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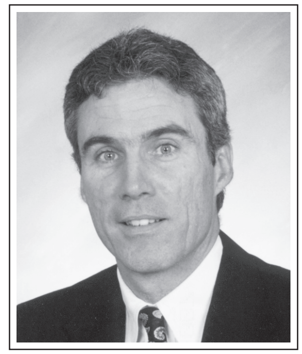
FROM THE EDITOR

RUSS EBBETS



THE END

Kevin McGill called me in 1999 and said he was stepping down as the editor of Track Technique/Track Coach. He said he recommended me to the publisher, Ed Fox, as I had worked with Kevin for years in numerous Level 1 Schools and written several articles for him. Kevin had been a legendary presenter at my Union College December Track and Field Clinics during the 1980s.

My immediate reaction was "yes," but tempered that enthusiasm by vowing that I had to come up with 25 good reasons why I should take the job. I was well aware, regarding the magnitude of the position and the huge shoes I would be stepping into. I got a blank sheet of paper and went to work. Thirty minutes later I had my list. I called Kevin and Ed Fox back to tell them I was interested. As I recall Ed's decision came quickly. I hung up the phone, went back to my list and tried to decide what I wanted to accomplish first.

In 1999 the IAAF World Indoor meet was to be held in Maebashi, Japan. As it turned out that was my first international assignment as the national team chiropractor. It was a long flight and more time zone changes than I could count. As it happened America's shot putter was Wake Forest's Andy Bloom. Bloom had a great collegiate career and was one of the last throwers to win both the disc and shot at the NCAA Outdoor Championships. He did this in 1996.

Andy Bloom's hometown was Niskayuna, NY, a small town adjacent to Schenectady and Union College where I had been the coach during the 1980s. Bloom was having a career year throwing 71'+, when that was an oddity. As he warmed up one morning at the Maebashi arena, I took a moment to introduce myself.

I told him who I was and that I used to coach at Union. For a second, that seemed to stop him in his tracks. He said, "Union? I used to go to your clinics there. Kevin McGill taught me the throws. That's what got me started!" And we both laughed. Since 1999, 100 issues of *Track Coach* have followed. There have been some successes and some failures, things I am glad about and some things I am disappointed we didn't get done. I want to thank close to 40 coaches, athletes and theorists for taking the time to answer questions in the interviews I conducted. We've done at least 15 roundtables where I assembled a panel of experts that shared their expertise on a

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THE EFFECTS OF STRENGTH TRAINING ON DISTANCE RUNNING PERFORMANCE AND RUNNING INJURY PREVENTION

BY JASON R. KARP, PHD, MBA

While it seem commonsensical that strength training should be of some benefit to distance runing performance and help to prevent injury the science is inconclusive. In this paper, Dr. Karp examines 45 studies on the subject. This paper first appeared in the Journal of Physical Education and Sport*,* 24(10):1352-1367, October 2024.

ABSTRACT

Introduction: From recreational to elite runners, strength training has become a popular addition to distance running training programs to improve performance and prevent running-related injuries. However, some incompatibilities exist between aerobic endurance training and strength training, including muscle hypertrophy and mitochondrial and capillary densities. Although our knowledge of the independent effects of aerobic endurance training and strength training date back a long time, our knowledge of the effects of strength training on aerobic endurance performance is still young.

Purpose: To bring greater clarity of the subject of strength training for distance running performance and running injury prevention to runners, coaches, clinical practitioners, and the scientific community, this comprehensive literature review offers a critical narrative summary of the research on strength training and distance running performance and running injury prevention and includes several important directions for future research.

Methods: All English-language published studies on the effects of strength training on distance running performance and the effects of strength training on distance running injury prevention were

found using PubMed and Google Scholar databases. All studies were eligible for selection, as long as the intervention included some type of strength training using various loads and reps/sets combinations and the dependent variable was either running performance, physiological factors related to running performance, or prevalence of distance running-related injury.

Results and Conclusions: Strength training, either with heavy loads (≥ 90% 1-rep max) or with explosive movements, has been shown to have a small, positive effect on running economy, laboratory measures of performance (e.g., maximal aerobic speed, time to exhaustion), and running time-trial performance over distances from 3 to 10 kilometers. However, strength training has not been found to improve other aerobic physiological factors related to distance running performance, including VO_2max and lactate threshold. Furthermore, no studies have examined the effect of strength training on real-life distance running race performance or on long-distance running performance (e.g., marathon, half-marathon). Regarding running-related injuries, muscle weakness, especially of the hip, seems to be a characteristic of injured runners in both retrospective and prospective studies, however, the evidence is lacking that muscle weakness is a cause of running injuries and is equivocal that strength training prevents running injuries, with studies limited to novice or recreational runners.

INTRODUCTION

The ability to run fast for long distances, even for a race as short as two minutes, primarily depends on the delivery and use of oxygen (Spencer & Gastin, 2001), which are cardiovascular and aerobic in nature, with mitochondrial respiration the dominant metabolic energy pathway. Middle-distance races, including 800, 1,500, and 3,000 meters, also heavily depend on anaerobic metabolism, including glycolysis and the buffering of metabolic acidosis.

OUR KNOWLEDGE OF STRENGTH TRAINING ON DISTANCE RUNNING PHYSIOLOGY AND PERFORMANCE IS NASCENT

While our knowledge of aerobic and anaerobic endurance training dates back a century, with its effects since well documented (e.g., increases in stroke volume, cardiac output, hemoglobin concentration, muscle capillary and mitochondrial densities, and glycolytic, citric acid cycle, and electron transport chain enzyme activity) (Coyle, 1995; Holloszy & Coyle, 1984; MacInnis & Gibala, 2017), our knowledge of strength training on distance running physiology and performance is nascent.

Regardless of the level of runner, all runners want two things: to get faster and to avoid injuries. To achieve these ends, runners utilize a number of means. Over the last couple decades, strength training has become one of those means among recreational and elite runners alike, even to the extent that it is often touted as an elixir, with many runners and coaches espousing its ability to improve performance and prevent injuries. However there remains controversy about the efficacy of strength training to improve performance. For example, Karp (2007) found that, as recently as 2004, athletes who qualified for the 2004 U.S. Olympic Marathon Trials averaged less than one strength workout per week (men) or one and a half strength workouts per week (women) during the year leading up to the Olympic Trials, with about half of the athletes not doing any strength training at all.

Theoretically, strength training may improve performance by improving muscle power, anaerobic, and/or neuromuscular factors related to distance running and may prevent injuries by strengthening muscle or tendon weaknesses. Survey- and interview-based research have found that lack of muscle strength is cited as the most common reason (or one of the most common reasons) for running injuries, with strength training cited as the most common way to prevent injuries (Blagrove et al, 2020; Johansen et al, 2017; Saragiotto et al, 2014). Contrary to the old days of only running, most runners these days believe strength training is a necessary part of training.

Perhaps in response to this newer, more holistic style of distance running training that incorporates both aerobic and strength components, there has been considerable research over the last two decades examining the effects of strength training on distance running physiology and performance and on running injuries. However, the collective results have been equivocal, necessitating a critical review of the subject. To attempt to get closer to answering the complicated question of whether or not strength training makes runners faster and prevents or reduces the risk of running injuries, this review offers a critical narrative summary of the research on strength training and distance running performance and running injury prevention. Repeated and separate searches were made to find all English-language published studies on the effects of strength training on distance running performance and the effects of strength training on distance running injury prevention, using PubMed and Google Scholar databases. All studies, regardless of study design (with or without a control group), level of runner in their population sample (e.g., novice, recreational, elite), and type and duration of intervention were eligible for selection and included in this review, as long as the intervention included some type of strength training (e.g., machines, free weights, bodyweight exercises, core exercises) using various loads and reps/sets combinations and the dependent variable was either running performance, physiological factors related to running performance (e.g., running economy), or prevalence of distance running-related injury.

DISTANCE RUNNING PERFORMANCE

Several of the physiological adaptations that result from aerobic endurance and strength training are incompatible. Endurance training promotes mitochondrial biogenesis and angiogenesis through its stimulation of molecular pathways (e.g., PGC-1, Ca2+/calmodulin-dependent kinases (CaMK), adenosine monophosphate-activated protein kinase (AMPK), and mitogen-activated protein kinases (ERK1/2, p38 MAPK)) that underlie the cellular processes that improve aerobic endurance capacity (Hawley et al, 2014). On the other hand, strength training promotes muscle hypertrophy as a result of myofibrillar protein synthesis, which may result in a consequent decrease in mitochondrial and capillary densities, characteristics that could impair aerobic endurance performance. An inverse relationship exists between muscle fiber cross-sectional area and mitochondrial oxidative capacity (van der Zwaard et al, 2018; van Wessel et al, 2010).

Recent systematic reviews and meta-analyses on concurrent strength and endurance training have found some interference effects, with compromised lower-body strength gains in males (but not in females) and a blunted improvement in VO_2max in untrained (but not in trained) subjects (Huiberts et al, 2024) and a small negative effect on type I muscle fiber hypertrophy with aerobic running (Lundberg et al, 2022). The meta-analysis by Schumann et al. (2022) found no effect of concurrent training on hypertrophy and maximal strength, but did find attenuated explosive strength gains, especially when both types of exercise are performed in the same training session. Since strength training using high intensity/low volume has been found to be the most effective method to improve maximal strength (Lopez et al, 2021; Schoenfeld et al, 2017), it has since become the main type of strength training research has focused on for distance running performance. Table 1 summarizes the research. (See p. 8003)

Of the three aerobic factors that influence distance running performance—VO_2max, lactate threshold, and running economy (Bassett & Howley, 2000; Joyner & Coyle, 2008)—running economy is the only factor strength training has been shown to improve (Berryman et al, 2010; Blagrove et al, 2018; Festa et al, 2019; Jung, 2003; Li et al, 2021; Llanos-Lagos et al, 2024; Millet et al, 2002; Paavolainen et al, 1999; Yamamoto et al, 2008). Several studies however have found no improvement in running economy following strength training (Damasceno et al, 2015; Ferrauti et al, 2010; Mikkola et al, 2007; Vikmoen et al, 2016) or a nonsignificant improvement that was no different from the improvement in an endurance training-only control group (Blagrove et al, 2018). Millet et al. (2002) found a 6.9% improvement in running economy in 7 well-trained triathletes after 14 weeks of strength training (e.g., hamstring curl, leg press, seated press, parallel squat, leg extension, and heel raise) twice per week using 3-5 sets of 3-5 reps to muscular failure. Li et al. (2021) found a 6% improvement in running economy and the velocity at VO_2max in recreational runners after 6 weeks of either heavy strength training or complex training (combination of a heavy strength exercise with a plyometric exercise), with no changes in an endurance-strength training group that trained at a much lower intensity. Støren et al. (2008) found a 5% improvement in running economy when running at 70% VO_2max and a 21% improvement in time to exhaustion at maximal aerobic speed in 8 well-trained runners (VO_2max = 61.4 ml.kg-1.min-1) following 8 weeks of strength training using 4 sets of 4-rep max half-squats three times per week. Studying 23 male and 19 female collegiate cross country runners during their competition season, Barnes et al, (2013) found a 1.7% (male) and 3.4% (female) improvement in running economy and a significant increase in peak treadmill speed following heavy strength training of 2-4 sets of 6-15 reps twice weekly for 7-10 weeks. In contrast, Ferrauti et al. (2010) found no change in running economy following 8 weeks of strength training twice per week using 4 sets of 3-5 reps for lower body and 3 sets of 20-25 reps for trunk muscles. Damasceno et al. (2015) also found no change in running economy following 8 weeks of strength training with half-squats, leg press, plantar flexion, and knee extension exercises twice per week using a periodized program of 3 sets of 8- to 10-rep max progressing to 3- to 5-rep max. Vikmoen et al. (2016) found no change in running economy in 11 female duathletes following 11 weeks of twice weekly heavy strength training consisting of 3 sets of 4- to 10-rep max of half squats, one-legged leg press, one-legged hip flexion, and ankle plantar flexion.

Reasons for contrasting results between studies could be due to several factors, including type and duration of training intervention, intersubject variability in response to the intervention (some studies that reported individual subject data show that not all subjects improved economy, although the mean result was a statistically significant improvement), number of speeds at which economy was tested, too small of a sample size in some studies to detect statistical significance, and timing of testing.

For example, Beattie et al. (2017) found a significant improvement in running economy among 11 collegiate and national-level distance runners after 20 weeks of maximal and explosive strength training but a nonsignificant improvement after 40 weeks; thus, if they had tested their subjects only after 40 weeks instead of after 20 weeks, they would have come to a different conclusion.

Also at issue is the combination of several types of training in a single study. For example, using a combination of explosive strength training with low loads and fast movement velocities, plyometric exercises (drop jumps, hurdle jumps, one-legged jumps), and 20- to 100-meter sprints, Paavolainen et al. (1999) found a significant decrease in the oxygen cost of running (improved economy) when running at 4.17 m.min-1 and a significant improvement in 5-km time in an experimental group of 10 distance runners (VO_2max = 63.7 ml.kg- 1.min-1) who had replaced 32% of their endurance training with the sport-specific explosive training for 9 weeks, while a separate control group of 8 runners (VO_2max = 65.1 ml.kg-1. min-1), who replaced only 3% of their normal endurance training with sport-specific explosive training, showed no change in running economy or 5-km time.

IT IS OBVIOUS THAT INCLUDING SPRINTS IN AN ENDURANCE TRAINING PROGRAM CAN RESULT IN BETTER RUNNING PERFORMANCE.

However, the authors' conclusion that simultaneous explosive-strength and endurance training improved running economy and 5-km time in well-trained endurance athletes is misleading, given that the sprinting and, perhaps secondarily, the plyometric exercises, performed by the subjects were likely the main contributors to the improved economy and 5-km time-trial performance. It is obvious that including sprints in an endurance training program can result in better running performance. Giovanelli et al. (2017) also found a decrease in the energy cost of running in well-trained ultra-endurance runners at four tested speeds following 12 weeks of heavy strength training, explosive strength training, and plyometrics, but did not separate the different types of training. Skovgaard et al. (2014) found a 3.1% significant improvement in running economy after 8 weeks of twice weekly speed endurance training (4-12 x 30-second sprints) and heavy strength training (3 sets of 8 reps of squats, deadlifts, and leg press at 15-rep max, progressing to 4 sets of 4 reps at 4-rep max). They also found 10-km time improved by 3.8% after 4 weeks (but no greater improvement after 8 weeks) and 1,500-meter time improved by 5.5% after 8 weeks (but not after 4 weeks). Vorup et al. (85) found a significant improvement in 400-meter time, maximal aerobic speed, and time to exhaustion during an incremental treadmill test, but a nonsignificant improvement in running economy and no change in 10-kilometer time-trial performance after 8 weeks of twice weekly speed endurance training (4-10 x 30-second sprints at 90-95% max speed) and twice weekly heavy strength training (1 set of 10-rep max, progressing to 2 sets of 8-rep max, 3 sets of 6-rep max, and 4 sets of 4-rep max). In none of these studies was a comparison of results made between the speed endurance training and heavy strength training.

A meta-analysis by Balsalobre-Fernández et al. (2016) revealed a significant beneficial effect of strength training interventions on running economy compared to control groups, although four of the five studies included in their analysis (Mikkola et al, 2007; Paavolainen et al, 1999; Saunders et al, 2006; Støren et al, 2008) used a combination of strength training, speed endurance training, and plyometrics. By including different types of training in the same study (or in a review of studies), it is difficult to determine which type of training is responsible for the significant results and makes it difficult for runners and coaches to know which training method(s) work.

Berryman et al. (2010) found that plyometric training resulted in an average greater decrease in the energy cost of running than did strength training consisting of loaded squats (7% vs. 4%, respectively, with several of the study's subjects exhibiting an increased energy cost of running following strength training). Other studies have also found an improved running economy or time-trial performance following plyometric training (Pellegrino et al, 2016; Ramírez-Campillo et al, 2014; Saunders et al, 2006; Spurrs et al, 2003; Turner et al, 2003), which may result from enhancement of the muscle stretch-shortening cycle during ground contact (Jung, 2003).

A recent meta-analysis by Eihara et al. (2022), in which they separated the effects of heavy strength training and plyometric training among 22 studies that included a total of 479 subjects revealed that heavy strength training had a greater effect than plyometric training on running economy and time-trial performance. They also found that strength training with loads ≥90% 1-rep max had a larger effect than strength training with loads <90% 1-rep max. Another recent meta-analysis by Llanos-Lagos et al. (2024), in which they separated the effects of different strength training loads on running economy at different speeds, found that heavy strength training (>80% 1-rep max) was most effective for improving economy at higher speeds (8.64 to 17.85 km.h-1), plyometric training was most effective for improving economy at speeds less than 12 km.h-1, and combined training was most effective for improving economy at speeds of 10 to 14.45 km.h-1, while neither submaximal strength training (40-79% 1-rep max) nor isometric training improved running economy. Both meta-analyses noted that although strength training improved running economy, the effect was small.

In addition to the mixing of different types of training in the same study (heavy strength training, explosive strength training, sprinting, and plyometrics) is the issue of how running economy is determined. Although the majority of research has found heavy strength training improves economy in distance runners, nearly all the studies measured changes in oxygen consumption (VO_2) at only one submaximal treadmill speed (Table 1), which limits interpretability of the research. Of the studies that measured VO_2 at more than one speed, not all found a significant reduction in VO_2 (i.e., improved economy) at every speed. Table 1 shows the magnitude of change in submaximal oxygen consumption pre- to post-intervention. It is unclear how the speed(s) used in these studies compare to the subjects' usual training speeds. Based on the scientific literature, the most that can be concluded is that heavy strength training has a small effect on running economy, which agrees with Eihara et al.'s meta-analysis (2022).

BOTH META-ANALYSES NOTED THAT ALTHOUGH STRENGTH TRAINING IMPROVED RUNNING ECONOMY, THE EFFECT WAS SMALL.

All the studies summarized in Table 1 found that subjects increased muscular strength following the strength training intervention and did so without an increase in muscle mass. This would certainly be beneficial for distance runners, since an increase in muscle mass would likely impair running economy and endurance performance. Studies have also found that subjects did not improve other physiological factors related to distance running performance, namely VO_2max and lactate threshold, suggesting the improvements in running economy do not result from cardiovascular or metabolic changes, but rather from some other mechanism. Changes to Achilles tendon stiffness and motor unit recruitment are possible candidates responsible for strength training's effect on running economy (Albracht & Arampatzis, 2013; Bohm et al, 2021; Fletcher & MacIntosh, 2017). Albracht and Arampatzis (2013) observed a 4% significant improvement in running economy accompanied by a 7% significant increase in plantar flexor muscle strength and 16% significant increase in triceps surae tendon-aponeurosis stiffness after 14 weeks of isometric ankle plantar flexion exercise. Bohm et al. (2021) found a 4% significant increase in running economy accompanied by a 10% significant increase in plantar flexor muscle strength and 31% significant increase in Achilles tendon stiffness after 14 weeks of isometric ankle plantar flexion exercise. In contrast, Fletcher et al. (2010) found no changes in running economy or tendon stiffness after 8 weeks of plantar flexion exercise.

IT HAS YET TO BE DETERMINED THAT STRENGTH TRAINING RESULTS IN FASTER REAL-LIFE RACE PERFORMANCE.

Alternatively, heavy strength training may train the central nervous system to synchronously and rapidly recruit motor units to enhance muscle force and power production. Athletic performance is ultimately limited by the amount of force and power that can be produced and sustained, which are influenced by several physiological factors, including neuromuscular coordination, skeletal muscle mechanics and energetics, efficiency of converting metabolic power into mechanical power, and muscles' aerobic and anaerobic metabolic capacities. Heavy strength training may enhance neuromuscular coordination and increase muscle rate of force development (i.e., power) by altering firing frequency and motor unit recruitment (Aagaard et al, 2002; Støren et al, 2008). However, these neuromuscular characteristics and muscle rate of force development have been assessed using similar strength exercises to those used in the studies' training interventions (Aagaard et al, 2002; Støren et al, 2008). There is currently no evidence that any muscle strength improvements or altered motor unit recruitment achieved from strength training transfers to running (Trowell et al, 2020), during which force is applied to the ground much more rapidly.

While a slight improvement in running economy may be a benefit of strength training, what runners really want is to get faster. Only a few studies have measured the effect of heavy strength training on running performance. Those studies have yielded mixed results, with most finding an improvement in performance (most often measured as a 3-km to 10-km time trial or other lab-based performance test) (Berryman et al, 2010; Damasceno et al, 2015; Karsten et al, 2016; Skovgaard et al, 2014; Vikmoen et al, 2017), while others have not (Schumann et al, 2015; Schumann et al, 2016; Vikmoen et al, 2016). Of the studies finding a significant improvement, running performance improved by 2 to 4 percent. While improved economy has often been the explanation for why performance improved in these studies, how or why performance was improved remains unclear, since an improvement in performance has been found even with no improvement in economy (Damasceno et al, 2015). It has yet to be determined that strength training results in faster real-life race performance. It's plausible that enhancement of neuromuscular factors and the greater muscle strength and power achieved from strength training can help a runner in middle-distance races (800 to 3,000 meters) that are run at speeds at or faster than VO_2max and that include a large anaerobic component, but may not be as important for longer races (e.g., half-marathon, marathon). There is currently no research on the effect of strength training on middle distance running performance, real-life track or road races, or long-distance races. In summary, there is ample evidence to conclude that heavy (or explosive) strength training may improve running economy but does not improve other aerobic factors (cardiovascular or metabolic) that influence distance running performance. Whether or not the improved economy from strength training results in faster race times is a direction for future research, as there is currently no evidence that it does. The scientific literature seems to contradict the popular belief that runners must strength train to run faster races.

RUNNING INJURY PREVENTION

Another perceived reason why runners strength train is to prevent injuries. In runners aged 15 to over 60, from local club level to international level, Blagrove et al. (2020) found that 62.5% engaged in strength training, with the most common reason for doing so to lower the risk of getting injured (63.1%). The prevalence of running injuries is well documented and widespread, with estimates ranging from 19% to 79% (van Gent et al, 2007), with the majority being joint/tendon or bone injuries, such as patellofemoral pain syndrome, Achilles tendinosis/tendonitis, and bone stress fractures. Running injuries are caused by a confluence of complex training and biomechani-

Table 1. Studies on Strength Training and Distance Running Performance

Study	Subjects (experimental group)†	Intervention	Results	Magnitude of Change in O2 Cost of Running ml/kg/min (tested speed)
Albracht & Arampatzis, 2013	26 recreational long-distance runners	5 sets of 4 reps of isometric ankle plantar flexion at 90% max 4 times/week for 14 weeks	Avg. 4% sig. improvement in RE at 2 tested speeds; 7% sig. increase in maximum plantar flexion muscle strength & 16% sig. increase in triceps surae tendon-aponeurosis stiffness	-1.9 (10.8 km/hr) -1.5 (12.6 km/hr)
Barnes et al, 2013	23 male & 19 female collegiate cross-country runners	heavy strength training of 2-4 sets of 6-15 reps & plyometrics twice weekly for 7-10 weeks	greater improvement in RE with heavy strength training (1.7% male; 3.4% female) compared to plyometrics (0.2% male; 1.0% female); sig. increase in peak treadmill speed after heavy strength training (4.6% male; 4.4% female) compared to plyometric training (1.0% male; 2.2% female)	heavy strength training: -1.2 (14 km/hr) plyometric training: -0.3 (14 km/hr)
Beattie et al, 2017	11 collegiate and national-level distance runners	max strength (3-8 reps), explosive strength (3 reps), & plyometrics; 1-2/week for 40 weeks	4.8% sig. improvement in RE after 20 weeks; 3.5% nonsig. improvement after 40 weeks	-1.8 (16.5 km/hr)
Berryman et al, 2010	35 trained distance runners	3-6 sets of 8 reps of semisquats for 8 weeks	sig. improvements in RE & 3,000-meter time-trial performance	heavy strength training: -1.6 (12 km/hr) plyometric training: -3.0 (12 km/hr)
Bertuzzi et al, 2013	16 recreational runners	3-6 sets of 4-10 reps of half-squats at 70-100% 1-rep max twice weekly for 6 weeks	no change in VO_2max, vVO_2max, time to exhaustion at vVO_2max, & respiratory compensation point	—
Blagrove et al, 2018	9 male & female adolescent runners	2-3 sets of 8-12 reps of back squat, Romanian deadlift, rack pull, single-leg press & calf raise, plyometric jumps, & 30-meter sprints; twice weekly for 10 weeks	nonsig. improvement in RE, with no difference between experimental & control groups; no change in vVO_2max or velocity at various fixed blood lactate concentrations; sig. improvement in 20-meter sprint time & difference from control group	-0.6(a) (LTP) -0.7(a) (LTP - 1 km/hr) -0.7(a) (LTP - 2 km/hr)
Bohm et al, 2021	13 recreational runners	5 sets of 4 reps of isometric ankle plantar flexion at 90% max 3-4 times/week for 14 weeks	sig. 4% increase in RE; sig. increase in plantar flexor muscle strength (10%) & Achilles tendon stiffness (31%)	-0.4(b) (9 km/hr)
Damasceno et al, 2015	9 recreational long distance runners	3 sets of 3-5 rep max to 8-10 rep max of half-squats, leg press, plantar flexion, & knee extension twice weekly for 8 weeks	2.5% improvement in 10-km time trial; no change in peak treadmill speed, respiratory compensation point, & RE	-0.6 (12 km/hr)
Ferrauti et al, 2010	11 recreational runners	4 sets of 3-5 reps lower body; 3 sets of 20-25 reps for trunk muscles	no changes in RE, stride length, stride rate, & blood lactate & heart rate at tested speeds	+1.6 (8.6 km/hr) +0.8 (10.1 km/hr)
Festa et al, 2019	18 recreational runners (9 flywheel strength training, 9 high-intensity run training)	flywheel strength (once weekly for 8 weeks): 4 sets of 7 eccentric reps at max velocity; high-intensity (3 times/week for 8 weeks): 95-140% mean velocity between VT1 & VT2	sig. increase in RE in flywheel strength group; sig. increase in vVT1, vVT2, vVO_2max, & avg. speed of 2- & 10-km time trials in flywheel & high-intensity groups	-13.9(c) (75% vVT1)
Fletcher et al, 2010	6 middle and long distance regional, national or international-level runners	4 x 20-second isometric plantar flexions at 80% maximum voluntary contraction 3 times/week for 8 weeks	no change in RE at 3 tested speeds & triceps surae tendon stiffness	+0.04(d) (12.3 km/hr) -0.01(d) (13.9 km/hr) -0.02(d) (15.6 km/hr)
Giovanelli et al, 2017	13 well-trained ultra-endurance runners	heavy strength training (single-leg half-squats, step-ups, lunges), explosive strength training (counter-movement jumps, split squats), & plyometrics 3 times/week for 12 weeks	sig. improvement in RE at 4 tested speeds (6.4% at 8 km/h, 3.5% at 10 km/h, 4.0% at 12 km/h, 3.2% at 14 km/h)	-1.7 (8 km/hr) -1.0 (10 km/hr) -1.4 (12 km/hr) -1.4 (14 km/hr)
Guglielmo et al, 2009	16 well-trained runners (9 explosive strength training; 7 heavy strength training)	explosive strength: 3-5 sets of 12-rep max heavy strength: 3-5 sets of 6-rep max; twice weekly for 4 weeks	6.2% sig. improvement in RE only in heavy strength training group; sig. increase in velocity at onset of blood lactate accumulation in both groups	-3.0 (14 km/hr)
Johnston et al, 1997	6 female distance runners	2 sets of 12- to 20-rep max & 3 sets of 6- to 8-rep max of lower & upper-body exercises 3 times/week for 10 weeks	4% sig. improvement in RE at 214 & 230 m/min	-1.7 (12.8 km/hr) -1.7 (13.8 km/hr)

Karsten et al, 2016	8 recreational endurance runners & triathletes	4 sets of 4 reps of Romanian deadlift, parallel squat, calf raises, & lunges at 80% 1-rep max twice weekly for 6 weeks	3.6% sig. improvement in 5-km time trial	—
Li et al, 2021	38 recreational marathon runners (13 complex training, 13 heavy-strength training, 12 endurance-strength training)	complex training: 3 sets of 5 reps at 70-85% 1-rep max for 3 exercise pairs (back squat + drop jump, split squat + single-leg hop, walking lunge + double-leg hurdle hop) heavy-strength: 5 sets of 5 reps at 70-85% 1-rep max (back squat, split squat, walking lunge) endurance-strength: 5 sets of 20-30 reps at 30-40% 1-rep max; twice weekly for 6 weeks	6% sig. improvement in RE at 2 tested speeds in complex & heavy-strength training groups; sig. increase in vVO_2max, squat jump, & counter-movement jump height in complex & heavy-strength training groups; no changes in endurance-strength group	NR (12 km/hr) NR (14 km/hr)
Lum et al, 2023	18 endurance runners (9 isometric strength training, 9 plyometrics training)	strength: 3 sets of 3 reps progressing to 3 sets of 4 reps & 3 sets of 5 reps of isometric mid-thigh pull & isometric ankle plantar flexion plyometrics: depth jumps, single-leg bounding, & split jumps	sig. improvement in RE only in strength training group; sig. improvement in 2.4-km time-trial performance & maximal aerobic speed in both experimental groups, with no differences between groups	strength: -0.02(e) (12 km/hr male/10 km/hr female) strength: -0.04(e) (14 km/hr male/12 km/hr female) plyometrics: -0.01(e) (12 km/hr male/ 10 km/hr female) plyometrics: -0.01(e) (14 km/hr male/12 km/hr female)
Mikkola et al, 2007	13 teenage distance runners	sprinting, jumping, & explosive strength training of 2-3 sets of 6-10 reps for 8 weeks	no difference in RE & maximal aerobic speed	+0.5 (10 km/hr) -0.9 (12 km/hr) -0.7 (13 km/hr) -1.5 (14 km/hr)
Millet et al, 2002	7 well-trained triathletes	3-5 sets to failure of 3-5 reps for 14 weeks	6.9% sig. improvement in RE	-2.6 (17.4-17.6 km/hr)
Paavolainen et al, 1999	10 distance runners	explosive strength training, plyometrics, & 20- to 100-meter sprints for 9 weeks	sig. improvement in RE & 5-km time trial	-4.0 (15 km/hr)
Piacentini et al, 2013	11 masters marathon runners (6 max strength training, 5 resistance training)	max strength training: 4 sets of 3-4 reps at 85-90% 1-rep max resistance training: 3 sets of 10 reps at 70% 1-rep max; twice weekly for 6 weeks	max strength training: 6.2% sig. improvement in RE at 1 of 3 tested speeds resistance training: no change in RE	- ~1.0 (1 km/hr slower than marathon pace) resistance training: no change in RE - ~4.0 (marathon pace) + ~1.0 (1 km/hr faster than marathon pace)
Schumann et al, 2015; 2016	13 recreationally endurance-trained runners	maximal & explosive strength training twice weekly for 24 weeks	no difference in 1,000-meter field test time between endurance & endurance + strength groups	—
Sedano et al, 2013	12 well-trained male runners (6 explosive-strength training + plyometrics; 6 endurance-strength training)	explosive-strength: 3 sets of 7 reps at 70% 1-rep max & plyometrics endurance-strength: 3 sets of 20 reps at 40% 1-rep max; twice weekly for 12 weeks	sig. difference in peak treadmill speed in both strength training groups; sig. improvement in 3-km time trial for explosive strength group; sig. improvement in RE at 2 of 3 tested speeds for explosive-strength group & 1 of 3 speeds for endurance-strength group	explosive strength: NR (12 km/hr) explosive strength: -2.3 (14 km/hr) explosive strength: NR (16 km/hr) endurance-strength: NR (12 km/hr) endurance-strength: -1.1 (14 km/hr) endurance-strength: NR (16 km/hr)
Skovgaard et al, 2014	12 moderately trained male runners	speed endurance training (4-12 30-sec sprints) & heavy resistance training (3 sets of 8 reps of squats, deadlifts, & leg press at 15-rep max, progressing to 4 sets of 4 reps at 4-rep max) twice weekly for 8 weeks	3.8% sig. improvement in 10-km time trial after 4 weeks & 5.5% sig. improvement in 1,500-meter time trial after 8 weeks; 3.1% sig. improvement in RE	-1.2 (12 km/hr)
Støren et al, 2008	8 well-trained runners	4 sets of 4-rep max half-squats 3 times per week for 8 weeks	5% sig. improvement in RE & 21% improvement in time to exhaustion at maximal aerobic speed	-0.034(f) (70% VO2max & 1.5% incline)
Taipale et al, 2010	28 male recreational runners (11 maximal strength, 10 explosive strength, 7 circuit training)	maximal strength: 3 sets of 4-6 reps at 80-85% 1-rep max (squats, leg press) & 2 sets of 12-15 reps at 50-60% 1-rep max (calf exercise); explosive strength: 3 sets of 6 reps at 30-40% 1-rep max (squats, leg press) & jumping exercises; circuit training: 3 sets of 40-50 seconds of lower- & upper-body exercises; twice weekly for 8 weeks	sig. improvement in speed at VO_2max in all groups; sig. improvement in RE at both tested speeds in maximal strength group & 1 speed in explosive strength group; no improvement in RE in circuit training group	maximal strength: - ~3.0 (10 km/hr) maximal strength: NR (12 km/hr) explosive strength: - ~1.0 (10 km/hr) explosive strength: NR (12 km/hr)

Vikmoen et al, 2016; 2017	11 female duathletes	3 sets of 4- to 10-rep max of half squats, one-legged leg press, one-legged hip flexion, & ankle plantar flexion twice weekly for 11 weeks	no change in RE; 4.7% sig. increase in running distance covered during all-out 5-min treadmill run following 90 min submax treadmill run; no change in running distance covered during all-out 40-min treadmill run	+ ~0.1 (10 km/hr)
Vorup et al, 2016	8 male endurance runners	strength training (1-4 sets of 4- to 10-rep max of squat, leg press, deadlift) twice weekly & speed endurance training (4-10 x 30 sec at 90-95% max speed) twice weekly for 8 weeks	4.8% sig. improvement in 400-meter time; 0.6 km/hr sig. improvement in maximal aerobic speed; 9.2% sig. improvement in time to exhaustion during incremental treadmill test; 32% sig. higher peak blood lactate during incremental treadmill test; no change in RE & 10-km time trial	-2.1 (60% max aerobic speed, ~11 km/hr) -2.2 (10-km pace, ~15 km/hr)

† Experimental groups performed combined endurance running and strength training. All studies with one experimental group included a control group of equal or similar size that performed only endurance running training.
(a) in kJ/kg-0.67/km
(b) in W/kg
(c) in ml/kg/km
(d) in kJ/kg/km
(e) in J/kg/km
(f) in ml/kg0.75/min
sig. = statistically significant; nonsig. = not statistically significant; NR = not reported; RE = running economy; vVO2max = velocity at VO_2max; VT1 & VT2 = velocity at ventilatory thresholds 1 & 2

cal factors. Most running injuries occur as a result of repeated microtrauma (from training volume and/or intensity) that causes the load experienced by the tissue to exceed its capacity.

Strength training recommendations to prevent running injuries are all over the Internet and social media—covering everything from resistance band clamshells and Russian twists to planks and pistol squats. The prevalence of these recommendations assumes that muscle weakness is a cause of running injuries. However, despite how much strength training is touted as a solution to the problem and despite the sizable percentage of runners who include strength training in their training programs, runners still get injured (Loudon & Parkerson- Mitchell, 2022). Indeed, injury rates among runners have not decreased over the last several decades. The etiology of running injuries is complex, multifactorial, and outside the scope of this review (for reviews, see Correia et al, 2024; Saragiotto et al, 2014; van der Worp et al, 2015). Research has shown that muscle weakness (commonly measured by knee extension, knee flexion, hip abduction, hip adduction, and ankle plantar flexion) may be associated with certain injuries, such as patellofemoral pain syndrome, anterior knee pain, iliotibial band friction syndrome, and Achilles tendinopathy (Duffey et al, 2000; Mahieu et al, 2006; Messier et al, 1991; Messier et al, 1995; Ramskov et al, 2015). For example, Niemuth et al. (2005) found that hip abductor strength of the injured leg of 32 recreational runners was significantly less than and hip adductor strength was significantly greater than the uninjured leg, while no differences in hip muscle strength between legs were found in a control group of 30 non-injured runners. In another descriptive study, Fredericson et al. (2000) found weaker hip abductors (isometrically) in the injured leg compared to the healthy leg of 24 male and female college and club long-distance runners with iliotibial band syndrome and compared to uninjured runners.

In a mixed-methods retrospective study, Vannatta et al. (2021) found that isometric hip abduction strength asymmetry in male runners and combined isometric hip abduction weakness and isometric hip external rotation weakness in female runners were significant predictors of a previous running injury. Whether the strength deficits observed in these studies is a cause of, consequence of, or unrelated to the injuries is unknown and needs to be elucidated by future research.

In a two-year prospective study of 98 high school runners, Finnoff et al. (2011) found that baseline hip external-to-internal strength ratio was lower in runners who developed patellofemoral pain than in uninjured runners. Among injured runners, hip abduction and external rotation strengths decreased from pre-injury to postinjury. Runners with greater baseline hip abduction strength and abduction-to-adduction strength ratio had an increased risk of injury, while runners with greater pre-injury hip external-to-internal rotation strength ratio had a decreased risk of injury.

In a 1-year prospective study of 629 novice male and female runners who started a self-structured running program, Ramskov et al. (2015) found that runners with higher-than-normal eccentric hip abductor strength were less likely to experience patellofemoral pain within the first 25 and 50 km of their running program. However, greater eccentric hip abductor strength was only protective against patellofemoral pain up to the first 50 km of running, since there were no significant differences between the high-strength group and the normal-strength group after 100, 250, or 500 km of running.

Many studies have found that strength is not associated with the development of running injuries. For example, in a two-year prospective observational study of 300 uninjured runners, Messier et al. (2018) found that hip abductor, knee extensor and flexor, and ankle plantar flexor strengths were similar between runners who became injured and those who did not and were not predictive of injury. In a one-year prospective study, Dillon et al. (2023) found that maximal isometric strength (ankle dorsiflexion, hip extension, and hip internal and external rotation) was not associated with the development of running injuries among 225 recreational runners, nor were measures of loading (impact acceleration) or factors affecting the dissipation of load (muscle strength, knee flexion angle at initial contact, foot strike pattern). Examining 36 male and female collegiate distance runners, Moffit et al. (2020) found no associations between back squat strength or isometric knee and hip extension strength and 14 kinematic and kinetic characteristics of running biomechanics that have previously been associated with overuse injuries in competitive distance runners. A systematic review by Mucha et al. (2017) found no meaningful association between hip abductor strength and injury status among runners across all levels of distance running. Reviewing the research on iliotibial band syndrome, patellofemoral pain syndrome, medial tibial stress syndrome, tibial stress fracture, and Achilles tendinopathy, only for iliotibial band syndrome did they find strong support for a relationship between muscle weakness and injury.

CURRENTLY AVAILABLE LITERATURE DOES NOT SUPPORT BIOMECHANICAL OR MUSCULOSKELETAL MEASURES AS RISK FACTORS FOR RUNNING INJURY IN NON-ELITE RUNNERS.

In a meta-analysis of prospective studies, Peterson et al. (2022) found that runners who developed an injury had significantly less knee extension strength and significantly lower hip adduction velocity than uninjured runners, however, the effect sizes were trivial to small and 23 of 25 pooled analyses detected no relationship between baseline biomechanical and musculoskeletal measures and the development of running injury, leading them to conclude that the currently available literature does not support biomechanical or musculoskeletal measures as risk factors for running injury in non-elite runners. Taken together, although muscle weakness in specific areas seems to be a characteristic of injured runners, most notably for iliotibial band syndrome, the effect is small and it cannot be said that muscle weakness is a cause of running injuries.

Only a handful of prospective running injury prevention studies have focused on strength training, and all of them have been conducted on novice or recreational runners. Table 2 summarizes the prospective and retrospective studies on strength training and running injuries. Of the 9 prospective studies, 4 of them found a significant difference in running injury prevalence between the strength training group and control group and 5 found no difference. Of the 4 studies that found a significant difference, one was conducted on youth female track & field athletes. Studying 433 recreational runners (21-55 years old), Desai et al. (2023) found no difference in overall running injury risk between a control group and a strength training group following 18 weeks of twice weekly strength training and foam-rolling exercises. However, the runners who were highly compliant with the intervention had a significantly lower risk of running injuries compared to the control group.

Taddei et al. (2020) found an experimental group of 57 male and female runners performing foot and ankle muscle training 4 times per week for 12 months was 2.4 times less likely to experience a running injury than a control group. Comparing hip and core muscle strengthening and foot and ankle muscle strengthening for 24 weeks, Leppänen et al. (2024) found a significantly lower incidence of running injuries in the hip and core group compared to a stretching-only control group, but no significant difference in the ankle and foot group. Toresdahl et al. (2020) found no difference in the prevalence of running injuries among 352 first-time marathon runners training for the New York City Marathon between those who strength trained 3 times per week for 12 weeks and those who did not (7.1% vs. 7.3%, respectively).

While weaker evidence than prospective studies, retrospective studies on the prevalence of running injuries have shown no apparent protective effect of strength training. All 3 known retrospective studies reported no difference in incidence of running injuries between runners who strength trained and those who did not (Table 2). Reasons for contrasting results between studies may be due to methodological differences (e.g., type and duration of strength training intervention), the degree of compliance with the intervention (in prospective studies), accuracy of reporting of past strength training (in retrospective studies), and the multifactorial nature of running injuries. For example, if an injury is due to suboptimal biomechanics or training errors rather than a muscle weakness or imbalance, it cannot be expected that strength training would prevent the injury. Without knowing the precise cause of a running injury, it becomes difficult to determine whether or not strength training may prevent it.

It's likely that the injured runners of these studies have multiple reasons for why they became injured. Studies and reviews on other non-strength training injury prevention interventions (e.g., stretching, pre-conditioning, warm-up, plyometrics) have also found no difference in injury rates between intervention and control groups (Bredeweg et al, 2012; Edouard et al, 2021; Fields et al, 2010; Lundstrom et al, 2019). Specific neuromuscular training comprised of a variety of jumps, landings, plyometrics, body-weight exercises, and running drills that include strength, endurance, agility, and balance exercises has been shown to be protective of injury in youth female track & field athletes when performed in addition to their normal training (Mendez-Rebolledo et al, 2021). However, a recent meta-analysis by Wu et al. (2024) and narrative review by Šuc et al. (2022) concluded there is little evidence to support inclusion of strength and conditioning exercises for the purpose of reducing running injuries. However, a post hoc analysis by Wu et al. (2024) revealed that when study interventions were supervised, there was greater compliance with the exercise programs and injury risk was significantly lower in the intervention groups compared to the control groups. However, there is evidence that greater quadriceps muscle strength is associated with more stress to the knee when running due to larger knee-joint loading, which may lead to injury (Messier et al, 2008).

THERE IS LITTLE EVIDENCE THAT STRENGTH TRAINING PREVENTS RUNNERS FROM GETTING INJURED, ESPECIALLY WHEN THE TRAINING IS UNSUPERVISED.

In summary, there is ample evidence, at least from retrospective studies, that muscle weakness, especially of the hip, is a characteristic of injured runners, but there is little evidence that strength training prevents runners from getting injured, especially when the training is unsupervised. There is currently no evidence that runners who don't strength train are more likely to experience a running injury. The scientific literature on this subject seems to contradict the popular belief that runners must strength train to prevent injuries.

CONCLUSIONS

A total of 45 studies (30 on strength training and distance running performance and 15 on strength training and running injury prevention) were included in this narrative review. While repeated attempts have been made to find all published studies on the subject, the possibility exists that not every study was found. Secondly, a narrative review has inherent limitations compared to a systematic review or meta-analysis, including the assignment and ranking of evidence level. Consequently, all studies are weighted equally. Thirdly, the studies in this review, which are summarized in Tables 1 and 2, exhibit a large variation in interventions that can be described but not statistically accounted for. Acknowledging these limitations, the following conclusions may be drawn based on the available scientific evidence:

1. Heavy and, to a lesser extent, explosive strength training seem to have a small, positive effect on running economy, although not all studies have found this to be the case.

2. Strength training does not im-

Table 2. Retrospective and Prospective Studies on Strength Training and Running Injury Prevention

Study	Subjects (experimental group)†	Intervention	Results
Baltich, 2016; Baltich et al, 2017	24 novice runners (resistance strength training group) 23 novice runners (functional strength training group)	resistance strength training: elastic band exercises, 4 sets of 10 reps functional strength training: lunges, squats, hops, single-leg stand 3-5 times/week for 8 weeks, then twice weekly for 4 months	no difference in running injury rates between experimental groups and control group
Brushøj et al, 2008	487 soldiers undergoing military training	strength, flexibility, & coordination training 3 times/week for 12 weeks	no difference in incidence of lower-extremity injury between experimental & control groups
Desai et al, 2023	433 recreational runners (21-55 years)	strength exercises (1-leg squats, forward lunges, side-plank, diagonal lifts, & side-steps, supine abduction, & foot supination with elastic training band) & foam-rolling exercises twice weekly for 18 weeks	no difference in overall running injury risk between experimental group & control group; experimental high-compliance group had significantly lower risk of running injuries compared to control group
Leppänen et al, 2024	hip & core: 108 male & female novice recreational runners ankle & foot: 111 male & female novice recreational runners	8 strengthening & neuromuscular control exercises for hip & core muscles or ankle & foot muscles for 24 weeks	sig. lower incidence of running injuries in hip & core group compared to control; no sig. difference in ankle & foot group compared to control
Letafatkar et al, 2020	neuromuscular training (NMT): 20 male novice runners neuromuscular training + knee valgus control instructions (NMT+VCI): 20 male novice runners	neuromuscular training: 2-3 sets of 10-20 reps of squats, deadlifts, lateral walks with resistance band, hip abduction & rotation, forward lunge, & balance exercises 3 times/week for 6 weeks; verbal & visual instructions to control pelvis & knee movement	sig. improvements in kinetics & kinematics in both groups after 6 weeks; sig. greater differences in kinetics between NMT+VCI compared to NMT; sig. 31.6% & 65.5% reduction of running injuries in NMT group & NMT+VCI group after 1 year
Loudon & Parkerson-Mitchell, 2022	68 masters female runners (>45 years)	—	97% of surveyed runners cross-trained & 78% strength trained; 71% had sustained more than one injury over their running history & 45% reported recurring injury; cross-training/strength training not associated with self-reported injury rates
Luedke et al, 2015	68 high school cross country runners (47 females, 21 males)	—	runners with stronger isometric hip abductor, knee extensor, & knee flexor muscle strength had sig. lower incidence of knee injury but not shin injury
Lundstrom et al, 2019	core training group: 12 college students (18-23 years) training for marathon plyometric training group: 11 college students (18-23 years) training for marathon	core training: low-to-moderate velocity muscular strengthening exercises for abdominal, hip, back, & gluteal muscles plyometric training: maximal velocity jumping & sprinting exercises; once/week for 12 weeks	no differences between core & plyometric training groups during marathon training in days missed, days missed due to injury, readiness to run, soreness, or RPE
Mendez-Rebolledo et al, 2021	11 youth female track & field athletes (15 years)	neuromuscular training, including jumps, landings, plyometrics, body-weight exercises, & running mixed with strength, endurance, agility, & balance exercises, 3 times/week for 6 weeks	sig. lower injury rate in experimental group compared to control group
Stenerson et al, 2023	473 female & 143 male recreational runners	—	no difference in running injury prevalence between runners who strength trained and those who did not
Taddei et al, 2020	57 runners (28 male, 29 female; mean age = 40.5 years)	foot & ankle muscle training consisting of 12 exercises 4 times/week for 12 months	experimental group was 2.42 times less likely to experience a running injury than control group
Toresdahl et al, 2020	352 first-time marathon runners training for New York City Marathon	strength training for core, hip abductors, & quadriceps, 3 times/week for 12 weeks prior to New York City Marathon	no difference in overuse injury resulting in marathon non-completion between strength training group & control group (7.1% vs. 7.3%), nor any difference in average marathon finishing time
Vannatta et al, 2021	82 NCAA Div III college cross country runners (38 males, 44 females)	—	males with hip abduction strength asymmetry & females with combined hip abduction weakness & hip external rotation weakness had increased likelihood of history of running injury
Voight et al, 2011	50 runners in Twin Cities Marathon	—	44% of surveyed runners strength trained; 54% did some type of cross-training (weight lifting, biking, swimming, yoga, aerobics, in-line skating, roller skiing, power walking, Nordic walking or skiing, rowing); no difference in injury rates between runners who cross-trained while training for a marathon & runners who didn't (14% cross-training vs. 8% no cross-training)

† Prospective intervention studies included a control group of equal or similar size not subject to intervention.

prove other aerobic physiological factors related to distance running performance, including VO_2max and lactate threshold.

3. Strength training improves muscular strength (measured as 1-rep max) in distance runners. Whether or not increased muscular strength per se results in faster races has yet to be determined.

4. There is no evidence strength training improves long-distance running performance (e.g., half-marathon, marathon, ultra-marathon). Studies measuring running performance have most often used 3-km to 10-km time trials or other lab-based performance tests to control for the many confounding variables that may affect "real-life" race performance on a given day. Given the impracticability of repeating a half-marathon or marathon time trial pre- to post-intervention and the recovery time needed after racing those distances, it is unknown whether or not strength training may improve long-distance running performance.

5. While retrospective studies have found that muscle weakness, especially of the hip, is associated with several types of running injuries, prospective studies have found that it is not.

6. There is equivocal evidence that strength training prevents or reduces the risk of running injuries. Prospective studies have often used lower loads and more isolated exercises (e.g., bodyweight, hip/core, and foot/ankle exercises) than those used in studies on running performance. Furthermore, there are no studies on runners of a higher than novice/recreational level.

DIRECTIONS FOR FUTURE RESEARCH

To ascertain whether or not strength training results in faster races and prevents running-related injuries, it would take a lot of systematic trial-and-error by runners and coaches and many carefully controlled, long-term studies. Several directions for future research may help to determine whether or not runners would benefit from including strength training in their training programs. Given the popularity of strength training for running performance improvement and injury prevention, an interesting question to explore in future research is why runners and coaches believe what they do about strength training.

The small improvement in running economy has been hypothesized to be due to enhanced neuromuscular characteristics, such as a more efficient use of stored elastic energy and improved muscle power. However, there is no direct evidence to suggest these characteristics translate into more efficient or optimal muscle recruitment patterns when running, as that would violate the law of specificity. Improved neuromuscular coordination would likely benefit only the specific exercises performed by the studies' subjects. Therefore, future studies should investigate the mechanism(s) of improved running economy, directly measuring motor unit recruitment patterns while running before and after strength training interventions.

The research to date that has shown positive effects of strength training on time-trial performance has not included a separate group that significantly increased its running training. Thus, the practical question that research has not yet answered is whether or not simply increasing the volume and/or intensity of one's running training would result in an equivalent (or greater) performance benefit compared to adding strength training to an existing endurance training program.

IT'S LIKELY THAT SIMPLY INCREASING RUNNING VOLUME AND/OR INTENSITY, INSTEAD OF ADDING STRENGTH TRAINING, WOULD ALSO IMPROVE PERFORMANCE.

For example, if the goal is to become a faster runner, is it better to increase one's weekly volume from 30 km per week to 50 to 70 km (or more) per week, or to remain at 30 km per week and add strength training two to three times per week? Likewise, is it better to increase the training intensity by introducing high intensity interval workouts or instead introduce heavy strength training? The studies including sprints in their strength training intervention have found that running performance improved (Paavolainen et al, 1999; Skovgaard et al, 2014). It's likely that simply increasing running volume and/or intensity, instead of adding strength training, would also improve performance. Furthermore, if a runner is running high mileage (e.g., >100 km.week-1)—which is typical of runners training for distance-running races—is it better to reduce the running volume to accommodate strength training? Nearly all the studies in Table 1 used recreational runners who were running a low enough weekly volume that they could physically handle the addition of strength training. Future studies should investigate the effects of strength training as an adjunct to different volumes and intensities of running training on running physiology and performance, as well as determining the most optimal (periodized) way of combining the two modes of training.

In line with this, it may be beneficial to compare strength training to more running-specific training methods, such as hill training. Although a different research question than the one presented in this review, a comparison of interventions may elucidate whether hill training may achieve the same goal for the runner as does strength training. It is possible, and even likely, that more sport-specific "power" training, such as hill sprints, as well as performing bounding and plyometric exercises up a steep hill, would be just as or more effective than traditional strength training with gym-based exercises for improving neuromuscular coordination, running economy, and distance running performance.

To date, little research has been conducted on the acute effects of strength training on distance running training. Athletes who perform both activities typically run first and then strength train, either immediately afterward or later the same day. Future research should determine which mode of training should be performed first, how strength training is best structured to fit within the context of run training, and whether or not any fatigue induced from strength training negatively affects the next day's run training. Studies on the acute effects of strength training on running physiology have yielded mixed results, with most showing a reduction in economy but no change in VO_2max following strength training (Doma & Deakin, 2014; Doma & Deakin, 2015; Gao & Yu, 2023).

Regarding running injuries, future research should examine the effects of strength training on more experienced runners and those of a higher performance level, as well as using heavier loads, similar to those used in the studies on running performance. In addition, all research to date linking muscle weakness to injury has measured maximal strength. However, maximal strength may not relate to and/or may not be as important to running injury prevention as how strength is applied while running. A strong, stable movement pattern, with optimal activation of muscles during the gait cycle, may be more likely to prevent injury rather than maximal strength itself.

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THE WISDOM OF YOGA

BY RUSS EBBETS, DC

It's the little things that count and TC editor Russ Ebbets shows how yoga might make a difference to an athlete's preparation.

The origins of yoga are somewhat unclear. Some authorities date the practice as beginning as recently as 1200 years ago. Other sources trace the beginning to the initial stages of recorded history, as early as 2500 years ago. For this discussion neither really matters. The important point is that the discipline is time tested and is not some marketing fad created to marginally capitalize on the fitness craze.

I was introduced to yoga as a high schooler through the old Book-of-the-Month Club (BOTMC). The initial offer of the BOTMC was usually five hardcover books for 99 cents. The choices included best-sellers, some reference books and titles that may be best described as eclectic. It bears mention that this "dollar" deal was when the minimum wage was $1.65.

The yoga book I purchased was more a series of pictures of an emaciated man, wrapped in a loin cloth, exhibiting various contortions that I couldn't even begin to approximate. We're talking foot behind the head, balancing the whole body on one hand and a series of pictures of him working a small string up his nose eventually exiting through his mouth. I couldn't see "the point" of any of this and unfortunately "the point" was never explained. Ultimately, a side-show job at Ringling Brothers was not in my future plans and the book got shelved.

Fast forward to senior year in college. I suffered a series of injuries that effectively ended the collegiate running career. After several laps of the medical merry-go-round, I was forced to accept the soul crushing reality that no one had a clue how to help me and that I'd better learn to live with my overtraining injuries.

Despite the knee and back injuries, I could lift weights. Although the college's weight facilities at that time were little more than a Universal Gym, I was able to design a workout that maintained some level of fitness.

Few people lifted in those days. Old wives' tales about becoming muscle bound and other tidbits of misinformation abounded which left workouts as much hit and miss as they were structured. One day one of the other people in the gym was a professor. To me, all he did was stretch, only stretch. On this particular day he began to talk with another professor about his recent trip to India and how he had contracted hepatitis. Until his hepatitis resolved he said he could not exercise per se, but he could do yoga. Yoga, I thought, what he did didn't look like anything I knew about yoga. Maybe there was more to the discipline than I thought I knew?

It turns out there was. At a local bookstore I found a copy of Richard Hittleman's *28 Day Guide to Yoga*. This was a progressive, step-by-step plan that over the course of a month not only introduced the practice of yoga but progressively challenged the body with an ever evolving series of poses or postures that worked to methodically manipulate the joints of the body and lengthen soft tissue. Additionally, yoga can develop or help restore a state of balance, poise and grace. With Hittleman's book as a guide, I have done yoga exercises almost daily my whole adult life.

But why did the poses evolve as they have to what practitioners use today? The genius of those who created yoga is that their rudimentary understanding of the body's anatomy and physiology became the foundation for the development of the postures. That may seem improbable in our high-tech, high cost, MRI diagnostic imaging world, but it is nonetheless true. Below is a quick examination of six classic poses or yogic practices with an explanation of why they are done, how they work and why they have remained standard practices for hundreds of years.

In general – Yoga practice accomplishes several goals. Most soon recognize an increased range of motion (ROM) the postures create over the course of days. A secondary benefit is the gentle "pulling" the stretch causes at the insertion sites of one's muscles, tendons and ligaments to make these attachments stronger. This, in turn, creates joint complexes that are more stable and less susceptible to injury. Technically, this is an application of Davis's Law and a form of invisible training. Davis's Law states that when tissue insertion sites are challenged the intuitive wisdom of the body increases the holding strength of the tissues. Davis's Law is the science behind the use of isometric training as a first step in rehabilitative care. This is called invisible training because to the naked eye there is no apparent change to the body.

THE SYNCHRONIZATION OF BREATHING WITH THE STRETCHING AND RELAXATION PHASES OF THE DIFFERENT POSTURES HELPS DEVELOP AND ESTABLISH AN UNCONSCIOUS IMPROVEMENT OF THIS CRITICAL BODY FUNCTION.

There are several general benefits worth noting. The synchronization of breathing with the stretching and relaxation phases of the different postures helps develop and establish an unconscious improvement of this critical body function. In fact, there is a yogic maxim – "he/she who half breathes, half lives." Body coordination is also sharpened as the slow, rhythmic movements in and out of the various postures programs or reprograms the sequential muscular firing patterns of various body movements. This teaches the body to move with a greater efficiency, less wear and tear and can be seen to promote longevity or contribute to the anti-aging process.

The Shoulder Stand – In truth, none of us spend much of our time upside-down in our daily lives. Our upright posture is the default position to walk, run or even sit for hours on end. The circulation of the blood throughout the body is driven by the heart, no news here, but what few realize is that the ejection of blood from the heart travels upwards first, against gravity, before it descends to circulate through the torso, legs and feet.
With an inverted posture (shoulder stand – Figure 1) or head stand the heart pumps the blood with gravity. In this upside-down position two areas that directly benefit from this repositioning are the brain and the neck. Oxygenated blood from the heart travels with a slightly greater pressure more thoroughly perfusing the various nooks and crannies of the neck and brain. But why the neck?

By one's mid-thirties to mid-forties virtually everyone starts to develop

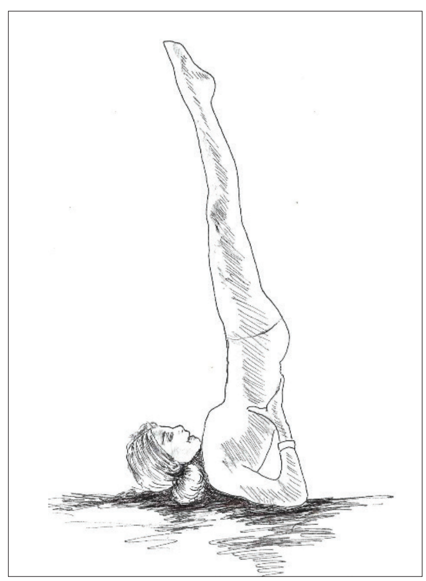


Figure 1: The Shoulder Stand

arthritis in the lower cervical spine. The reasons here are varied but would include untreated motor vehicle crashes, poor postures at work and the ubiquitous falls that created a whiplash to the neck with the lower cervical spine suffering the most long-term damage. While most may experience minimal pain, the damage to the discs and arthritic changes to the spinal vertebrae can cause one to start to lose height and close the holes of the spinal nerves exiting from the spinal cord, compromising the function of the nerves and the tissues supplied.

Of import here is the thyroid gland and its production of its three hormones. Coincidentally, the thyroid gland is located in the area of the lower cervical spine. The thyroid hormones influence the body's metabolic rate and protein synthesis. This is why the medical solution for a 40ish patient is thyroxine, a hormone supplement for waning energies. An alternative is the use of the shoulder stand with the repositioning of the heart to "flush" the thyroid gland with blood, capitalizing on the naturally occurring hormone remaining and using it to stimulate the body.

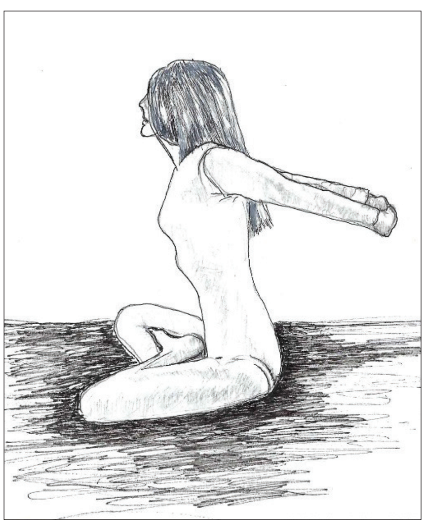


Figure 2: Seated Posture Clasp with the legs in the Lotus Position

Inverted postures can initially be challenging. There are modified positions that offer some similar benefits without the chance to topple over. Better to start conservatively than to find out quickly what one cannot do.

The Lotus Posture – The seated, crossed legged lotus position (Figure 2) may be the most universal symbol for yoga. This posture clearly expresses the intent of yoga for advertising, business cards or book covers. In the lotus posture one can practice meditative thought, breathing exercises or use the position to chant selected mantras. But there are additional benefits for the runner.

AN ATF WITH GREATER ELASTICITY IS BETTER ABLE TO HANDLE THE STRESSES OF RUNNING.

As we age the foot slowly loses its ability to dorsiflex. Dorsiflexion is the biomechanical term for lifting the toes and forefoot from the floor while the heel remains in ground contact. The foot dorsiflexes twice during the running/walking gait cycle. For heel strikers the dorsiflexion is at heel strike. In the toe-off phase the foot also dorsiflexes. Over the weeks, months and years of an athletic career this sequence is repeated. But why is the loss of dorsiflexion problematic?

The aging loss of dorsiflexion contributes to the shorter stride and a decreased force production with toe-off. Attempts to "maintain" performance levels as we age, begin to place more and more stress on the tissues of the foreleg. What is a telltale sign of an aging (35+ year-old) runner? Achilles problems, and in the weekend warrior, who does not warmup properly, a spontaneous rupture of the Achilles is an ever present possibility.

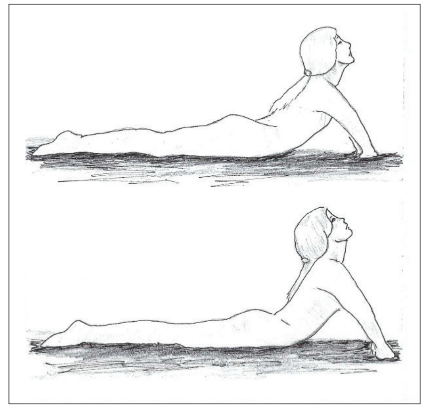


Figure 3: The Cobra

There are three ligaments on the lateral aspect of the ankle. The most anterior is the anterior talofibular ligament (ATF). In addition to stabilizing the ankle this ligament also checks foot dorsiflexion. Sitting in a cross legged lotus posture places the foot in a plantar flexed and inverted position that stretches the ATF. An ATF with greater elasticity is better able to handle the stresses of running. Coincidentally, one's ability to maintain a healthy dorsiflexion range of motion at the ankle can also help with fall prevention in an older population as a more mobile ankle allows for better balance and proprioceptive feedback, foot to brain.

The Cobra – To many the Cobra Posture (Figure 3) is simply a backward bend done lying on one's stomach. The posture accomplishes two general goals and also plays an important role in challenging the spinal column and discs that separate the individual vertebrae.

The bending motion is one of the six positions the body can move into and out of. Bending can be forward or backward or side-to-side. The interesting point here is that with the bending, one side of the body gets stretched, while the other side gets compressed or pushed together. Everybody gets the stretching part, but the compression part may be confusing.

All joint complexes (read that as adjacent bones) have a desired movement pattern or ranges which they can normally, safely move. Problems arise when one's lifestyle chronically limits the ranges of motion one routinely goes through due to one's work patterns (repetitive motions), handedness, mental state (drooped shoulders) or simply laziness (the recliner and a TV remote). Over time not exercising the full range of motion (ROM) of a joint complex subsequently shrinks and is commonly blamed for the "aging process."

The Cobra Posture stretches the tissues on the front of the spine and compresses the check joints (facets) of the posterior spine together helping to maintain one's forward

Figure 4: Standing Posture Clasp

and backward ranges of motion. It is important to emphasize here that the positions assumed should be done so gradually. Rapid movements, where one quickly forces the facet joints together, can literally jam the facets together, cause the local muscles to spasm, and compromise one's symmetric ROM defeating the purpose of the Cobra pose.

The Cobra Pose has been adopted by physical therapists and evolved into the widely prescribed McKenzie Technique for the treatment of low back disc injuries. But again, for this technique to be successful, it takes a time commitment of weeks and the actions must be completed in a smooth and gradual manner.

The Posture Clasp – It was mentioned earlier that breath control was one of the main focuses of yogic practice. One of the ways this is accomplished is the promotion of "good posture." But past your mother's admonition to "stand up straight" we get little direction throughout life. The Posture Clasp can be performed from the seated Lotus Pose (Figure 2) (preferred) or standing (Figure 4). The Posture Clasp is performed with the hands clasped behind the back and then the arms are lifted (shoulders extended) to end range.

This uncommon lifting pattern stretches the shoulder's capsule increasing shoulder ROM. This action also activates the muscles between the shoulder blades that when toned help bring the shoulders backwards, opening up the chest, thus allowing for a greater inspiration. Interestingly, this Posture Clasp can also cause the sternoclavicular joint to slightly

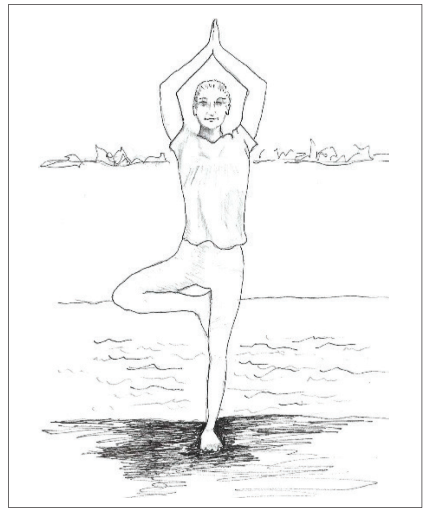


Figure 5: The Tree Pose

move. The sternoclavicular joint is the only bony attachment of the arm to the body. All the other attachments of the arm, the rotator cuff, rhomboids, pecs and serratus anterior are muscles.

BALANCE IS THE MOST IMPORTANT BIOMOTOR SKILL, AND ARGUABLY THE LEAST TRAINED.

Stooped postures, one sided lifting patterns, use of cell phones, computer work or gathering actions of white collar work can roll the shoulders forward and cut off the apices of the lungs decreasing the inspiratory capacity of the lungs which is a more technical way of saying – those that half breathe, half live.

The Tree Pose – Balance is the most important biomotor skill, and arguably the least trained. Instability in upright posture promotes injuries, compromises the effectiveness of training, decreases force production and generally shortens athletic careers and one's life. Loss of balance and falling down can be a nuisance to the adult and fatal for the elderly.

The Tree Pose (Figure 5) is a simple way to challenge one's balance and proprioception. It bears mention that balance uses one's sight while proprioception uses one's muscle sense without sight, eyes closed.

Standing on one leg we use visual cues and muscular strength to maintain the pose. Fatigue is signified by the eventual "wobble" one feels as the postural muscles tire. The practice of the position, over time, extends the time-until-wobble or fatigue which is an endurance quality. The ability to perform the Tree Pose with the eyes closed challenges one's proprioceptive sense adding another layer of complexity to the "simple" pose. The necessary caveat here is to make sure one has an open space as falls or necessary re-steps can happen.

The Lion – The Lion is a lesser known posture within the practice of yoga. The Lion is usually performed from a kneeling position (Figure 6). It is a series of six movements to create exaggerated features of the face, neck and hands. Ideally doing the Lion tones the muscles beneath the skin of these areas, increases the circulation and theoretically will decrease the incidence of wrinkles. To perform The Lion the eyes are widened, the mouth is open wide, the tongue extended, the nostrils are flared, the hands are either extended along the legs or raised to the side of the head with the fingers spread wide and a guttural "roar" is produced. For some this is a silly, fun gesture, but there is method to this madness.

Figure 6: The Lion – Eyes widened, nostrils flared, mouth open, tongue extended, fingers spread and a guttural roar is performed.

There are 12 pairs of nerves that supply the sensory and motor functions to the head, neck and shoulder areas of the body called the cranial nerves. The nerves exit at the base of the skull and are responsible for expression of the five senses. Sight, smell, taste, phonation, sense of touch and taste are all possible due to the cranial nerves.

What the exaggerated features of the Lion do is momentarily stimulate these nerves. This sudden and comprehensive challenge floods the brain with stimulation creating a momentary jolt that stimulates or jump starts the brain to an overall heightened awareness. If you have ever observed a sprinter preparing to get into the starting blocks or a football kick-off returner about to receive the kick-off, they often perform a "knees-to-chest" jump. This knees to chest creates a similar stimulus flooding the brain with sensory input from throughout the body with the brain responding with a momentary sense of heightened awareness.

Interestingly, cranial nerve X, the vagus nerve, is the longest nerve in the body and travels from the skull all the way to the large intestine. Along the way branches of the vagus nerve innervate the heart, lungs, liver, gall bladder, stomach, spleen, pancreas, kidneys, bladder and sex organs. The vagus nerve is essentially responsible for the functions of the parasympathetic nervous system (the wine or dine responses).

Flexibility is one of the five biomotor skills. Oddly, it is the only non-competitive biomotor skill. Yoga is flexibility, but I think now you can see that this is a simplistic view. Even though we discussed six poses or postures we only scratched the surface.

Modern day yoga is done in hot rooms, with goats and has even produced its own scandalous Netflix documentary. Although yoga has been promoted for women, that is misleading as men will benefit from the practice as much, if not more. To get started I have long suggested Richard Hittleman's *28 Day Guide to Yoga*. It is a safe, progressive program requiring minimal equipment other than some floor space and 20-30 minutes of your time daily. In the span of 28 days, one will become conversant in the ability to attend to virtually any area of the body feeling discomfort. And when done in the safety of your own home one can roar to one's heart's content.

Artwork by Joan Parsnick

DEVELOPING AN EFFICIENT DISCUS MODEL

BY MIKE MAYNARD

Mike Maynard was the head track & field coach at Boise State from 2000 to 2009 and at UCLA from 2009 to 2017. This piece is adapted from the January 2010 issue of Long and Strong, *Glenn Thompson, Editor.*

The discus throw allows for a wide range of individual expression of the technical fundamentals. Current successful technical expressions of the discus cover a wide variety of styles and philosophies of throwing. The physical parameters of successful discus throwers, on the world stage, indicates the necessity for well above average size. For example, world class male discus throwers tend to be about 1.95m/115kg [6'5"/254lbs]. However, exceptions to these physical parameters readily exist on both the national and world levels. The athletes who comprise these exceptions typically compensate for physical deficits with a particularly exceptional specific physical talent(s), and/or an exceptionally well-adapted technical model.

The dynamic nature of the discus movement has historically witnessed a variety of successful technical expressions. Many of these utilize large and sweeping movements to accomplish mechanical advantage within the throw. Those technical models will continue to be successful. The technical model should seek to maximize the athlete's particular physical attributes (i.e., system of levers, range of movement, bio-motor capabilities).

The technical model to be presented and discussed in this article is meant to pare down the movements of the discus thrower to a bare and essential minimum.

The objective in restricting the variables of the technical movement within the discus model is meant to create a system of throwing which is efficient and easy to replicate as a model. The efficient technical model promotes consistency of expression via repetition, faster progression toward habituation of movement, and offers the opportunity of lower degradation of the quality of movement due to competitive stressors. In addition, this type of model can offer coaches a simple and precise task-oriented teaching progression. The successful lowering of the minimum physical parameters necessary for high level success, offered by an efficient technical model, may also offer coaches a greater population with regard to athlete selection.

ESTABLISHING SYSTEM AXIS

A key and central element of the technical model being presented is a stable and consistent axis of the thrower-implement system. This system axis must be established and maintained throughout the throw. Athlete posture is the basis of this efficient dynamic axis. **The development of an efficient axis can be accomplished by stabilizing the trunk axis in an upright posture with the hips tucked under the athlete during the preliminary wrap of the discus.** This vertical posture should be maintained throughout the entire throw, with the exception of the axis tilt in the power position.

Coaching Cue: The coach should introduce, and consistently cue, the athlete to maintain an erect posture with the hips stabilized and tucked underneath throughout the learning process. Posture precedes balance.

The objective of establishing this axis is intended to minimize head radius of the athlete throughout the entire movement. The error of excessive lateral deviation of axis is best observed when viewing the athlete from the back of the circle and towards the throwing direction, or 180 degrees. The goal is to minimize any lateral deviation (I.E. wobble) of the axis. This stable and efficient axis allows forces imparted to the system, such as the push in the direction of the throw off the single support base out of the back of the circle, to result in a corresponding increase in forces available to be applied to the discus during the delivery phase. If the axis remains efficiently stable, the treatments of the free leg, drive leg, and CMT displacement, can be organized to create effective resultant forces for the discus delivery. An efficient system axis allows for effective maintenance and use of separation/torsion, in the form of stored elastic energy, within the throw delivery.

PATHS OF CENTER OF MASS

An additional technical goal of the athlete during the discus throw should be the creation and use of dynamic / directional displacement of the center of mass. **An efficient technical model should seek to align those forces generated parallel with the intended direction and angle of projection of the throw.** This aim should be achieved while creating a dynamic and specific directional balance of the thrower-implement system about an efficient axis. Direction, paths of the thrower/implement system, and angle of implement projection should be taught early and often within the teaching progression of the discus throw.

Paths to be covered should include the paths of Center of Mass of the Thrower (CMT) and Center of Mass of the Implement (CMI) and with intended angles of projection and orbital considerations. Development of the awareness of these paths by novices, early in the learning progression, can be effective in the development of spatial and kinesthetic awareness of the athlete. At the outset of the discus movement, the transition from double support to single support necessitates a shift of the CMT toward the single support base.

The degree of this shift over the base of support is relative to the degree of Center of Mass displacement / counter in the direction of the throw (i.e., hip counter). In order to create an effective throwing direction the necessary path of the CMT is roughly as follows (see Figure 1).

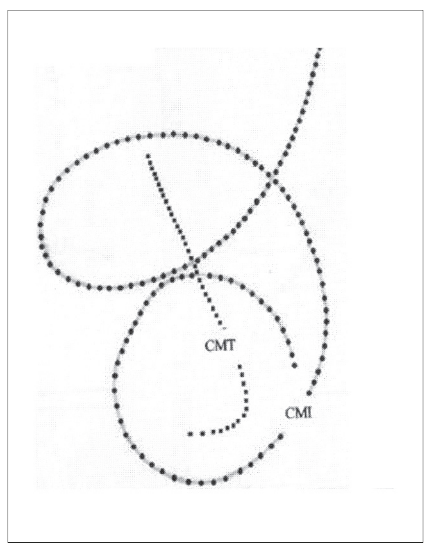


Figure 1

ALIGNMENT OF FORCES

The actions of the swing/free leg and the push-off of the drive/support leg aid in establishing the intended path of projection of the implement. The CMT and the forces established by the swing/free leg and drive/support leg out of the back of the circle combine to create a resultant which is ideally parallel to the discus projection path.

Those forces should be directed as closely as possible to align with both the intended angle of projection, as well as the directional path of the implement. The direction of the push out of the back of the circle should be aligned with the path of the CMT (see Figure 1). The push direction may require modification, due to the actions of the free/ swing leg, so that the resultant system direction is accurate to the intended path. Reduction of deflected forces makes it easier to apply those forces generated during the throw into an efficient delivery sequence. This efficiency of movement offers either higher performance for a given level of forces generated or equal performances with less force required, relative to a less efficient model of throwing.

The discus orbit is a resultant of the system axis and the forces applied to the thrower/ implement system. The push-off of the first single support establishes the direction of CMT, as well as the pitch angle of the orbital plane. When viewing the throwing movement from 90° to the side in the throwing direction, **the angle of the push-off of the single** support leg should be applied parallel to the desired angle of projection of the implement (see Figure 2).

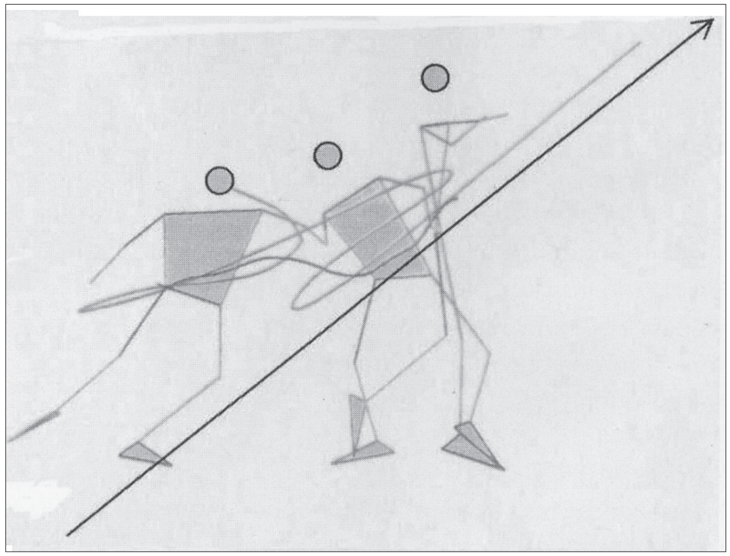


Figure 2

Coaching Cue: Single-support push angle alignment can be determined by checking to see that the angle of the lower leg (tibia) is parallel to the angle of projection of delivery, when the athlete executes the push out of the back of the circle (see Figure 3). The discus orbit should be symmetrical. A symmetrical orbit is evident when the implement is neutral, relative to horizontal, at both 90 and 270 degrees. There should be minimum yaw of the orbit on the longitudinal axis. Applying forces within a symmetrical orbit aids the efficiency of the thrower-implement system upon delivery.

Coaching Cue: Orbital mistakes, such as late high point or "scooping," should be addressed by developing proper axis, and proper alignment of forces with regard to both direction of CMT and angle of projection.

SEPARATION AND TORSION

Separation and torsion are distinct skills that are required in the discus throw. **The elastic energy that the combined movements of torsion and separation provide serves as the primary engine for the acceleration of the discus in the delivery.** A technical model that stresses the maintenance of an efficient axis offers the athlete the ability to maintain and utilize separation and torsion to a higher degree.

Coaching Cue: Torsion can be defined as the positive angle, or space, created between the hip axis, and the trailing end of the shoulder axis. Separation can be defined as the positive angle or separation of axis between the shoulder axis and the throwing arm axis as it extends through the CM of the implement. For the purposes of this article, and to better delineate between the aspects of these energy storage systems, the terms total lead/space will be used to define the cumulative amount of torsion and separation (see Figure 3).

SEPARATION & TORSION

In the case of each of the skills of separation, and torsion, the thrower can pre-stretch the agonists, and thereby facilitate and maximize the storage of elastic energy. In addition to creating the ability to exploit the stretch reflex, the throwing side arm/ lever, and trunk, range of motion is maximized through these movements. Proper delivery timing will generate the conditions optimal for the efficient summation of forces and delivery sequence.

SEPARATION

When properly executed, both separation and torsion offer the thrower an opportunity to maximize bio-motor and mechanical components of the throw. Separation can be achieved if the athlete contracts the triceps, and cocks back the throwing side shoulder. The contraction of the rear throwing side (*antagonistic*) musculature causes a relaxing of the chest deltoid area (*agonistic)* musculature that increases both the range of motion of the throwing arm lever, and the storage of elastic energy.

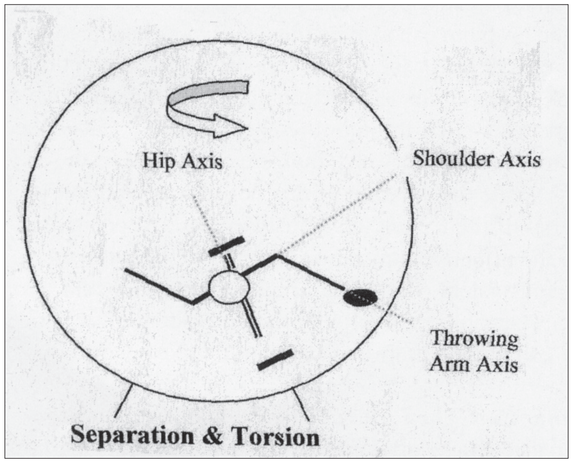


Figure 3

Coaching Cue: The coach should introduce, and consistently cue, the athlete/ thrower early in the learning process to actively contract the antagonistic to the throwing side musculature. Active cues such as "squeeze the backside muscle," or "cock & lock'' the rear shoulder and inside head of the triceps aids in maximizing separation. Lowering the throwing side arm increases range of motion and contributes to proper discus tilt on delivery.

Over time and as throwers progress in the skill of creating and maintaining separation, it is likely that passive cueing of the skill of separation can be used. This is especially true for those throwers who have gained stabilization of the skill. The passive cueing of separation would be achieved by instructing the thrower to relax and leave the discus trailing behind the system during the movement as far as possible. The goal of this passive cueing is meant to maximize the total lead in the system.

National and world-class discus throwers can at times lose their separation levels during high-intensity throws. The most common cause of this fault is related to an inefficient axis. The problem can also be the result of an especially effective push-off of the single support/drive leg out of the back of the circle. The stretch created by an effective push creates stretch through the chest and may cause the discus to "bounce" forward, thus creating slack in the system. While the creation of this negative separation is not a goal of the technique, the cause can be a positive sign of the effective translation of force to the thrower-implement system. The skill of regaining position and the necessary separation level with the corresponding elastic energy can be taught through effective use of drills.

Coaching Cue: The Cast & Catch style of the South African drill can be effective for this purpose. This drill can be practiced with balls, puds, pipes, or just about anything that would typically be thrown in training. It may be advisable to use the standard style of South African drill, with a constant total lead, when throwing the discus as the primary drill. This will reduce confusion within the athlete regarding the differing goals between the drills.

The lack of separation of the throwing arm axis relative to the shoulder axis can be simply described as "slack" in the system. Slack becomes evident to the coach by observing the relationship between the throwing arm axis relative to the shoulder axis. A negative separation angle is easily noted as the discus seems to lead the thrower as the thrower-implement system moves in the direction of the throw toward the orbital high point. **The negative/neutral separation angle effectively inhibits the opportunity for the thrower to impart any force to the implement until the slack is removed from the system.** If the separation angle is reduced to any extent during the conclusion of the first single support or non-support phase it should be regained prior to the re-contact of the second single support in the center of the ring.

TORSION

Torsion can be defined as the positive angle, or space, created between the hip axis, and the shoulder axis (see Fig. 4). Torsion affords an opportunity to store elastic energy in the torso of the thrower for use during the delivery sequence. The counter wrapping of the free arm in non-support can be an effective means of re-establishing and maintaining torsion. **Actions of the free side arm and shoulder, when combined with active counter-rotation and contraction of the torso musculature, will maximize the torsion level between the shoulder axis and the hip axis.** It is possible to establish a torsion position upon the preliminary wrap of the discus movement by "setting" the left shoulder inside the left hip in the initial wrapping movement of the throw. Some athletes are sensitive to the tendency of this early torsion to somewhat inhibit rotation within the throw. However if the axis is efficient, then additional rotational forces can be added via the swing/free leg inversion, as well as shortening the free arm, to counteract this inhibited rotation. An early establishment of torsion greatly reduces the opportunity for later mistakes that may result in the loss of torsion.

Coaching Cue: The torsion position can be set from the back of the circle by setting the shoulder axis behind and inside the leading side hip axis. Cue the athlete to hold this left shoulder inside the leading side hip until delivery sequence is initiated. Free arm can aid in re-establishing torsion in non-support by casting it in a subtle counter-wrap motion.

SECOND SINGLE SUPPORT

The second single support contact phase is a critical phase within the throw, because it represents a major opportunity for the loss of angular velocity of the implement due to thrower-implement system friction. This friction tends to reduce the separation/torsion level via system deceleration. The loss of separation can be avoided if there is an active cueing of squeezing the throwing side arm/shoulder back to maintain separation level. This can be achieved by cueing the contraction of the antagonistic/backside musculature, and/or an active inversion, or pivoting ahead, of the second single support side both prior to and subsequent to the second double support re-contact (i.e., left foot re-contact for a right-handed thrower).

The loss of angular velocity of the thrower-implement system, due to the second single support friction, can also be mitigated by reducing the time between the second single support contact and the second double support contact. **Delaying the re-contact of the second single support in the center of the ring will reduce friction, and shorten the time interval between the second single support contact, and the second double support contact** (i.e., the time between right foot, and left foot touch-down for a right-handed thrower). This delaying of the re-contact of the second single support foot can be accomplished by lifting the knee of the swing / free leg (right leg for a right-handed thrower) during the nonsupport phase following the swing invert action. The re-contact of the second single support can also be delayed by the active dorsiflexion of the swing leg foot. These movements serve to delay the re-contact and shorten the time interval between single support and double support. They also have the added benefit of creating knee flexion and an ankle lock position which aids in the storage of ad-

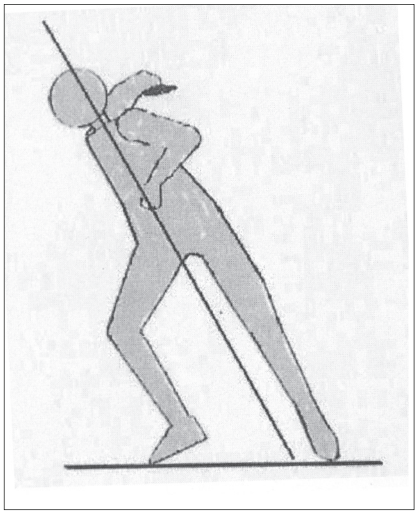


Figure 4

ditional elastic energy in the leg for use later in the delivery sequence. The re-contact of the second single support should be with the foot axis oriented at, or around, 315 degrees. However, a case could be made for delaying re-contact even later to reduce the negative impact of friction on implement velocities.

Coaching Cue: The athlete should be instructed to turn in the air, not on the ground. The desired angle of the foot axis upon re-contact of the second single support should be approximately at 315 degrees. It is important that the thrower does not stay on the first single support beyond the line of direction of the CMT out of the back of the circle. This error leads to the technical fault of "over-rotation" and results in a poor heel tuck/ heel recovery on the drive leg.

TILT OF AXIS IN POWER POSITION

When observing the axis of the system, from the perspective of 90 degrees in the throwing direction, there should be a tilt of the axis away from the throwing direction when the athlete is in the Power Position (see Figure 4). However in order to maintain effective summation of the system upon delivery, there should still be minimal deviation of the axis (i.e., head radius) in the system axis. The axis tilt aids in establishing the angle of projection of the implement. The axis tilt maximizes the force path of the implement, and thereby the opportunity to impart forces in the delivery of the discus. In addition the axis tilt delays the transition of the CMT in the direction of the throw, which results in a more effective use of forces generated. **The tilt/orientation of the axis is achieved during the non-support phase of the throw.** As the free leg is inverted, and lifted, a center axis of rotation is established. The free arm, and shoulder, is counter wrapped away from the direction of the throw. This wrapping of the free arm side maximizes torsion between the hip axis and shoulder axis, and initiates the tilt of the axis away from the throwing direction. The lower body travels toward the front of the circle, and the tilt is complete. The tilt of the axis is relative to the desired angle of projection of the implement, and the technical proficiency of the thrower (i.e., throwers with greater technical mastery can achieve and utilize a greater axis tilt).

Coaching Cue: During the learning phase atletes should be instructed to maintain a more erect vertical posture throughout the throw until technical mastery allows the use of greater system axis tilt. Axis tilt should be introduced as the novice thrower becomes more adept at achieving the fundamentals of the standing throw position.

COACHING CONSIDERATIONS

Teaching progressions should be based on task/skill identification and should develop the athlete toward mastery of necessary skills. The coach should seek to create specific learning periods with an objective emphasis towards specific skill acquisition. The process of skill introduction should follow the following process:

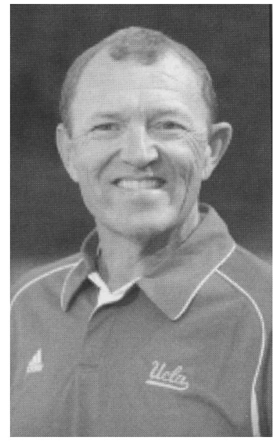
Coaching Cue: Repetition of an introduced movement creates a learned movement. Stabilization of a learned skill occurs through repetition of the learned movements. Habituation of a movement skill occurs through repetition of stabilized movements.

- Introduce the skill
- Drill the skill
- Instill the skill *(via repetition)*

The goal of the teaching progression should be to move motor skills along the continuum from learned movements to habituated skills/ movements. Related/ parallel movements and task-oriented drills should be used, in conjunction with cueing within the throw, to aid in the learning progression of identified skills. For the aid of developing an appropriate skill progression the following is a non-exhaustive list of skills related to the discus technique:

Task/ Skill Identification

1. Double Support Axis/ Balance/ Posture
2. Hip/ Pelvis stabilization
3. Pivoting in Single and Double Support
4. Transferring/ Countering of CM
5. Single Support Axis/ Balance/ Posture
6. Use of Focal Points
7. Establishing and Maintenance of Torsion & Separation
8. Free Arm Mechanics
9. Swing/ Free Leg Actions
    a. Sweeping
    b. Inversion
    c. Knee Drive/Lift
    d. Dorsiflexion (*ankle lock)*
10. Drive Leg Actions
    a. Sprint/ Push
    b. Heel Tuck/ Recovery
    c. Adduction
11. Maintenance of position Axis/ Balance/ Posture during Non-Support Rotation
12. Re-contact Stabilization
    a. Single Support
    b. Double Support
13. Effective Transfer of CM
14. Use of Torsion & Separation in Delivery Sequence
15. Blocking Mechanics
    a. Upper body
    b. Lower body
16. Recovery Mechanics



Maynard

SUMMARY

It is possible to pare down the movements of the discus throw to an essential minimum. The creation of a throwing model based on a stable vertical axis is an important part of that endeavor. Such a model may promote consistency of expression, faster progression toward habituation of movement, and lower degradation of quality of movement due to stressors. A stable system axis allows for maintenance of increased levels of torsion and separation, as well as promoting the effective use of the elastic energy stored in the torso. In addition a stable system axis will aid in maximizing the utilization of properly aligned forces for the delivery sequence.

EDITORIAL COLUMN

Continued from page 7996

variety of topics that were all pertinent to their discipline or areas of expertise.

Special thanks go to Ed Fox, Teresa Tam and the crew at *Track & Field News* for continually producing both a print and digital journal that has serviced the sport worldwide since the 1950s. Best wishes to all and continued success. It has been my honor and privilege to serve in this capacity for the last 25 years.

USATF COACHING EDUCATION

USATF CALENDAR OF SCHOOLS

https://www.usatf.org/programs/coaches/calendar-of-schools

Jan 17-19	*USATF Marathon Specialist Course - Zoom*
Jan 25-26	*USATF Level 1 School – Zoom (PT)*
Feb 7-9	*USATF Level 1 School – Zoom (ET)*
Feb 13-14	*USATF Level 1 School - Reno-Sparks Convention Center, Reno, NV*
Feb 15-16	*USATF Level 1 School – Ironwood Throws Center, Rathdrum, ID*
Feb 22-23	*USATF Level 1 School – Zoom (ET)*
March 8-9	*USATF Level 1 School – Zoom (ET)*
March 29-30	*USATF Level 1 School – Zoom (PT)*

Watch for summer program dates for the USATF Level 2 School, Emerging Elite Coaches Camp, and USATF Cross Country Specialist Course to be announced in the spring issue.

ON TIME 2024 USATF LEVEL 1 RECERTIFICATION APPLICATIONS ACCEPTED THROUGH JANUARY 31, 2025

Members with a Level 1 certificate expiring on December 31, 2024, were invited to access the recertification application in November. On-time applications are extended for a limited time, and members are encouraged to take action now; a late fee will go in-effect thereafter. Members must hold a current USATF membership, current SafeSport Training, complete an eligible USATF continuing education course, and submit registration to renew their Level 1 certificate for an additional four calendar years. Members who elect to retake the USATF Level 1 Program in lieu of one of the approved continuing education courses do not need to complete the recertification application. USATF Level 2 and 3 coaches are exempt from Level 1 recertification and no action is necessary. Members may check their certificate expiration date on USATF Campus under Skills Passport.

Full recertification protocols for all USATF Coaching Education Programs are posted at the link below. Members may contact coachingedu@usatf.org for assistance in the recertification process.

https://www.usatf.org/programs/coaches/recertification

COACHING RACE WALKING NOW AVAILABLE ON USATF CAMPUS

Dr. Christine Brooks, the USATF Coaching Science Instructor, and Ian Whatley, a Team USA athlete and coach specializing in race-walking, collaborated to create Coaching Race Walking, a new self-paced course available on USATF Campus. It offers essential knowledge for coaches aiming to help athletes progress from novice to early-stage advanced race walkers. The course also covers the topic of power walking, which is particularly popular among athletes in the masters age groups. Depending on the depth of your review, it will require approximately 7-9 hours to complete the online training. The course includes lessons on walking techniques, race walking teaching progressions, technique correction steps, and fundamentals of race preparation. A USATF Connect profile (free) is required to register for USATF Campus courses. Click Coaching Schools (left-hand menu) when logged into your account to purchase Coaching Race Walking.

https://www.usatf.org/programs/coaches/usatf-campus-online

USATF MARATHON SPECIALIST COURSE RETURNS JANUARY 17-19, 2025

Ahead of the spring marathon season, the USATF Marathon Specialist Course will be offered on Zoom the weekend of January 17-19, 2025. Join coaches from across the country and learn about the history, training science, critical workouts and strength programming, nutrition, environmental factors, race day and mental preparation strategies to develop a comprehensive training plan specific to athletes' abilities and their marathon performance goals. The course also features a hands on group assignment specific to the athlete population you coach, and an online examination follows the training.

USATF Coach Educator, Olympian, and multi-time national team coach, Kathy Butler, OLY and Christopher Lundstrom, PhD, who guided Dakotah (Lindwurm) Popehn to a 12th place finish and top American woman at the 2024 Paris Olympic Marathon return as the lead course instructors.

No prior coaching education is required; however registrants must be current USATF members and at least 18 years of age to register.

https://www.usatf.org/programs/coaches/specialty-programs/usatf-marathon-specialist-course

2025 USATF COACHING ENHANCEMENT GRANT APPLICATIONS OPENING SOON

Watch for 2025 coaching grant applications to open soon in the new year and feature new grant opportunities available to members. Among the opportunities, the USATF Emerging Female Grant will be expanded to include all females, regardless of race, and feature an increased funding amount. All grant applicants must minimally be current USATF members and SafeSport

Trained. Applicants are encouraged to apply early for interested opportunities as deadlines and funding amounts vary by program.

https://www.usatf.org/programs/coaches/grants

YEAR END COACHING ACHIEVEMENT AWARDS ANNOUNCED AT USATF ANNUAL MEETING

Joanna Hayes Named 2024 USATF Nike Coach of the Year

Recently named the director of track and field at her alma mater, UCLA, Hayes guided Rai Benjamin to Olympic gold in the men's 400 hurdles at Paris, where he ran a 46.46 to win by more than a half-second. Benjamin also earned gold in the men's 4x400 relay, anchoring the U.S. to a 2:54.43 that just missed the world record. Undefeated in 2024, Benjamin also ventured over the flat 400 once, winning the Mt. SAC Relays in 44.42. With her collegiate coaching cap on, Hayes helped lead USC to a 10th-place NCAA outdoor finish in the women's team standings, with 400 hurdles champion Jasmine Jones setting the pace. Jones went on to make the Olympic team and place fifth in the 400H at Paris, and she was also the NCAA indoor 60H champion.

Joe Vigil Sports Science Award: Christopher Lundstrom, PhD, USATF Minnesota

This award recognizes a coach who is very active in the area of scholarship and contributes to the coaching literature through presentations and publications. This award identifies a coach who utilizes scientific techniques as an integral part of his/her coaching methods or has created innovative ways to use sport science.

Ron Buss Service Award: Kathy Butler, OLY, USATF Colorado

This award recognizes a coach who has a distinguished record of service to the profession in leadership roles, teaching, strengthening curricula, and advising and mentoring coaches. This person is a leader, whose counsel is sought by others, and who selflessly gives his/her time and talent.

Fred Wilt/Educator of the Year Award: Scott Christensen, USATF Minnesota

This award recognizes a coach who has a distinguished record, which includes sustained, exceptional performance. This award is presented annually to recognize one individual who has exemplified passion and leadership nationally for the promotion of USATF Coaching Education.

Vern Gambetta/Young Professional Award: Sara Macey, USATF San Diego-Imperial

This award recognizes a young coach in the first 10 years of his/her career that has shown an exceptional level of passion and initiative in Coaching Education. This award is presented annually to recognize one individual who has exemplified passion and leadership nationally for the promotion of USATF Coaching Education.

Terry Crawford/Distinguished Female in Coaching Award: Darcy Wilson, USATF New England

This award recognizes a female coach who has shown an exceptional level of accomplishment, passion, and initiative in Coaching Education. This award is presented annually to recognize one female coach who has exemplified passion and leadership nationally for the promotion of USATF Coaching Education.

Kevin McGill/Legacy Award: Glen Sefcik, USATF Southwestern

This award recognizes a veteran coach with 25+ years of involvement who has shown an exceptional level of passion and initiative in Coaching Education. This award is presented annually to recognize one individual who has exemplified passion and leadership nationally for the promotion of USATF Coaching Education.

Level 2 Coaches/Rising Star Award: Jared Tyler, USATF Southwestern and Charlotte Sneed, USATF Pacific

This award recognizes a coach who has utilized the USATF Level 2 Program to make an impact on their coaching that includes sustained, exceptional performance. This award is presented annually to recognize one individual who has recently completed the level 2 school and implemented its teachings in their coaching. This award winner exemplifies the impact of the USATF Coaching Education program.

You can nominate a deserving coach for a 2025 coaching education award at the link below.

https://www.usatf.org/programs/coaches/coaching-education-awards

HELP USATF CLIMB THE NGB LEADERBOARD BY COMPLETING THE FREE CONNECTION BASED COACHING COURSE

USA Track & Field (USATF) joined the U.S. Olympic & Paralympic Committee (USOPC) in their NGB Connection Based Coaching Challenge as a part of the Million Coaches Challenge, an initiative led by the Susan Crown Exchange to train one million coaches in youth development techniques by 2025. To support the goals of the Million Coaches Challenge, the USOPC created a free, self-paced online course called Connection Based Coaching, which focuses on teaching social and emotional learning skills. The USOPC aims to train at least 40,000 coaches by 2025 using this curriculum, which consists of three 30-minute modules. As part of this initiative, USATF and other National Governing Bodies (NGBs) are participating in the Connection Based Coaching Challenge to help the USOPC reach their 40,000-coach goal with up to $15,000 in funding to be awarded to an NGB with the most coaches trained. USATF invites members, fans, coaches, and supporters to join the movement to ensure kids across the country have access to coaches who are well versed in youth development techniques to help kids succeed in and out of competition. Those interested in supporting USATF in the Connection Based Coaching Challenge can sign up for a free series of three 30-minute training courses on the USOPC Mobile Coach Platform by registering under track and field when selecting their NGB of choice.

https://www.usatf.org/programs/coaches/partner-courses/million-coaches-challenge

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