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Strength Training in Female Distance Runners: Impact on Running Economy

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ABSTRACT

This study determined the effects of a 10-week strength training program on running economy in 12 female distance runners who were randomly assigned to either an endurance and strength training program (ES) or endurance training only (E). Training for both groups consisted of steady-state endurance running 4 to 5 days a week, 20 to 30 miles each week. The ES undertook additional weight training 3 days a week. Subjects were tested pre and post for $\dot{V}O_2$ max, treadmill running economy, body composition, and strength. A repeated-measures ANOVA was used to determine significant differences between and within groups. The endurance and strength training program resulted in significant increases in strength ($p < 0.05$) for the ES in both upper (24.4%) and lower body (33.8%) lifts. There were no differences in treadmill $\dot{V}O_2$ max and body composition in either group. Running economy improved significantly in the ES group, but no significant changes were observed in the E group. The findings suggest that strength training, when added to an endurance training program, improves running economy and has little or no impact on $\dot{V}O_2$ max or body composition in trained female distance runners.

Key Words: oxygen uptake, aerobic demand, resistance training, women

Introduction

One of the unresolved questions in the area of endurance performance is the influence of strength training on certain endurance related variables. Maximal oxygen uptake (10, 11, 30), fractional utilization of aerobic capacity (5, 30), anaerobic threshold defined as the onset of blood lactate accumulation (OBLA) (10, 11, 22), and running economy (RE) defined as steady-state oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) for a standardized running speed (4, 7, 25) have been known to influence distance running performance.

Compared with endurance training, strength training appears to be ineffective for increasing $\dot{V}O_2$ max (1, 12, 17, 18, 20, 24). Although $\dot{V}O_2$ max may be a good measure of aerobic capacity, it is not a good predictor of distance running performance (4, 5, 10, 11). For example, Hickson et al. (18) reported increased TM running (12%) time to exhaustion following a program of heavy resistance training, despite no changes in $\dot{V}O_2$ max when subjects exercised at 100% of their pretraining $\dot{V}O_2$ max. It was suggested that this improvement was related to increases in leg strength and/or thigh girth, and that possibly the mechanism responsible for the increased endurance may be the neuromuscular response to strength training that alters motor unit recruitment patterns.

Similar conclusions were reached in a later study by Hickson et al. (17) that involved cycling- and running-trained subjects who were at a steady-state level of performance. Significant improvement (13%) was again demonstrated in short-term (4–8 min) running time to exhaustion following a weight training program that was added to an endurance training program. Hickson et al. (17) suggested the improvement could be related to the strength training effects on fiber-type recruitment during exercise.

In regard to running economy, any changes that allow a runner to use less energy at a given speed should reduce the oxygen demand for the same absolute effort (42). A reduced $\dot{V}O_2$ may allow one to run longer at the same speed or faster with the same relative effort. Although we have found no research on strength training effects on RE, results are conflicting as to the impact of other training programs on RE. While two studies (8, 41) revealed no change in RE following short training periods of 8 weeks, other investigators (31, 35, 39) reported improvements in RE after a longer period of training (14 wks to 22 mos). It was suggested that the training related enhancement of RE may be due to better mechanical efficiency, TM habituation, alterations in running style and oxidative energy supply, and optimization of motor unit recruitment patterns (31, 35, 39).

The relationship between muscle strength and RE warrants consideration, due to the effect of increased strength on mechanical efficiency and motor unit recruitment patterns (17, 18, 24, 28, 32). Therefore the purpose of this study was to compare running economy in a group of female distance runners who undertook endurance and strength training (ES) versus a group that only performed endurance training (E).

Methods

Subjects and Procedure

Twelve female distance runners (age 30.3 ± 1.4 yrs, range 23–36 yrs) volunteered to participate in the study. All subjects signed informed consent documents and all procedures were approved by the human subjects review board of the university. Six subjects were randomly assigned to an endurance and strength training group (ES) while the other 6 were assigned to the control condition and thus only undertook endurance training (E). All subjects had been running 20 to 30 miles a week and trained 4 to 5 days a week for at least 1 year prior to the study. None had engaged in a regular weight training program for at least 3 months.

All subjects reported for 2 test sessions before and 2 sessions after the training programs. Body composition, RE, and $\dot{V}O_2$ max were measured during Session 1, and one-repetition maximum (1-RM) lifts were measured during Session 2. Each test session was separated by at least 2 days. The E group participated in all aspects of the testing procedures. Subjects were instructed not to undertake endurance or strength training on test days and not to eat for 3 hours prior to the tests. Each runner was tested at the same time of day and wore identical clothing and shoes for each session. All tests were conducted by the same investigator.

Training. Endurance training for both groups consisted of running 4 to 5 days a week for 20 to 30 miles each week. Each subject maintained a steady-state level of endurance training, running at the same frequency, intensity, and distance at least 12 weeks prior to and throughout the 10-week study. The participants recorded all endurance exercise daily in a training log which was reviewed weekly by the investigator. While not statistically analyzed, the investigators can attest via the training logs that frequency, intensity, and duration of endurance workouts did not change over the course of the study.

A strength training program was added to the ES group and consisted of weight training 3 days a week for 10 weeks. The following exercises were performed with free weights: parallel squat, seated press, hammer curl, weighted sit-up, lunge, bent-leg heel raise, and bench press.

The 14 exercises were divided into 2 groups. Group A consisted of the parallel squat, knee flexion, straight-leg heel raise, seated press, rear lat-pulldown, hammer curl, and weighted sit-up. Group B consisted of the lunge, knee extension, bent-leg heel raise, bench press, seated row, front lat-pulldown, and abdominal curl. Group A and Group B exercises were alternated with each strength training session. During each session the ES group performed 2 sets of 20-RM for the bent-leg heel raise, 2 sets of 12-RM for the straight-leg heel raise, 2 sets of 15-RM for the weighted sit-up, and 2 sets of maximum repetitions for the abdominal curl. The subjects also performed 3 sets of 8-RM for the knee flexion, knee extension, front and rear lat-pulldown, and seated row; they performed 3 sets of 6-RM for the parallel squat, seated press, hammer curl, lunge, and bench press.

A 2-min rest interval was allowed between sets. Different RMs were used because of the concern about possible injury when using heavy loads (e.g., calf exercises and Achilles tendon), and lighter loads were chosen for assistive exercises. As strength increased (i.e., performing more than the required repetitions), additional weight was added to maintain the same relative resistance. Strength training was performed on Monday, Wednesday, and Friday and was supervised by a trained instructor. At least 5 hours separated the weight training and endurance training sessions for the ES group.

Measurement of Body Composition. Body mass was measured on a Detecto platform scale to the nearest 100 grams. Skinfold sites included the tricep, subscapula, abdomen, suprailiac, and thigh. Skinfolds were measured on the right side and recorded to the nearest 0.1 mm using a Holtain skinfold caliper. Skinfold measurements were taken 3 times per site and the mean value was recorded. Body density was calculated from the sum of 5 skinfolds (13). Percent body fat was estimated from body density using the Siri equation (34). Procedures from Lohman et al. (23) were followed for measuring body circumferences. Shoulder, chest, waist, abdominal, hip, midthigh, calf, and relaxed and flexed upper arm circumferences were measured with a steel tape to the nearest 0.1 cm. Body circumference measurements were taken 3 times per site and the mean value was recorded.

Measurement of Running Economy and $\dot{V}O_2$ max. Pre and posttest sessions included a series of 6-min submaximal, level-grade TM runs followed by a $\dot{V}O_2$ max test. Subjects trained routinely on a treadmill and were therefore familiar with treadmill running prior to the study. Submaximal test velocities used in this study were 214 and 230 $m \cdot min^{-1}$. Preliminary warm-up runs (10–15 min) preceded testing each day and a 5-min rest separated each submaximal test. Steady state for each subject was determined when $\dot{V}O_2$, HR, and R measurements were stable.

Inspired air was measured with a Parkinson-Cowan CD-4 gas meter that was interfaced with a microcomputer (Zenith Data Acquisitions). Expired air was collected in a mixing chamber and measured continuously with Ametek CO_2 (Model CD · 3A) and O_2 (Model S-3 A/1) analyzers. Prior to each test the gas analyzers were calibrated with gases of known composition. The $\dot{V}O_2$ Plus on-line metabolic software for IBM and compatible computers (Exeter Research, Inc.) was used to monitor and record the data. The gas meter and O_2 and CO_2 analyzers were connected to an analog-digital (A-D) conversion circuitry board. Data was recorded in 30-

sec intervals and values for the gas collections obtained during the last 2 min of running were averaged to determine the oxygen uptake for that pace. A 5-lead electrocardiogram was used to monitor heart rate and rhythm. Heart rate was calculated and averaged over a 10-sec time period.

Ten minutes following the final submaximal run, a $\dot{V}O_2$ max test was conducted using a constant TM velocity of either 214, 230, or 247 m · min^{-1} (subject's preference). The first 2 min of each maximal test were run at 0% treadmill grade. The grade increased by 2.5% every 2 min thereafter until the subject reached volitional exhaustion. A leveling off of oxygen uptake and heart rate when work rate was increased, and a respiratory exchange ratio of at least 1.1, were the criteria used to determine if $\dot{V}O_2$ max was achieved. Metabolic data were recorded in 30-sec intervals during the test, and heart rate was recorded each minute.

Measurement of Strength. Strength was assessed by determining the maximum amount of weight that could be lifted for one repetition (1-RM) in a parallel squat, knee flexion, seated press, hammer curl, bench press, and rear lat-pulldown. Subjects performed multiple single repetitions against increasing resistances and each subject rested 3 min between attempts. Maximum strength was determined by the subject's inability to perform a single repetition.

Statistical Analysis. A repeated-measures ANOVA was used to determine if there were any between- or within-group pre- and posttraining differences in $\dot{V}O_2$ max, running economy, HR, strength, and body composition measures. The conservative Geisser-Greenhouse correction factor was used to evaluate observed within-group F ratios (21). Within-group post hoc comparisons consisted of planned orthogonal contrasts using means/regression coefficients (21). Statistical significance was set at $p < 0.05$.

Results

After the 10-week training program there were no significant changes in body mass, fat free mass (FFM), fat mass (FM), or %BF in either group (Table 1). In addition, body circumference measurements did not change significantly in either group following the training program.

The weight training program resulted in significant increases in strength for ES in both upper (24.4%) and lower body (33.8%) lifts. Increases were observed in the parallel squat (40%), knee flexion (27%), seated press (21.5%), hammer curl (36%), bench press (19.5%), and rear lat-pulldown (22%) (Table 2). No significant strength increases occurred in any lifting movement between initial and final values for the control (E) group.

Running economy improved in the ES (4%) following the 10-week resistance training program (Tables 3 and 4). Relative $\dot{V}O_2$ decreased significantly in the ES

Table 1
Body Composition Measurements Before and After Training

	Experimental (n = 6)				Control (n = 6)			
	Pre		Post		Pre		Post	
Variable	*M*	±*SE*	*M*	±*SE*	*M*	±*SE*	*M*	±*SE*
Height (cm)	162.6	2.4	–	–	163.7	1.6	–	–
Mass (kg)	56.9	2.7	58.2	2.6	51.5	2.0	51.2	2.1
Fat (%)	18.6	1.4	18.4	1.2	16.2	2.0	15.7	2.1
Fat free mass (kg)	46.3	2.3	47.5	2.2	43.1	1.7	43.1	2.0
Fat mass (kg)	10.6	0.9	10.7	0.8	8.4	1.2	8.1	1.3
Shoulder (cm)	97.5	1.5	98.6	1.9	94.6	1.5	95.2	1.8
Chest (cm)	83.3	1.4	84.4	1.2	81.4	1.6	81.9	1.9
Waist (cm)	66.2	2.5	67.1	2.3	65.1	1.5	65.4	1.5
Abdominal (cm)	70.9	1.9	71.2	1.9	69.7	1.2	69.6	0.4
Buttocks (cm)	94.8	2.1	94.2	2.0	88.9	1.8	88.7	1.7
Midthigh (cm)	47.4	1.0	48.1	0.9	44.9	0.5	44.3	0.8
Calf (cm)	35.6	0.7	35.4	0.7	33.1	0.4	33.1	0.5
Upper arm, relaxed (cm)	25.9	0.7	26.6	0.7	24.7	0.3	24.7	0.5
Upper arm, flexed (cm)	27.2	0.7	27.9	0.7	25.9	0.4	26.1	0.6

Table 2
1-RM Strength Values (in Kg) Before and After Training

	Experimental (n = 6)				Control (n = 6)			
	Pre		Post		Pre		Post	
Variable	*M*	±*SE*	*M*	±*SE*	*M*	±*SE*	*M*	±*SE*
Parallel squat	58.3	2.8	81.8	6.0*	58.0	5.0	59.1	5.2
Knee flexion	33.3	2.2	42.4	2.6*	29.5	1.9	29.5	1.9
Seated press	28.4	2.5	34.5	2.4*	26.1	1.3	26.9	1.4
Hammer curl	9.8	1.0	13.3	0.9*	10.2	0.8	10.2	0.8
Bench press	36.7	2.4	43.9	3.0*	34.5	3.0	34.1	3.3
Rear lat-pulldown	29.5	2.9	36.0	2.5*	28.2	2.0	28.6	3.2

*Significantly different from before training, $p < 0.05$.

Table 3
Performance Values Before and After Training

	Experimental (n = 6)				Control (n = 6)			
	Pre		Post		Pre		Post	
Variable	*M*	±*SE*	*M*	±*SE*	*M*	±*SE*	*M*	±*SE*
$\dot{V}O_2$max (ml · kg^{-1} · min^{-1})	50.5	2.2	48.0	2.0	51.5	2.4	51.0	1.9
$\dot{V}O_2$max (L · min^{-1})	2.84	0.14	2.78	0.13	2.70	0.08	2.65	0.08
HRmax (beats · min^{-1})	191	3.5	191	3.5	204	3.9	204	3.9
$\dot{V}O_2$ (ml · kg^{-1} · min^{-1})								
at 214 m · min^{-1}	41.6	1.1	39.9	0.8*	39.8	0.5	40.0	0.7
at 230 m · min^{-1}	44.5	1.0	42.8	1.1*	42.8	0.7	43.2	0.7
$\dot{V}O_2$ (L · min^{-1})								
at 214 m · min^{-1}	2.36	0.13	2.32	0.10	2.09	0.08	2.09	0.07
at 230 m · min^{-1}	2.52	0.13	2.49	0.12	2.25	0.06	2.25	0.07
HR (beats · min^{-1})								
at 214 m · min^{-1}	173	5.6	170	5.6	171	6.2	171	6.2
at 230 m · min^{-1}	181	6.1	177	5.5	183	5.7	183	5.7

*Significantly different from before training, $p < 0.05$.

Table 4
Running Economy Measurements ($\dot{V}O_2$)
Before and After Training

	At 214 m · min^{-1}		At 230 m · min^{-1}	
Subjects	Pre	Post	Pre	Post
Experimental				
1 B.D.	41.99	41.04	43.21	41.72
2 R.D.	43.52	42.17	45.58	45.45
3 J.C.	37.87	38.10	42.47	40.70
4 L.C.	40.63	38.43	43.19	40.03
5 B.E.	40.07	37.86	43.24	41.72
6 C.A.	45.81	41.70	49.18	46.98
Control				
7 A.Q.	39.12	40.93	43.84	45.45
8 B.P.	40.92	42.02	44.84	44.42
9 C.Q.	39.01	39.00	40.19	41.77
10 C.A.	40.48	40.10	43.98	43.86
11 S.G.	41.16	40.73	42.80	42.51
12 M.G.	37.81	37.22	41.22	41.20

$\dot{V}O_2$max values are ml · kg^{-1} · min^{-1}

while running at 214 m · min^{-1} (41.7 to 39.9 ml · kg^{-1} · min^{-1}) and 230 m · min^{-1} (44.5 to 42.8 ml · kg^{-1} · min^{-1}), while no changes were evident in the E group. Submaximal heart rate while running at 214 and 230 m · min^{-1}, maximal heart rate, and maximal oxygen uptake (absolute and relative) did not change significantly in either group following training (Table 3).

Discussion

The purpose of this study was to determine whether strength training influenced running economy in trained female distance runners. Strength enhancement was clearly evident in our study, although it was not accompanied by significant increases in body mass, FFM, %BF, or body circumference measurements. Possibly these strength improvements during the early stages of training were due predominantly to neural factors (14, 32, 40); however, it appears that during this time significant changes contributing to strength gains also take place in the muscle (36–38).

In an investigation by Staron et al. (36), 13 male and 8 female untrained subjects performed heavy resistance training for 8 weeks. After the training program there were no significant changes in body mass, FFM, %BF, or girth measurements, despite significant increases in strength. There were gradual increases in the cross-sectional areas of fiber types I, IIa, and IIb throughout the 8-week training period.

Although it has been found that concurrent strength and endurance training are not compatible for optimal strength development (9, 15, 16, 19, 33), much less is known about the impact of concurrent strength and endurance training on endurance related performance variables. Strength training appears ineffective for improving $\dot{V}O_2$ max, HR, stroke volume (SV), cardiac output (Q), and arterial-mixed venous O_2 difference (a-v O_2 diff.) during submaximal exercise (1, 12, 17, 18, 20, 24).

However, high intensity cycling and running times to exhaustion can be improved following a strength training program (17, 18, 24). It has been suggested that these improvements may be due to strength training effects on fiber-type recruitment during exercise (17, 24), muscle fiber conversion (38), and the neuromuscular response with subsequent alterations in motor unit recruitment patterns (18).

A question that has not been addressed concerns the influence of strength training on running economy. While the results of the present study indicate there were no significant differences in $\dot{V}O_2$ max and body composition with the addition of a strength training program to an endurance training regimen, they do suggest that weight training has an impact on running economy. Running economy improved significantly in the ES group at each TM speed after strength training.

One explanation for improved RE may be related to greater leg strength leading to changes in motor unit recruitment patterns (28, 32). Strength training may primarily cause hypertrophy of fast-twitch (FT) fibers (36, 37), yet hypertrophy of slow-twitch (ST) fibers also occurs (36, 37), thus requiring less motor unit activation to produce a given force (28). Further, Sale (32) states that strength training induces changes in the nervous system. This would allow one to more fully coordinate the activation of all relevant muscles, thus producing a greater net force in the intended direction of movement. Regardless of whether strength gains in this study occurred at the muscular level, at the neural level, or both, if a more efficient recruitment pattern was induced, it may decrease the oxygen cost at each running speed (3, 31).

Another possible explanation for improved running economy could involve muscle fiber-type conversion, although work by Coyle et al. (6) would refute this. Staron et al. (36–38) found a decrease in the percent of fast glycolytic type IIB fibers, with a concomitant increase in the percent of fast oxidative glycolytic type IIA fibers, following a lower body weight training program in men (38) and women (36–38).

Type IIA fibers are more oxidative than type IIB fibers and have functional characteristics more similar to type I fibers. Therefore an increase in type IIA fibers should increase the oxidative capacity of the muscle, which could contribute to improved endurance performance (38) perhaps by improving running economy. Coyle et al. (6) studied 7 endurance-trained subjects 12, 21, 56, and 84 days after cessation of training. Oxygen uptake (ml · kg^{-1} · min^{-1}) remained unchanged for the same absolute submaximal intensity throughout the detraining period. This occurred despite a large shift from type IIA to IIB fibers. This research would suggest that muscle fiber conversion has little or no impact on oxygen uptake and running economy.

A final explanation for improved running economy may be due to greater total body strength leading to changes in the mechanical aspects of running style, thus allowing a runner to do less work at a given submaximal running speed. Results of a study by Williams and Cavanagh (42) have identified a number of biomechanical variables that seem to be related to running economy, thus providing support for the hypothesis that mechanical aspects of running style have an influence on metabolic energy costs. Research by Nelson and Gregor (29) demonstrated that running mechanics can change over time and that this change does produce faster race performances.

While the results of the current study suggest that running economy improved in female distance runners with the addition of a strength training program to an endurance training program, other factors may have contributed in part to the change in $\dot{V}O_2$. These include the day-to-day variation in running economy as well as the possible changes in body mass.

Daily variation of running economy could have an impact on the results of this research. Morgan et al. (27) found that the aerobic demand of running in trained, nonelite subjects would be expected to vary ±1.32% to ±2.64% in trials that control treadmill running experience, time of day, footwear, and training. Similar results were found in a later study by Morgan et al. (26) with well-trained male and female distance runners. Daily variation of running economy should produce both high and low values for oxygen uptake at standard submaximal running speeds. However, this was not the case in the present study. The ES group improved RE in 11 of 12 trials, while oxygen uptake values for the E group were variable (Table 4).

In addition, a slight but insignificant body mass increase in the experimental group could also result in a decrease in relative $\dot{V}O_2$ at each submaximal TM speed. However, Subjects 3, 5, and 6 had no change in body mass throughout the training program yet still improved RE in 5 of 6 trials (Table 4). Further, there was a slight decrease in absolute $\dot{V}O_2$ values and submaximal HR in the ES group for each TM speed, but no change in the E group (Table 3), thus suggesting a decrease in effort at each running speed for the ES group following a strength training program.

Finally, sample size may have influenced the results of this study. However, estimated sample sizes were calculated for determining a significant difference at the two running speeds using a range of effect sizes as suggested by Williams et al (43). Standard deviations ranged between 1.10 and 2.20 $ml \cdot kg^{-1} \cdot min^{-1}$ and the method described by Blalock (2) was used. The results of this calculation, as shown below, suggest that a sample size of 6 per group was adequate for determining the differences we observed:

Effect Size	*SD* ($ml \cdot kg^{-1} \cdot min^{-1}$)	
($\dot{V}O_2$ $ml \cdot kg^{-1} \cdot min^{-1}$)	1.10	2.20
0.5	19	74
0.75	8	33
1.00	5	19
1.25	3	12
1.50	2	8
1.75	2	6
2.00	1	4

Although the results of this study may be influenced by the daily variation of RE and a small increase in BM, they do suggest that strength training, when added to an endurance training program, improves running economy and has little or no impact on $\dot{V}O_2$ max or body composition in trained female distance runners.

Practical Applications

The results of this study suggest that implementing a vigorous strength training program in previously untrained (strength) female distance runners may yield positive results in running economy. Upper and lower body strength improvements are evident and expected in a program of this type. Also, this improved strength is not associated with significant changes in body composition. The improvement in running economy would be significant for a competitive distance runner. It could shave vital seconds off her time and it is these seconds that determine a runner's placement in a race.

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