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INTERACTION BETWEEN CONCURRENT STRENGTH AND ENDURANCE TRAINING. PHASE I

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INTERACTION BETWEEN CONCURRENT STRENGTH AND ENDURANCE TRAINING

REPORT ON PHASE I

(Contract serial number 8SE85-00082)

by

DR. D.G. SALE

Department of Physical Education

McMaster University

Hamilton, Ontario

L8S 4K1

Submitted to:

Dr. Ira Jacobs
Biosciences Division
Defence and Civil Institute of
Environmental Medicine
1133 Sheppard Avenue West
Downsview, Ontario
M3M 3B9

ABSTRACT

Four young men (M) and women (F) did combined strength (S) and endurance (E) training with one leg and S training only with the other leg. A second group (4 M, 4 F) did combined (E + S) training with one leg and E training only with the other leg. Training (3 sessions/wk for 22 wks) consisted of 6 sets of 15-20 RM on a weight resistance leg press machine (S) and 5, 3 min bouts of cycle ergometer exercise at 90-100% $\dot{V}O_2$ max (E). Voluntary strength (1 RM, leg press) increased after training in both legs of the S/S + E group ($p < .01$). There was no significant impairment of strength development in the S + E leg. $\dot{V}O_2$ max ($p < .01$), repetitions at 80% 1 RM increased in both legs. Repetitions at 80% 1 RM increased more in the S + E than the S leg ($p < .05$). $\dot{V}O_2$ max ($p < .01$), repetitions at 80% 1 RM ($p < .05$) and repetitions with the pretraining 1 RM increased in both E and E + S legs after training; E + S training did not impede development of $\dot{V}O_2$ max, but caused greater increases in repetitions at 80% 1 RM and repetitions with the pretraining 1 RM ($p < .05$). Voluntary strength increased more in the E + S leg than the E leg ($p < .05$). It was concluded that E + S training, 1) does not impede strength development, 2) does not impede development of $\dot{V}O_2$ max, 3) enhances (vs E) increases in repetitions at 80% 1 RM and repetitions with the pretraining 1 RM.

INTRODUCTION

Three recent studies demonstrated an apparent antagonism between concurrently conducted strength and endurance training. In two of the studies, endurance training superimposed on strength training impeded strength development. For the third study, there was a trend toward inpeding increases in maximal aerobic power by concurrent strength training. The mechanisms responsible for the antagonism between strength and endurance training are unknown; however, the trend toward reduced development of aerobic power in the one study was associated with reduced increases in an oxidative enzyme.

Such research is presently particularly relevant to the military in light of the increasing awareness of the strength component which is involved in many military tasks. Special strength training programmes have been instituted for high performance aircraft crew because of the purported beneficial effect on +Gz tolerance. The benefits of endurance training are well established and accepted; therefore, it is important to the military in particular to clarify any possible antagonism between strength and endurance training in order to develop efficient training methods to avoid such antagonism.

STATEMENT OF WORK

Accordingly, a project was designed to answer the following two questions:

1. What are the mechanisms underlying the apparent antagonism between concurrent strength and endurance training?
2. How can strength and endurance training be combined to minimize antagonism?

Phase I of the project (1985-86) addressed question 1 and Phase II (1986-87) will address question 2. The design of Phase II will be developed on the basis of the findings of Phase I. Herein the results of Phase I are reported.

REVIEW OF LITERATURE

Three recent studies have addressed the possible antagonism between concurrent strength and endurance training. In one study (Hickson, 1980), concurrent strength and endurance training for 10 weeks impeded strength but not endurance development. One group (S) of subjects (7M, 1F) trained exclusively for strength 5 days per week. On 3 days, subjects performed parallel squats (5 x 5 RM), knee flexions (3 x 5 RM) and knee extensions (3 x 5 RM). On 2 days, leg presses (3 x 5 RM) and calf raises (3 x 20 RM) were done. A second group (E, 5M, 3F) trained exclusively for endurance 6 days per week. On three days per week, 6, 5 min bouts on a cycle ergometer were done at a power output close to $\dot{V}O_2$ max. Bouts were separated by 2 min rest periods. On the three other days per week, subjects ran as fast as possible for 30-40 min. A third group (S + E) of subjects (5M, 2F) did both the strength and endurance training. There was usually about 2 h of rest between the two types of training. Strength (1 RM, parallel squat) increased in both the S and S + E groups for the first 7 wks of training. Thereafter, strength in the S + E group declined whereas strength continued to increase in the S group until the end of the training period (10 wks). Thus, concurrent endurance training caused an impairment of strength development. However, there was no significant difference between the S and S + E groups in increases in thigh girth. The E group did not make significant increases in strength or thigh girth. Endurance, measured in $\dot{V}O_2$ max. on the cycle ergometer and treadmill, increased significantly and similarly in E and S + E groups; thus, concurrent strength and endurance did not impede development at $\dot{V}O_2$ max.

In a second study (Nelson et al. 1984), concurrent strength and endurance training for 20 weeks did not cause a significant impairment of strength or endurance development, although there was a trend toward impairment of endurance development. One group of male subjects (N = 5) trained for strength on an isokinetic device (Cybex II) 4 d/wk by doing 3 sets of 6 knee extensions at 30^{o}. A second group (N = 4) trained for endurance 4 d/wk by pedalling for 1 h/d at 85% max HR on a cycle ergometer. A third group (S + E) of subjects (N = 5) trained for both strength and endurance. Although the E group made greater increases in $\dot{V}O_2$ max and citrate synthase (from needle biopsy samples of vastus lateralis) than the W + E group, the difference in response was not significant. The S and S + E groups made similar increases in strength (peak torque on the Cybex II). Both S and E training caused similar hypertrophy of type II fibres but no change in type I fibres.

In the third study (Dudley and Djamil, 1985), concurrent strength and endurance training for 7 wks did not impede endurance development but did impede high but not low velocity isokinetic strength. Twenty-two subjects (14F, 8M) were divided into 3 groups (sex distribution not specified). One group (E, N = 10) trained exclusively for endurance 3 d/wk on a cycle ergometer by doing 3, 5 min bouts at a power output approaching $\dot{V}O_2$ max. Five minute rest periods separated bouts. A second group (S, N = 6) trained exclusively for strength 3 d/wk by performing 2, 30s sets of maximal knee extensions (about 26 - 28 extensions per bout) at a velocity of 4.19 rad/s. A third group (S + E, N = 6) did the endurance training 3 d/wk and the strength training 3 other d/wk. The E and S + E groups made similar increases in $\dot{V}O_2$ max. The S group made significant increases in isokinetic strength at all velcities (0, 0.84, 1.68, 2.51, 3.35, 4.19 rad/s) up to and including the training velocity. The S + E group increased strength only at the 3 lowest velocities (0, 0.84 and 1.68 rad/s). It was concluded that concurrent S and E training impeded the development of high but not low velocity isokinetic strength.

Two (Dudley & Djamil, 1985; Hickson 1980) of the three studies reviewed above demonstrated a significant antagonism of combined training on strength development, although in the one study only high velocity strength development was impeded (Dudley and Djamil, 1985). All three studies (Dudley and Djamil, 1985; Hickson, 1980; Nelson et al 1984) were consistent in showing no significant impairment of endurance ($\dot{V}O_2$ max) development with combined training, although one study (Nelson et al 1984) showed a trend toward impaired endurance development. However, it would appear from these studies that strength rather than endurance development is more likely to be impeded by combined training.

The three studies differed in the total volume (exercises, bouts and sets per training session) of training conducted. In particular, the training volume in the study by Hickson (1980) was very high; subjects did both strength and endurance training 5 d/wk. If there is a threshold volume and intensity of combined training beyond which antagonism occurs, then the design of the study by Hickson (1980) ensured that this threshold was exceeded. Indeed, the authors (Dudley and Djamil, 1985) of a later study suggested that the impairment of strength development in the final weeks of training in the study by Hickson (1980) was the result of residual fatigue. Nevertheless, strength but not endurance development was impaired under these condiions. By comparison, the training volume in the other two studies (Dudley & Djamil, 1985; Nelson et al. 1984) was somewhat less and in one (Nelson et al. 1984) no significant antagonism was found between concurrent strength and endurance training.

In summary, combined strength and endurance training is more likely to impede strength rather than endurance development. High velocity strength development is impeded more than low velocity strength development. There appears to be a threshold of volume of training beyond which antagonism occurs.

METHODS

Subjects

The subjects were 8 young women and 8 young men without previous experience in intense strength or endurance training. According to the Ethical Guidelines for Research on Human Subjects at McMaster University, subjects were clearly appraised of the purpose of the study and the physical, psychological and/or social risks involved in the research, and signed an informed consent form.

Design

Half (4 women, 4 men) of the subjects (Group A) were randomly assigned to train both lower limbs for strength and one limb for endurance. The other half of the subjects (Group E) trained both limbs for endurance and one limb for strength. Thus, Group A tested whether concurrent strength and endurance training impedes development of strength, while Group E tested whether concurrent strength and endurance training impedes development of endurance.

Training

Training consisted of two 11 week periods divided by a 3 week break period. There were 3 training sessions per week during the training periods. Each training session lasted approximately one hour. The prescribed training programmes took into consideration the factors of feasibility and practicality. In terms of intensity and volume, the programmes were intermediate between the two extremes reported in the literature (Hickson, 1980; Nelson et al, 1984).

Strength Training. Strength training was performed on a leg press weight training machine. Subjects in Group A performed 6 sets of 15 - 20 RM (repetitions maximum) with each leg in the leg press movement. Sets were alternated between legs, with one minute rest periods, until each leg completed the 6 sets. Subjects in Group E performed 6 sets of 15-20 RM with the randomly designated leg. There were 2 minute rest periods between successive sets.

Endurance Training. Endurance training was performed on a cycle ergometer. The training consisted of 5 three minute bouts at a power output corresponding to 90-100% $\dot{V}O_2$ max. In Group A, which trained only one randomly assigned leg for endurance, 3 minute rest periods intervened between successive bouts. Group B performed the 3 minute bouts alternately with both legs, with one minute rest periods between successive bouts.

The training programme is summarized in Table 1.

Measurements

1) Aerobic Power. Aerobic power ($\dot{V}O_2$ max) was measured for each leg separately and for both legs together. The test was performed on an electronically braked cycle ergometer using a standard continuous, progressive loading protocol. ECG monitoring and an open circuit computerized gas analysis system provided a display of heartrate, VE, $\dot{V}O_2$, VCO_2 and RER every 20s during the test.

2) Voluntary Strength. Voluntary strength of each leg was measured as the greatest weight that could be lifted for one repetition (one repetition maximum = 1 RM) on the weight training apparatus. Measurements were made to the nearest kilogram by means of adapter plates that could be placed on the apparatus weight stacks. Subjects used the same apparatus and body positioning (apparatus seat position) for all tests and training.

3) Relative Endurance. Relative endurance was measured for each leg on the weight training apparatus as the number of repetitions that could be one with 80% of the 1 RM.

4) Absolute Endurance. At the mid point and conclusion of the training programme, absolute endurance was measured for each leg on the weight lifting apparatus using the pre training 1 RM value. For both endurance tests, a metronome controlled the rate of doing repetitions to 10/min.

5) Muscle cross-sectional area. Cross-sectional area of the thigh muscles was measured with a computerized digitizer from photographs of CT scans obtained

with a Computed Tomography Scanner (Model 20-30 Ohio-Nuclear).

*6) Muscle fibre areas and muscle fibre composition. Needle biopsy samples were taken from the vastus lateralis of each leg, from which the relative proportions and cross-sectional areas of type I and II fibres were determined.

*7) Enzyme activities. Selected oxidative and glycolytic enzyme activities were measured from muscle biopsy samples.

8) Ultrastructural anlysis. A portion of one biopsy sample was prepared for electron microscopy and subsequent morphometric analysis. Stereological measurements of myofibrillar, mitochondrial, lipid, sarcoplasmic reticulum and cytoplasm volume density were made from electron micrographs.

*These measurements were done under the direction of the project officer at DCIEM, Dr. I. Jacobs.

Statistical Analysis

Data were analyzed with a two factor (state of training, training condition) ANOVA with repeated measures on one factor (pre and post training).

RESULTS

The present report is limited to the results of the performance measurements made before and after the training period. The morphological and biochemical analyses are still in progress.

Effect of Concurrent Strength and Endurance Training on Strength Development (Table 2)

Both the strength-trained leg (S) and the strength- and endurance-trained leg (S + E) increased voluntary strength (1 RM) significantly ($p < .01$) after training. Although there was a trend toward less strength increase in the S + E leg, this interaction was not significant ($p > .05$).

Both S and S + E legs made significant increases in $\dot{V}O_2$ max, repetitions with 80% 1 RM and repetitions with the pre-training 1 RM. Only in repetitions with 80% 1 RM, in which the S + E leg increased more than the S leg ($p < .05$), was there a difference in the response of the S and S + E legs.

Effect of Concurrent Strength and Endurance Training on Endurance Development (Table 3).

Both endurance-trained (E) and the endurance- and strength-trained legs (E + S) made significant ($p < .01$) increases in $\dot{V}O_2$ max; combined (E + S) training did not impede the development of $\dot{V}O_2$ max.

Both E and E + S legs made significant increases in repetitions at 80% 1 RM and repetitions with the pre-training 1 RM. The E + S leg made greater increases in these measures of endurance than the E leg ($p < .05$).

Both E and E + S legs increased strength (1 RM) significantly ($p < .01$) after training; however, the increase was greater in the E + S leg ($p < .05$).

DISCUSSION

The present study confirmed previous reports that combined strength and endurance training does not impede development of $\dot{V}O_2$ max. The present study also failed to show significant impairment of strength development by concurrent stength and endurance training, although a trend was evident. This finding confirmed one previous study (Nelson et al., 1984) but differed from that of another study (Hickson, 1980), in which strength development was impaired in the final 3 wks of a 10 wk training programme. Our finding of no impairment of low velocity strength development by combined strength and endurance training also confirmed the results of Dudley and Djamil (1985); however, these investigators did find that high velocity strength development was impaired by combined (S + E) training.

There is no obvious explanation for the different results in the different studies. The duration of training in the present study (22 wks) was similar to one study (20 wks, Nelson et al., 1984), but exceeded the duration of training in the two other studies (7 wks, Dudley & Djamil, 1985; 10 wks, Hickson, 1980). The only study (Hickson, 1980, 10 wks) to show significant impairment of low velocity strength development was intermediate in duration relative to the studies which showed no impairment. On the other hand, the Hickson (1980) study was unique in the high daily and weekly training volume that was performed.

The pattern of results prompts the speculation that impairment of strength development is more sensitive to the training volume per day and per week, rather than to duration of training over weeks.

A comparison of results of the different studies should consider differences in the design of the training models employed. In the present study, subjects served as their own controls; that is, one leg trained solely for strength or endurance, whereas the other leg trained both for strength and endurance. This design eliminated the influence of intersubject responses to training, which could affect comparisons made among small groups of subjects training in different ways. The within subject model is not without limitations. The "cross-training" effect would tend to increase voluntary strength in the untrained contralateral limb. Endurance training of one limb might, by central cardiorespiratory adaptations, enhance performance of the contralateral untrained limb. These limitations did not present a problem in the present study. For example, in the comparison of S and S + E legs in strength development, any central adaptations to endurance training in the S + E leg would not be expected to influence strength performance in th S leg. On balance, we favoured the within subject control model for studying possible antagonism of concurrent strength and endurance training.

In the present study, combined strength and endurance training did not impede the development of $\dot{V}O_2$ max. Presumably, improvement in endurance tasks which correlate highly to $\dot{V}O_2$ max would also not have been impeded. In contrast, short term endurance performance, as reflected by repetitions at 80% 1 RM and repetitions with the pre-training 1 RM, increased more in the S + E leg than the E leg. Thus, for this endurance task, improvements in performance depended not only on increases in $\dot{V}O_2$ max but also on increases in strength. Therefore, it is important to recognize that combined strength and endurance training may not affect progress (relative to E only training) in some endurance tasks but enhance progress in others.

The primary purpose of this study was to determine possible mechanisms for any antagonism that was found between concurrent strength and endurance training. To achieve this purpose, CT scanning to measure changes in muscle cross-sectional area, and muscle biopsies to assess morphological and biochemical adaptations, were performed. The data obtained by these techniques are still being analyzed.

In summary, concurrent strength and endurance training did not impede the development of $\dot{V}O_2$ max or strength. Concurrent strength and endurance training, in comparison to endurance training alone, enhanced the improvement in a short-term endurance task.

References

Dudley, G.A. and R. Djamil. Incompatibility of endurance- and strength-training modes of exercise. J. Appl. Physiol. 59(5): 1446-1451, 1985.

Hickson, R.C. Interference of strength development by simultaneously training for strength and endurance. Eur. J. Appl. Physiol. 45: 255-263, 1980.

Nelson, A.G., R.K. Conlee, D.A. Arnall, S.F. Loy & L.J. Silvester. Adaptations to simultaneous training for strength and endurance. Med. Sci. Sports Exerc. 16(2): 184, 1984.

Table 1 Training programme*

Group A (4F, 4M)		Group B (4F, 4M)	
Leg #1	Leg #2	Leg #1	Leg #2
Endurance		Endurance	Endurance
5 3 min bouts at 90-100% $\dot{V}O_2$ max		5 3 min bouts at 90-100% $\dot{V}O_2$ max	5 3 min bouts at 90-100% $\dot{V}O_2$ max
Strength	Strength		Strength
6 sets 15-20 RM	6 sets 15-20 RM		6 sets 15 - 20 RM

* Note 1) Each training session lasted approximately one hour

2) Three training sessions were conducted each week on non-consecutive days.

3) There was two 11 week training periods divided by a 3 week rest period.

Table 2 Training response to strength training (one leg) and combined strength and endurance training (other leg) (N = 8).

	Training Condition					
	Strength			Strength + Endurance		
Measure	Pre	Post	Diff.	Pre	Post	Diff.
$\dot{V}O_2$ max, $\ell \cdot m^{-1}$	2.53 ±0.37	2.73** ±0.41	0.204 ±0.066	2.66 ±0.35	2.88** ±0.34	0.220 ±0.060
1 RM, kg	101.1 13.0	131.6** ±14.4	30.5 ±8.7	104.1 ±13.1	125.3** ±11.0	21.2 ±5.2
80% 1 RM, repetitions	16.5 ±3.1	29.8* ±4.2	13.3 ±4.9	13.9 ±3.0	35.0* ±6.8	21.1† ±5.9
Pre-training 1 RM, repetitions	1.0 ±0.0	26.8[a] ±3.5	26.8 ±3.5	1.0 ±0.0	24.4[a] ±3.9	24.4 ±3.9

Values are $\bar{x}$ ± SE

* $p < .05$, ** $p < .01$, significant main effect, pre-post training

† $p < .05$, significant difference between conditions

[a] pre-post analysis not done.

Table 3 Training response to endurance training (one leg) and combined strength and endurance training (other leg) (N = 8)

	Training Condition					
	Endurance			Endurance + Strength		
Measure	Pre	Post	Diff.	Pre	Post	Diff.
$\dot{V}O_2$ max, $\ell \cdot m^{-1}$	2.62 ±0.20	2.80** ±0.23	0.18 ±0.05	2.65 ±0.21	2.84** ±0.19	0.19 ±0.04
1 RM, kg	95.1 ±7.6	114.4** ±9.1	19.3 ±3.1	95.3 ±8.2	127.8** ±9.7	32.5† ±3.6
80% 1 RM, repetitions	11.6 ±3.1	18.6* ±3.8	7.0 ±4.9	15.9 ±3.7	40.8* ±8.2	24.9† ±7.9
Pre-training 1 RM, repetitions	1.0 ±0.0	16.0[a] ±2.7	16.0 ±2.7	1.0 ±0.0	51.0[a] ±14.6	51.0† ±14.6

Values are $\bar{x}$ ± SE

* $p < .05$, ** $p < .01$, significant main effect, pre-post training

† $p < .05$, significant difference between conditions

a pre-post analysis not done.

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13. ABSTRACT

Four young men (M) and women(F) did combined strength (S) and endurance (E) training with one leg and S training only with the other leg. A second group (4 M, 4F) did combined (E + S) training with one leg and E training only with the other leg. Training (3 sessions/week for 22 wks) consisted of 6 sets of 15-20 RM on a weight resistance leg press machine (S) and 5, 3 min bouts of cycle exercise at 90-100% VO2max (E). Voluntary strength (1 RM, leg press) increased after training in both legs of the S/S+E group ($p<0.01$). There was no significant impairment of strength development in the S+E leg. VO2max ($p<0.01$), repetitions at 80% 1 RM increased in both legs. Repetitions at 80% 1 RM increased more in the S+E than the S leg ($p<0.05$). $\dot{V}$O2max ($p<0.01$), repetitions at 80% 1 RM ($p<0.05$) and repetitions with the pretraining 1 RM increased in both E and E+S legs after training;E+S training did not impede development of VO2max, but caused greater increases in repetitions at 80% 1 RM and repetitions with the pretraining 1 RM ($p<0.05$). Voluntary strength increased more in the E+S leg than the E leg ($p<0.05$). It was concluded that E+S training, 1) does not impede strength development, 2) does not impede development of $\dot{V}$O2max, 3) enhances (vs E) increases in repetitions at 80% 1 RM and repetitions with the pretraining 1 RM.

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