BRIEF REVIEW

The Effects of Resistance Training on Endurance Distance Running Performance Among Highly Trained Runners: A Systematic Review

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Abstract

Yamamoto, LM, Lopez, RM, Klau, JF, Casa, DJ, Kraemer, WJ, and Maresh, CM. The effects of resistance training on endurance distance running performance among highly trained runners: a systematic review. *J Strength Cond Res* 22(6): 2036–2044, 2008—The current perception among highly competitive endurance runners is that concurrent resistance and endurance training (CT) will improve running performance despite the limited research in this area. The purpose of this review was to search the body of scientific literature for original research addressing the effects of CT on distance running performance in highly competitive endurance runners. Specific key words (including running, strength training, performance, and endurance) were used to search relevant databases through April 2007 for literature related to CT. Original research was reviewed using the Physiotherapy Evidence Database (PEDro) scale. Five studies met inclusion criteria: highly trained runners ($\geq$ 30 mile·wk^{-1} or $\geq$ 5 d·wk^{-1}), CT intervention for a period $\geq$ 6 weeks, performance distance between 3K and 42.2K, and a PEDro scale score $\geq$ 5 (out of 10). Exclusion criteria were prepubertal children and elderly populations. Four of the five studies employed sport-specific, explosive resistance training, whereas one study used traditional heavy weight resistance training. Two of the five studies measured 2.9% improved performance (3K and 5K), and all five studies measured 4.6% improved running economy (RE; range = 3–8.1%). After critically reviewing the literature for the impact of CT on high-level runners, we conclude that resistance training likely has a positive effect on endurance running performance or RE. The short duration and wide range of exercises implemented are of concern, but coaches should not hesitate to implement a well-planned, periodized CT program for their endurance runners.

Key Words resistance training, endurance training, endurance athlete, performance

Introduction

"We knew we could run in the mud because of our strength training," reported Coach Keith Andrew after his Coatesville, Pennsylvania high school boys cross-country team won the 2006 Nike Team Nationals on a waterlogged Portland Meadows 5K course (29).

Concurrent resistance and endurance training (CT) challenges the perception that improvements in endurance running performance are achieved only through aerobic training. However, current research indicates that muscular strength and anaerobic power may also be important for increased running performance through neurological and muscular changes (1,21,34). Positive muscular adaptations may include increased anaerobic enzyme activity, increased force production, increased intramuscular glycogen, or shifts within major fiber type groups (1,21,34). Neural adaptations may include improved motor unit recruitment and synchronization, improved force development rate, and improvements in the stretch-shortening cycle (1,21,30,34). In combination, these positive adaptations may enable runners to sustain attacks, climb hills, or sprint in the final minutes, which should enhance running performance (38).

Historically, runners were hesitant to resistance train because of concerns of possible negative side effects of hypertrophy on capillary density and mitochondrial function (23). However, others have found no negative change in maximal oxygen uptake ($\dot{V}O_2max$) from resistance training (RT) (22), and RT can increase running efficiency by

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attenuating the reduction of Type I muscle fibers and connective tissue (22) and potentially stave off injury.

Instead of running performance, many CT researchers focus on running economy (RE), which involves the relationship between $\dot{V}O_2$ and a given running velocity. Running economy has been shown to influence performance for well-trained distance runners (28). Improved RE would increase speed over a given distance or increase distance traveled at a given speed because of decreased oxygen consumption (16,35,37,39), and, thus, it would increase performance. The benefit of RT may improve RE through several mechanisms: 1) increased strength may improve mechanical efficiency, muscle coordination, and motor recruitment patterns (34), 2) greater total body strength may lead to advantageous mechanical changes in running style (16), or 3) increased muscular strength and coordination may reduce relative intensity (14). Improved RE may be a result of both improved running mechanics and neuromuscular efficiency to reduce oxygen consumption at a given speed (14,16). Simultaneous RT and endurance training (ET) has been associated with limited strength development and no change in $\dot{V}O_2max$ (6,13,15). However, this line of research focused predominantly on the impact of ET on strength performance and not on the effects of RT on endurance performance (2,6,10,12,15). Additionally, most subjects were previously untrained runners, which accounted for the large improvements in running performance or RE (3,9,20).

Several review articles focus on CT and summarize the available data; however, these reviews do not synthesize the best available research to address a specifically defined question (17,18,38). This systematic review focuses specifically on valid research of highly trained endurance runners on the effects of CT on performance and/or RE. The use of CT in endurance athletes continues to grow with increased desire for improved performance. However, there is a lack of evidence supporting potential beneficial effects of RT on endurance performance in highly trained athletes. Does RT increase long-distance running performance? If so, what type of RT is best suited for increased performance? What manipulation of the acute program variables (choice of exercise, order of exercise, volume, rest, and intensity [19]) is best? The purpose of this systematic review was to search the body of scientific literature for original research addressing the effects of CT on distance running performance in highly competitive endurance runners.

Methods

Experimental Approach to the Problem

A search was performed using MEDLINE, Sport Discus, *Journal of Strength and Conditioning Research* archives, and ProQuest Dissertations and Theses databases through September 2007 for literature related to CT. Key words used were (marathons OR marathoning OR running[mesh]) AND ("strength training" OR "resistance training" OR "weight lifting" OR "weightlifting") AND (performance OR speed OR time trials OR endurance) AND English[language] NOT (obese OR obesity OR sprint OR sprinters OR stroke OR soccer OR "Running/injuries" NOT amphetamine).

Research specific to measures of performance with CT in elite athletes were identified. All randomized controlled trials (RCTs) assessing the effects of RT on endurance exercise were initially examined (Figure 1). All articles were read, and the outcomes of each article were recorded. The references of identified articles were examined to identify additional articles that were eligible for this review. The majority of

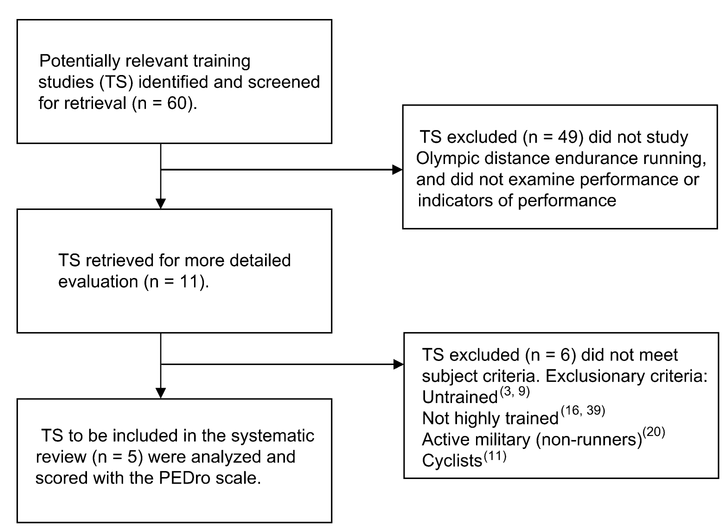

FIGURE 1. Criteria for selection of articles for review.

the articles that examined CT were review articles or training studies for untrained or recreationally trained individuals, that were retained for review and discussion; however, these articles were not included for analysis because they did not meet inclusion criteria. Resistance training was defined as nonrunning, weight-bearing or weight-loaded activity including free-weight and machine exercises. The subcategories for RT included circuit training (a series of free-weight and/or machine exercises performed one after the other with minimal rest between exercises), heavy weight training (dynamic constant external RT with exercises such as back squat, and bench press), and explosive strength training (plyometric or stretch-shortening cycle exercises) (7).

Inclusion and exclusion criteria for this analysis were established to narrow the focus of the analysis. Inclusion criteria were highly trained runners ($\geq$ 30 mile·wk^{-1} or $\geq$ 5 d·wk^{-1}), CT intervention for a period $\geq$ 6 weeks, performance distance 3K–42.2K, and a quality score $\geq$ 5. Exclusion criteria were untrained subjects, prepubertal children, and elderly populations.

Once the five articles were identified, the Physiotherapy Evidence Database (PEDro) scale (32) was used to rate the articles. The PEDro scale examines the internal validity and interpretability of experimental trials. The scale scores internal validity through aspects of study design, such as randomization, allocation, similarity of key measures at baseline, and blinding of subjects, therapists, and assessors. Additionally, the scale measures interpretability of research by examining between-group statistics, descriptions of point measures, and measures of variability. The 11-item scale (Table 1) yields a maximum score of 10 points if all criteria are satisfied.

We chose the PEDro scale because it has tested reliability data and was developed to evaluate RCT evaluating physical therapist interventions. Although we are not looking at physiotherapy, the similarity of the type of trials warrants the use of the PEDro scale. Maher et al. (24), examined the reliability of the 11 items and the total score of the PEDro scale, and found interclass correlations of 0.56 for total score for individual ratings and 0.68 for panel ratings.

Table 1. PEDro scale (32).

	Paavolainen et al. (30)	Spurrs et al. (37)	Mikkola et al. (26)	Saunders et al. (36)	Millet et al. (27)
Eligibility criteria were specified (no points awarded).	Yes	Yes	Yes	Yes	Yes
Subjects were randomly allocated to groups.	0	1	0	1	1
Allocation was concealed.	0	0	0	0	0
The groups were similar at baseline regarding the most important prognostic indicators.	1	1	1	1	1
There was blinding of all subjects.	0	0	0	0	0
There was blinding of all therapists who administered the therapy.	0	0	0	0	0
There was blinding of all assessors who measured at least one key outcome.	0	0	0	0	0
Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups.	1	1	1	1	1
All subjects for whom outcome measures were available received the treatment or control condition as allocated, or, where this was not the case, data for at least one key outcome were analyzed by "intention to treat."	1	1	1	1	1
The result of between-group statistical comparisons is reported for at least one key outcome.	1	1	1	1	1
The study provided both point measures and measures of variability for at least one key outcome.	1	1	1	1	1
Total points awarded	5	6	5	6	6

TABLE 2. Reviewed articles.

Authors	Subject description	Age (y)	Resistance training type and duration	Description of treatment and control groups	Results	Improvement (%)	PEDro Scale (32) score (max = 10)
Paavolainen et al. (30)	18 elite male distance runners; $\dot{V}O_2max$ = 68 ml·kg^{-1}·min^{-1}	20–30	Plyometric training, 9 wk	CT = 68% ET, 32% sport-specific plyometric training; ET = 97% ET, 3% sport-specific plyometric training	Decreased 5K run time in CT; improved RE in CT	3.1 (5K); 8.1 (RE)	5
Spurrs et al. (37)	17 male distance runners; $\dot{V}O_2max$ = 57 ml·kg^{-1}·min^{-1}		Plyometric training, 6 wk	CT = concurrent plyometric training (two sessions per week for 3 weeks, then three sessions per week for 3 weeks) and normal ET; ET = continued normal training	Decreased 3K run time in CT; improved RE in CT	2.7 (3K); 4–7 (RE)	6
Mikkola et al. (26)	18 male, 7 female distance runners; $\dot{V}O_2max$ = 62 ml·kg^{-1}·min^{-1}	16–18	Plyometric training, 8 wk	CT = 81% endurance and supplemental training, 19% sport-specific explosive strength training; ET = 96% endurance and supplemental training, 4% sport-specific explosive strength training	No Δ RE or $\dot{V}O_2max$; increased anaerobic and selective neuromuscular performance in CT	3	5
Saunders et al. (35)	15 elite male distance runners; $\dot{V}O_2max$ = 68–70 ml·kg^{-1}·min^{-1}	20–30	Plyometric training, 9 wk	CT = concurrent plyometric training (three sessions per week) and normal ET	Improved RE in CT	4.1	6
Millet et al. (27)	15 elite male triathletes; $\dot{V}O_2max$ = 67–69 ml·kg^{-1}·min^{-1}	18–30	Heavy weight training, 14 wk	CT = concurrent HWT (lower limb, two sessions per week) and consistent, supervised aerobic training; ET = consistent, supervised aerobic training	Improved RE in CT	5.3	6
Average			9.2 wk			4.5	5.6

CT = concurrent resistance and endurance training; ET = endurance training; HWT = heavy weight training; RE = running economy.

TABLE 3. Description of treatment and control group training.

	Author	Paavolainen et al. (30)	Spurrs et al. (37)	Mikkola et al. (26)	Saunders et al. (36)	Millet et al. (27)
CT group	Endurance	84% below, 16% above anaerobic threshold	Running: 60–80 $km \cdot wk^{-1}$	71% endurance, >95% below anaerobic threshold, mainly running	Running: 100.2 ± 48.1 $km \cdot wk^{-1}$	Run: 48 ± 7 $km \cdot wk^{-1}$ swim: 18.3 ± 5.0 $km \cdot wk^{-1}$ cycle: 221 ± 49 $km \cdot wk^{-1}$
	Sport-specific explosive/heavy weight training	32%: Sprinting (5–10 × 20–100 m), jumping (alternating, bilateral countermovement, drop, hurdle, one-legged), weighted explosive leg press, knee extension/flexion (30–200 contractions)	2 × 10 squat jump, 2 × 10–12 scissor jump, 2–3 × 10–12 double-leg bound, 2–3 × 10–15 alternate-leg bound, 2–3 × 10–15 single-leg forward hop, 2–3 × 6–10 depth jump, 2–3 × 10 double-leg hurdle jump, 2–3 × 10 single-leg hurdle hop	19% sport-specific explosive: Sprinting (5–10 × 30–150 m), jumping (alternating, calf, squat, hurdle), strength (2–3 sets × 6–10 reps, half squat, knee extension/flexion, calf raises)	1–2 × 15 back extension, 2–5 × 6–8 leg press, 1–3 × 6 countermovement jump, 1–3 × 20 knee lift, 1–3 × 10 ankle jump and hamstring curl, 1–6 × 10 alternate-leg bound, 1–5 × 30–20 m skip for height and single-leg ankle jump, 5 × 5 hurdle jumps, 5 × 8 scissor jump for height	Heavy weight training: Hamstring curl, leg press, seated press, parallel squat, leg extension, heel raise
	Frequency		1 time per week (weeks 1–3), 2 times per week (weeks 4–6), 3 times per week (weeks 7–9)	3 times per week	3 times per week	2 times per week
	Duration	15–90 minutes		30–60 min	30 minutes	2–3 warm-up sets, 3–5 sets × 3–5 reps to failure
	Supplemental/circuit training	Circuit training: Unweighted, slow-velocity abdominal and leg exercises		10% supplemental: Coordination training, circuit training, ball games		
Control group	Endurance	84% below, 16% above anaerobic threshold	Running: 60–80 $km \cdot wk^{-1}$	82% endurance, >95% below anaerobic threshold, mainly running	Running: 114.1 ± 39.8 $km \cdot wk^{-1}$	Run: 44 ± 5 $km \cdot wk^{-1}$ swim: 19.8 ± 4.0 $km \cdot wk^{-1}$ cycle: 210 ± 40 $km \cdot wk^{-1}$

Sport-specific explosive/heavy weight training	3%: Sprinting (5–10 × 20–100 m), jumping (alternating, bilateral countermovement, drop, hurdle, one-legged), weighted explosive leg press, knee extension/flexion (30–200 contractions)	
Frequency		3 times per week
Duration	15–90 minutes	30–60 min
Supplemental/circuit training	Circuit: Unweighted, slow-velocity abdominal and leg exercises	14% supplemental: Coordination training, circuit training, ball games

CT = concurrent resistance and endurance training.

Five RCTs that met the inclusionary criteria were independently evaluated by two reviewers using the PEDro scale. Scores were recorded, and full consensus was achieved over the scores given to the five articles. A third reviewer was not needed as a tiebreaker to resolve differences in article scores. The kappa value (measure of observed agreement) for all five RCTs was 1.0 (perfect agreement).

As currently reported, CT studies do not score high with the PEDro scale because of the difficulty of researchers to blind allocation, treatment, and assessment. Future researchers could increase their PEDro score by concealing allocation, stating random allocation, and blinding assessors as to the groups to which subjects were allocated.

Data Synthesis

Scores on the PEDro scale for the five selected articles ranged from 5 to 6 of a maximum 10 points (Table 1). All authors reported increased running performance or RE with CT compared with ET alone. Two of the five authors (30,37) reported increased running performance and RE, although at different distances (5K vs. 3K, respectively), whereas the other three authors (26,27,36) reported improved RE only. Additionally, four of the five authors (26,30,36,37) implemented plyometric training in their studies, whereas only one author (27) employed heavy weight training. All five studies are summarized in Tables 2 and 3.

The Paavolainen et al. (30) and the Mikkola et al. (26) articles both scored 5/10 on the PEDro scale. Random allocation of subjects into training groups was not specified. The Mikkola et al. (26) study attempted to randomly allocate subjects, but some subjects initially assigned to the CT group were moved to the ET group for personal reasons (personal communication). Please see Table 1 for specific scores on the PEDro scale.

The PEDro scale scores for the three additional articles (27,36,37) were 6/10. Concealment of allocation is not entirely relevant for these training studies, because one subject is no more likely to improve with training than another subject if training is monitored for volume and intensity. Additionally, blinding of subjects and therapists is not possible; blinding of assessors was not specified. Please see Table 1 for specific scores on the PEDro scale.

Paavolainen et al. (30) compared the combined effects of sport-specific explosive strength and ET for 9 weeks on running performance and RE. The sport-specific plyometric training consisted of sprints and jumps (unloaded, or with low loads) to optimize high or maximal movement velocities. This study had no true control group because both training groups performed plyometric training; however, the CT group had a significantly greater proportion of plyometric training as their total training volume, compared with the control group (32 vs. 3%, respectively). Concurrent resistance and endurance training resulted in significantly decreased 5K time trials and increased RE.

Spurrs et al. (37) examined 6 weeks of concurrent plyometric and ET in 17 male distance runners. All subjects ran 60–80 km·wk^{-1}; intensity and volume were maintained and monitored over the course of the study. Plyometric training (two sessions per week for 3 weeks, followed by three sessions per week for 3 weeks) consisted of various unloaded jumps, bounds, and hops in both the horizontal and vertical planes. Both groups were tested pre- and posttraining for RE, $\dot{V}O_2$max, lactate threshold, relative stiffness of the musculotendinous system, maximal isometric force, rate of force development, countermovement jump, a five-bound test, and a 3K time trial. The ET group trended toward superior pretraining 3K time trial performance, but no significant baseline differences existed between groups. The CT group significantly improved in all posttraining measures, but the ET group remained unchanged.

Mikkola et al. (26) compared concurrent explosive strength training and ET in postpubertal teenage distance runners (male and female). No true control group existed because both groups performed supplemental (coordination, and circuit training, ball games, etc.) and explosive strength training; however, strength training for CT was 19% of total training hours, with only 4% for ET. Strength training sessions lasted 30–60 minutes and occurred three times per week. Exercises included running sprints, jumping exercises without external load, and half squats, knee extensions, knee flexions, calf raises, abdominal curls, and back extensions with low load. For both groups, >95% of ET occurred below their anaerobic threshold. Several outcomes significantly increased in the CT group: maximal speed of anaerobic and 30-m speed running tests, concentric and isometric leg extension forces, and force-time characteristics accompanied by increased rapid neural activation of the muscles. For both groups, thickness of the quadriceps femoris increased, whereas maximal speed of aerobic running test and $\dot{V}O_2$max remained unchanged. Running economy only slightly ($3 \pm 4\%$, $p = 0.07$) increased in the CT group.

Saunders et al. (36) examined the effects of short-term (9 weeks) plyometric training on RE in highly trained distance runners. Plyometric training (three sessions per week, loaded and unloaded exercises) were added to subjects' normal training for the CT group. The subjects were tested for RE at 14, 16, and 18 km·h^{-1} at weeks 5 and 9. Significant improvement for CT was only found at week 9 for the 18 km·h^{-1} test. All other measures ($\dot{V}O_2$max, respiratory exchange ratio, heart rate, stride rate, blood lactate concentration, strength, and power) were not significantly different at baseline or after the intervention.

Millet et al. (27) compared the combined effects of CT during 14 weeks. The ET was predominantly aerobic, with the majority of the training under 70% of $\dot{V}O_2$max. The strength training consisted of three to five sets of three to five repetitions of lower-body exercises (hamstring curl, leg curl, leg press, seated press, parallel squat, leg extension, and heel raises) twice per week. Periodization of the training program was composed of several 3-week periods, during which weight was incrementally increased to approximately 90% of one-repetition maximum; one-repetition maximum was reassessed every 3 weeks to ensure maintenance of maximal loads for the duration of the study. The CT group significantly increased RE as measured by increased velocity associated with $\dot{V}O_2$.

Discussion

This systematic review of five CT studies suggests that strength training (explosive and/or heavy weight) improves long-distance running performance and/or RE (an indicator of running performance). The moderate PEDro scale scores (5 or 6) should not diminish the quality of the reviewed studies, considering the constraints that training studies have in blinding subjects, therapists, and assessors to the treatment received. Despite the numerous CT studies (3,9,11,14,16,20,26,27,30,31,36,37,39), relatively few of these studies have looked at highly trained endurance runners. This review is unique because of its narrow focus on highly trained endurance runners. One limitation of this review was the small number of articles that met the inclusion criteria, but this further emphasizes that CT is used by distance running coaches with little empirical evidence. Although all studies included provide evidence that concurrent training may improve distance running performance, further research is needed to elucidate the most effective training programs.

Despite the strong relationship between RE (4,5,33) and explosive strength training, only two of the five articles reviewed examined running performance (30,37). The importance of $\dot{V}O_2$max, lactate threshold, RE, and neuromuscular measures should not be ignored, but for athletes the most important variable is race time, or time trial performance. Additionally, many of the studies in this systematic review consisted of relatively short training duration (average = 9.2 weeks) and used athletes who were not strength trained. It is unknown how chronic adaptations to CT will affect endurance running performance. Early improvements on running with RT are associated with neuromuscular adaptations (34), but the effects of chronic RT on muscle mass, muscle metabolic activity, or the risk:benefit are still unknown. Because the studies in this review assessed high-level athletes, it was likely difficult to control training for a longer period of time because of the competitive season cycle.

Each researcher attempted to tightly control RT and reported workout regimens; however, aerobic training program descriptions were noticeably absent. The RT programs were all well-planned protocols that tested strength gains to adequately increase workout intensity for the duration of the study. Most competitive athletes engage in a myriad of aerobic workouts (steady state, tempo, interval, etc.), which also vary with different phases of training. Interpretation of CT results with ET would be more insightful if aerobic training programs had been defined.

Many authors report that CT is well studied (17,18,27) and recommend highly specific RT programs (17). However, the majority of the studies cited studied nonelite runners (16,20,39), elite cross-country skiers (14,31), or untrained subjects (3,9,20). Untrained or recreationally active subjects had improved running performance regardless of whether CT or ET alone was used (9,20,39). However, these results may not necessarily translate to highly trained, elite distance runners because of their high degree of fitness and adaptation that has already occurred.

To disseminate the results of CT, researchers must consider the different types of RT. Circuit training, which involves a variety of resistance exercises with minimal rest, has only been shown to improve endurance performance in untrained individuals (8,25). Traditional RT (e.g., squat, bench press) improved RE in trained cross-country runners, but it has not been researched in conjunction with performance per se (27). Explosive, or plyometric, training (loaded and unloaded) is the most frequently studied type of RT in endurance runners. The addition of plyometric exercises to ET consistently improved both distance running performance (30,37) and RE (26,36).

Practical Applications

Current research supports increased RE with CT. The importance placed on RE in performance warrants the incorporation of sport-specific explosive strength or heavy weight training programs to current ET in highly trained runners. Additionally, the research presented showed improved 3K and 5K run times in trained distance runners who incorporated loaded and unloaded explosive strength training to their normal ET programs. The authors recommend the inclusion of well-structured, periodized RT programs in their athletes' training regimens based on the health and ability of individual athletes during each training phase. We believe that the positive benefits of CT cannot be overlooked despite the limited body of evidence. However, it is evident that there is a need for further research with trained distance runners on the potential benefits of various forms and on periodization of RT on distance running performance.

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