training was not statistically different between the E, and S and E groups (Fig. 2). $\dot{V}O_{2\,max}$ in $l \cdot min^{-1}$ increased slightly (4%) ($p < 0.01$) in the S group during bicycle exercise; otherwise, strength training did not result in any significant changes in maximum oxygen uptake either when expressed in absolute or relative values.

Discussion

To determine whether it is possible to adapt to these different types of exercise at the same time the following considerations were taken into account in the experimental design: (1) both types of training would involve the same muscle groups; (2) the responses to the endurance regimen and to the strength regimen would not overlap; that is, there would be no increase in strength with endurance training; and there would be no increase in $\dot{V}O_{2\,max}$ with strength training; and (3) the magnitude of change in the criteria variables ($\dot{V}O_{2\,max}$ and strength) would be large enough to detect any divergent responses by the groups. An endurance program that involved low resistance, high-repetition weight training was not considered because such programs do not increase $\dot{V}O_{2\,max}$ to a great extent (Allen et al. 1976; Gettman et al. 1978; Wilmore et al. 1978). The exercise programs in this current investigation were patterned after previous endurance (Hickson et al. 1977) and strength (Thortensson et al. 1976) training studies, because they most clearly fulfilled the design considerations stated above.

Heavy resistance training produced increases in strength so that on a weekly basis it was possible to note significant improvement throughout the 10-week training program. In contrast, heavy resistance training combined with a program of endurance training produced significant improvement in strength during the first 6–7 weeks, followed by a leveling-off period, then surprisingly strength decreased during the last 2 weeks of the training program. These results provide suggestive evidence that at the upper limits in the development of strength, aerobic training inhibits or interferes with further increases in strength.

Since the subjects were training 80 $min \cdot day^{-1}$ an argument could be made that the marked impairment of strength development by the S and E group is the result of the development of residual fatigue. Yet, this may not be the case. Endurance work per week performed on the bicycle ergometer increased at approximately the same rate in the E, and S and E groups, particularly during the 9th and 10th weeks of training, at a time when strength gains in the S and E group were dramatically decreasing. Thus, the effects on strength development appear to be selective.

In the early stages of the training, it appeared these apparently opposite adaptations (increases in strength and $\dot{V}O_{2\,max}$) were occurring in the S and E group to the same extent as they would have normally occurred if either strength or endurance training were being performed alone. In addition, there was a possibility this training would have an additive effect; in other words, S and E training would result in greater increases in strength or endurance or both than observed with either type of training performed alone. As it turned out, neither possibility prevailed with respect to the attainment of strength. Nevertheless, the increases in $\dot{V}O_{2\,max}$ were similar in the E, and S and E groups. Consequently, these findings suggest there is no relationship between the acquisition of strength and the rate of increase in aerobic power.

From a practical standpoint, light resistance, high-repetition training is used by athletes preparing for low-intensity, long-duration events; while heavy resistance, low-repetition training is used by athletes preparing for high-intensity, short-duration events. The results of this study suggest that there is little or no benefit for endurance athletes to strength train at the same time; and furthermore, it might be deleterious for strength athletes to perform strenuous endurance activities simultaneously.

It has generally been thought that $\dot{V}O_{2\,max}$, as measured on a cycle, is related to leg-muscle size; whereas, on the treadmill it is less so. The results of the present study showed that $\dot{V}O_{2\,max}$ in the E group increased approx. 25% on the cycle-ergometer without any change in thigh circumference. In contrast, in the S group thigh girth increased with training, yet there were only minimal changes in $\dot{V}O_{2\,max}$ on the cycle. These findings suggest indirectly that other adaptations within the circulatory system and skeletal muscles, besides an increase in muscle size, are involved in the increase in $\dot{V}O_{2\,max}$ during cycling with endurance training.

Skeletal muscle adaptations to strength and to endurance training are quite varied and appear unrelated. Strength-induced changes include hypertrophied muscles with a larger area of fast-twitch fibers (Gollnick et al. 1972; Costill et al. 1979) an increased potential for myofibrillar contractility (Thorstensson 1975), an increased capacity to rapidly resynthesize ATP from immediate sources of energy (Thorstensson et al. 1976; MacDougall et al. 1977), and no change or a decrease in respiratory capacity (Gollnick et al. 1972; Carlo et al. 1975). On the other hand, the muscles of endurance-trained individuals contain a greater mitochondrial concentration with an associated capacity to generate ATP aerobically without an increased muscle size (Holloszy and Booth 1976), contractile properties are unchanged in mixed muscles (Barnard et al. 1970) or only slightly increased in slow-twitch muscles (Baldwin et al. 1975; Fitts and Holloszy 1977), and the capacity to rapidly resynthesize ATP from immediate sources of energy also remains unchanged (Oscai and Holloszy 1971). Although it is beyond the scope of this study to speculate on the biochemical adaptations to S and E training, an important unanswered question is whether the observed impairment of strength development, but not to endurance during the training, is directly related to the muscles inability to adapt to both forms of exercise.

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