Strength and Conditioning for Adolescent Endurance Runners

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ABSTRACT

For the adolescent athlete who chooses to specialize in endurance running, strength and conditioning (S&C) activities provide a means of enhancing several important determinants of performance and may reduce the risk of overuse injury. It is recommended that adolescent endurance runners include at least 2 S&C sessions per week that comprise movement skills training, plyometric and sprint training, resistance training, plus exercises designed to target specific tissues that are vulnerable to injury. This article describes how these modalities of training can be integrated into the routine of adolescent endurance runners.

INTRODUCTION

Endurance running is a popular choice of sport for young athletes. For example, in 2016–2017, cross-country was the fourth and fifth largest sport by participation for boys and girls, respectively, in USA high schools (www.nfhs.org/ParticipationStatistics), and endurance running represented the second most popular sport (18.7%) in a survey (n = 7,794) of Scandinavian 14 year olds (83). Young athletes should be exposed to a wide range of sports and physical activities during their adolescence; however, the priority should be placed on the development of rudimentary motor skills and muscular strength (49). Endurance training during early adolescence (11–14 years) should form part of an active healthy lifestyle but should not take precedence over other modalities of sport training (80). Endurance sports are typically associated with a high volume of training (80), which places the developing body of a young athlete under a high level of stress that could leave them susceptible to overtraining syndrome, illness, and overuse injury (54). Therefore, specialization in endurance running should not occur until late adolescence, when a young athlete's body is sufficiently mature and well conditioned to cope with the rigors of this type of training. Strength and conditioning (S&C) activities might contribute toward lowering the risk of injury in athletes (45,82); therefore, providing sport-specific recommendations for this vulnerable population is important.

Endurance running is primarily limited by cardiovascular and metabolic factors; however, there is an abundance of research showing that strength training (ST) activities (resistance training [RT], explosive RT [ERT], and plyometric training [PT]) can provide performance benefits to middle- (0.8–3 km) and long-distance (>3 km) runners (16,29). A plethora of literature also exists that demonstrates ST activities are also a safe and effective way of enhancing proxy measures of athletic performance in adolescents of both sexes (10,41,46). Specifically, compared with sport-only training, various forms of ST augment improvements in maximal strength, explosive strength, muscular endurance, sprint speed, agility test time, tennis serve velocity, kicking velocity, throwing velocity, and general motor skills (10,40,41,46). However, there are currently no articles that have specifically summarized the effect of ST modalities on aerobic-related qualities in young athletes. For practitioners working with young distance runners in particular, it would be useful to establish whether ST activities offer any benefit to

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KEY WORDS:
pediatric; endurance; distance running; youth; concurrent training

performance-related factors and how such training techniques could be applied in practice. Therefore, the aims of this article are to briefly review the literature that has investigated the efficacy of ST on the determinants of endurance running in adolescent runners, and provide guidelines for best practice to improve performance and minimize the occurrence of overuse injury.

DETERMINANTS OF ENDURANCE RUNNING PERFORMANCE

Endurance running performance is determined by several key physiological variables, which are summarized in Figure 1. The physiological determinants of performance for adolescents seem to be similar to those of adult runners (3,27). A number of investigations have confirmed that maximal oxygen uptake ($\dot{V}O_2max$) is a significant predictor ($r = 0.5–0.9$) of performance for 1.5 km (1,3), 3 km (1,50,87), 5 km (1,27), and cross-country (24,34) in young (10–18 years) groups of runners. The proportion of $\dot{V}O_2max$ that can be sustained for a given duration (known as "fractional utilization") has also been shown to significantly correlate with endurance running performance in adolescents (50,87). Running economy (RE), defined as the metabolic cost of running a given distance (79), is related to middle- (3,87) and long-distance running performance (24,34) and, importantly, is influenced by neuromuscular-related qualities, which can potentially be improved with ST activities (16,29). In addition, speed at $\dot{V}O_2max$, which is a product of $\dot{V}O_2max$ and RE, correlates well with distance running performance in adolescents (1,3,24,27).

The contribution of anaerobic factors to endurance running performance in adults is well established (20); however, the influence of anaerobic determinants on performance in young endurance runners has not been fully delineated. This is likely due to the unspecific nature of the tests (Wingate test, isokinetic strength tests, and countermovement jump height) used to quantify anaerobic and neuromuscular capacities in studies that have investigated young distance runners (3,24,28). Anaerobic capacity and neuromuscular capabilities are thought to play a large role in discriminating performance in runners who are closely matched from an aerobic perspective (22,67). Mahon et al. (50) also showed that 55-m sprint and countermovement jump were significant predictors of 3-km time trial in preadolescent children, although given the age of the participants, this finding could simply be a reflection of individuals possessing high or low levels of athletic ability across the range of the tests used. Speed at $\dot{V}O_2max$ probably provides the most sport-specific representation of neuromuscular capabilities in distance runners; however, measures of maximal running speed and anaerobic capacity are also important attributes (65). For an 800-m specialist in particular, near-maximal velocities of running are reached during the first 200 m of the race (74), which necessitates a high capacity of the neuromuscular and anaerobic system. Similarly, the quickest finisher at the end of a middle- or long-distance race often determines the winner (85); thus, possessing a higher top speed is potentially crucial for achieving success in distance running. Regardless of the capacity for anaerobic and neuromuscular factors to predict endurance performance in adolescents, activities to develop sprint speed and muscular strength qualities as part of a well-rounded physical training program are recommended during adolescence irrespective of whether sport-specialization has occurred (47,49).

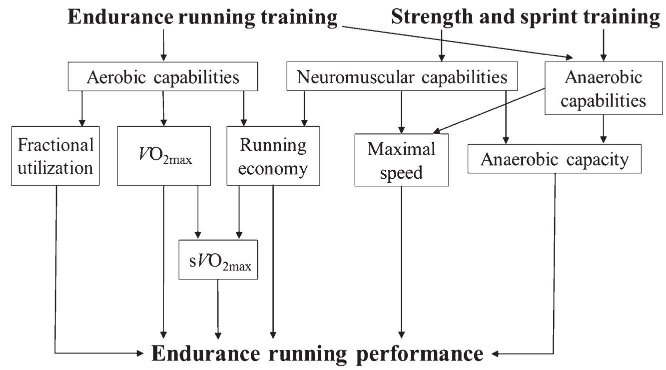

Figure 1. Primary determinants of endurance running performance and the modalities of training to improve each. $s\dot{V}O_2max$ = speed at maximal oxygen uptake; $\dot{V}O_2max$ = maximal oxygen uptake.

EFFECT OF STRENGTH TRAINING ON AEROBIC-RELATED PARAMETERS

Based on the findings of recent reviews (16,29), it is suggested that supplementing the training of an endurance runner with ST is likely to provide improvements in RE, time-trial (1.5–10 km) performance, and anaerobic parameters such as maximal sprint speed. Improvements in RE in the absence of changes in $\dot{V}O_2max$, speed at $\dot{V}O_2max$, blood lactate, and body composition parameters suggest that the underlying mechanisms predominantly relate to alterations in intramuscular coordination and increases in stiffness (16). Specifically, ST brings about increases in motor unit recruitment, firing frequency, and musculotendinous stiffness, which are thought to optimize the length-tension and force-velocity relationships of active skeletal muscle, thus reducing the metabolic cost of running (36). It is clear that the inclusion of ST also does not adversely affect $\dot{V}O_2max$, blood lactate markers, or body composition (16). Concurrently, RE showed improvements of 2–8% with ST compared to a running-only control group after a 6–14-week intervention that includes 2–3 ST sessions per week (16).

EFFICACY IN ADOLESCENT RUNNERS

Three studies have investigated the effect of ST specifically in young (<18 years) middle- or long-distance runners and these are summarized in Table 1. A recent study by Blagrove et al. (17) found that 2 weekly sessions of ST (mainly PT and RT) added to the program of postpubertal adolescent distance runners (17 years) for 10 weeks was "possibly beneficial" for RE (effect size: 0.31–0.51) and "highly likely beneficial" for maximal sprint speed. However, only the maximal speed improvement reached statistical significance ($P < 0.05$) compared with the change observed in the control group. Mikkola et al. (58) took a group of trained male and female distance runners (mean: 17 years, $\dot{V}O_2max$: 62.5 $mL \cdot kg^{-1} \cdot min^{-1}$) and after 8 weeks of ERT, PT, and sprint training, noted a difference (−2.7%) in RE at 14 $km \cdot h^{-1}$ and improvements in anaerobic capabilities (speed during the maximal anaerobic running test and 30-m sprint) compared with a running-only group. It is noteworthy that both of these investigations (17,58) included sprints (3–10 × 30–150 m) as part of the intervention, which provides a highly specific overload to the neuromuscular system in endurance runners. Interestingly, participants in the ST intervention groups in these studies reduced their weekly running volume to accommodate the additional S&C activities. Total time spent training was however very similar between intervention and control groups.

Bluett et al. (18) found that 10 weeks of concurrent aerobic and ST provided little strength advantage and no change in 3-km time-trial performance in 10–13-year-old competitive runners compared with running only. This study used mainly single-joint machine-based RT and did not measure any physiological parameters, which may explain the lack of effect observed. The authors speculated that excessive fatigue resulting from the concurrent training regimen may have compromised both strength and endurance adaptations (18). Interestingly, the blunting of strength adaptation, which is often observed in adult performers when both ST and endurance training are included in the same training session (90), seems not to occur in children (53) and adolescents (75,76). As the interference phenomenon is mediated by training volume and recovery from sessions (5), it seems likely that the volumes of each training modality included in the aforementioned studies were insufficient to negatively impact on strength-related adaptation. Indeed, in elite youth soccer players (17 years) who use higher workloads compared with younger performers, larger improvements were evident in strength and sprint performance after 5 weeks when ST was performed after sport-specific endurance training on 2 days per week, compared with a group who adopted an ST followed by endurance training sequence (33).

Research investigating the impact of ST techniques on performance-related measures in young athletes has tended to use participants from field-based sports, martial arts, court sports, aquatic sports, gymnastics, and strength-based sports (40,46). A number of studies using adolescent participants from other sports that require high levels of aerobic fitness have observed superior improvements in the Yo-Yo test (44,51,72,91) and middle-distance time-trial performance (70,73) after various modalities of ST were added (6–12 weeks) to a sports-specific training program, compared with only practicing the sport.

Taken together, it seems that the addition of 2–3 ST sessions to the weekly routine of adolescent endurance runners provides a small but potentially meaningful benefit to RE and maximal sprint speed after intervention over 8–10 weeks. Evidence for improvements in performance exists for adult runners (16); however, there is currently a lack of research in younger endurance runners. Benefits are likely to be larger for interventions of a longer duration (29) and for ST programs that are supervised by qualified practitioners (16). Although the majority of studies in adults supplement a runner's training with ST, there also seems to be no disadvantage to reducing weekly running volume to accommodate the addition of 2 weekly ST sessions.

PRACTICAL APPLICATIONS

TIMING OF SPECIALIZATION AND LONG-TERM ATHLETE DEVELOPMENT

Adolescence represents an important period of development in young athletes where significant alterations in hormonal status cause rapid physical growth (52). Contemporary views of long-term youth development suggest adolescents should avoid training routines that focus on intensive training in a single sport (for >8 months per year), or a total weekly training volume (in hours) that exceeds the athletes age in years, until late adolescence (47,49,63). Evidence from several endurance sports show that elite senior athletes tend to specialize at a later age and participate in a diverse range of sports during their earlier years (26,60). Recent work has also shown that very few middle-distance runners ranked in the UK top 20 in the under-13 and under-15 age groups experience success as senior runners (43). Young athletes who adopt an early-diversification, late-specialization approach to their development have fewer injuries, are at less risk of overtraining, and play sports longer than those who specialize in one sport before puberty (21,30).

The youth athlete development model suggests a wide range of physical activities and training modalities should be used during adolescence; however, movement skills training (MST) and development of strength qualities should be prioritized (47,49). The emphasis on ST activities throughout an athlete's development is thought to maximize adaptations to intermuscular and intramuscular coordination, during a period when neuroplasticity is high (64). Improvements in muscular strength and motor control during this period have also been shown to improve physical performance (10,46) and lower the risk of sustaining an injury (62,82). It is recommended that

Table 1
Summary of studies (n = 3) that have investigated the effects of a strength training (ST) intervention on adolescent endurance runners

Authors	Participants, n (I/C), sex, age	Study duration (weeks)	Running volume	ST frequency	ST prescription	Main strength outcomes	Main running-related outcomes
Blagrove et al. (17)	18 (9/9), both, 17.2 y	10	I: 151 min·wk^{-1}; C: 213 min·wk^{-1}	2 per week	PT (3–4 × 6–8/15 m): box jumps, A-skips, hurdle jumps; RT (2–3 × 6–8 reps): back squat, RDL, rack pull, deadlift, step-ups, leg press, calf raise	MVC (15.4%, ES = 0.86, P < 0.05), $vGRF_{jump}$ (6.1%, ES = 0.93); CMJ, little difference compared with C	RE@ sLTP (3.2%, ES = 0.31), sLTP −1 km·h^{-1} (3.7%, ES = 0.47), sLTP −2 km·h^{-1} (3.6%, ES = 0.51); 20-m sprint (3.6%, ES = 0.32, P < 0.05)
Bluett et al. (18)	12 (6/6), both, 10–13 y	10	Both groups: 2 × runs per week (1 × 25–30 min continuous, 1 × intervals)	2 per week	RT (3–4 sets × 10–12 reps): leg curl, leg extension, leg press, upper-limb/trunk exercises	Increase (12.2–24%) loads lifted during ST but no change in peak torque pre-post I	3 km TT no change in either group
Mikkola et al. (58)	25 (13/12), both, 17.3 y	8	I: 8.8 h·wk^{-1} (19% running replaced with ST); C: 8.5 h·wk^{-1}	3 per week	PT: alternative jumps, calf jumps, squat jumps, hurdle jumps; ERT (2–3 × 6–10 reps): half-squats, knee extension, knee flexion, leg press, calf raise	MVC (8%), 1RM (4%), RFD (31%) on leg press; all P < 0.05; CMJ and 5-bounds little difference compared with C	RE@14 km·h^{-1} (2.7%, ES = 0.32, P < 0.05), @10, 12, 13 km·h^{-1}, NS; BL@12 km·h^{-1} (12%, P < 0.05), @14 km·h^{-1} (11%, P < 0.05); sMART (3.0%, P < 0.01), s30-m sprint (1.1%, P < 0.01)

1RM = 1 repetition maximum; BL = blood lactate; C = control; CMJ = countermovement jump; ERT = explosive resistance training; ES = effect size; I = intervention; MVC = maximum voluntary contraction; NS = not statistically significant; PT = plyometric training; RDL = Romanian deadlift; RE = running economy; RFD = rate of force development; RT = resistance training; sLTP = speed at lactate turnpoint; TT = time trial; $vGRF_{jump}$ = vertical ground reaction force during squat jump.

Table 2
Example of a 7-day microcycle for an adolescent endurance runner

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Session	(am) Easy 30-min run; (pm) S&C session	Interval training session	(am) Cycle or swim 30 min; (pm) S&C session	Tempo run[a] (20–30 min)	Rest	Race or interval training session	Easy 45-min run

[a]Continuous fast run performed at approximately 10 km race pace (speed at lactate turnpoint).

S&C = strength and conditioning.

endurance training (and metabolic conditioning) is not emphasized, relative to other biomotor abilities, until late adolescence (49) because typically this type of training is associated with high volumes of work, which may lead to injury or overtraining (54). Moreover, prepubertal children have tended to show smaller changes (<10%) in aerobic measures after endurance training interventions compared with postpubertal adolescents and adults (54,56). A recent study also showed that prepubertal boys (11 years) were metabolically comparable with well-trained endurance athletes and experienced less fatigue during high-intensity exercise compared with untrained adults (14). It was suggested that prepubertal children avoid specific training to develop aerobic metabolic qualities and shift priority during postpubertal years once movement technique and mechanical competency have been developed (14). Due to the risks associated with early specialization, it is recommended that adolescent athletes younger than 15 years do not solely specialize in endurance running, but should participate in a wide range of sports and physical activities, including ST.

ORGANIZATION OF THE TRAINING MICROCYCLE

Before specialization in a sport of a young athlete's choice, physical training should be semistructured and not emphasize peaking for competitions (26,63). Conversely, an adolescent endurance runner will typically run 45–55 miles weekly in preparation for a race (80) which, when combined with academic and social commitments, can place a high level of physical and psychological stress on a young athlete (54). This necessitates a well-organized approach to training that caters to the needs of individual athletes and ensures sufficient periods of recovery between bouts of training.

Two 7-day microcycle designs are shown in Tables 2 and 3 to illustrate how an adolescent endurance runner could incorporate S&C activities into their routine. Adolescent distance runners typically perform 2–3 high-intensity running sessions per week (15), and these should form the priority sessions in the program (Tables 2 and 3; Tuesday, Thursday, and Saturday). Similarly, a minimum of 2 ST sessions per week are suggested for adolescents (11,48) and endurance runners (16). RT sessions should ideally take place at least 3 hours after a running session (6) and at least 24 hours of recovery should follow after ST before an intensive running session (31). A novel approach to organizing S&C activities around training and lifestyle commitments with young runners is to incorporate shorter periods of activity ("training units") as part of running sessions wherever possible (Table 3). This type of programming is useful for young runners who perhaps cannot access a specialist S&C facility, and therefore perform a largely home-based routine, or are unable to commit to 2 full S&C sessions per week. Each training unit takes 10–20 minutes to complete, thus making it easy to integrate some purposeful S&C before or after running sessions. It is important to note that studies in adolescent distance runners (17,58) have shown that including weekly ST sessions are more effective than increasing running volume, at least in the short term (8–10 weeks).

Assuming runners are of a non–strength-trained status, it seems that

Table 3
Example of a 7-day microcycle for an adolescent endurance runner with strength and conditioning activities organized as training units before or after running sessions

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Session	Easy 30-min run + PT and RT	MST + interval training session	Cycle or swim 30 min + RT and SC	PT + tempo run (20–30 min)	Rest	Race or interval training session + SC	Easy 45-min run + MST

Training units should last 10–20 minutes with the focus on movement quality rather than inducing high levels of fatigue.

MST = movement skills training; PT = plyometric training; RT = resistance training; SC = specific conditioning.

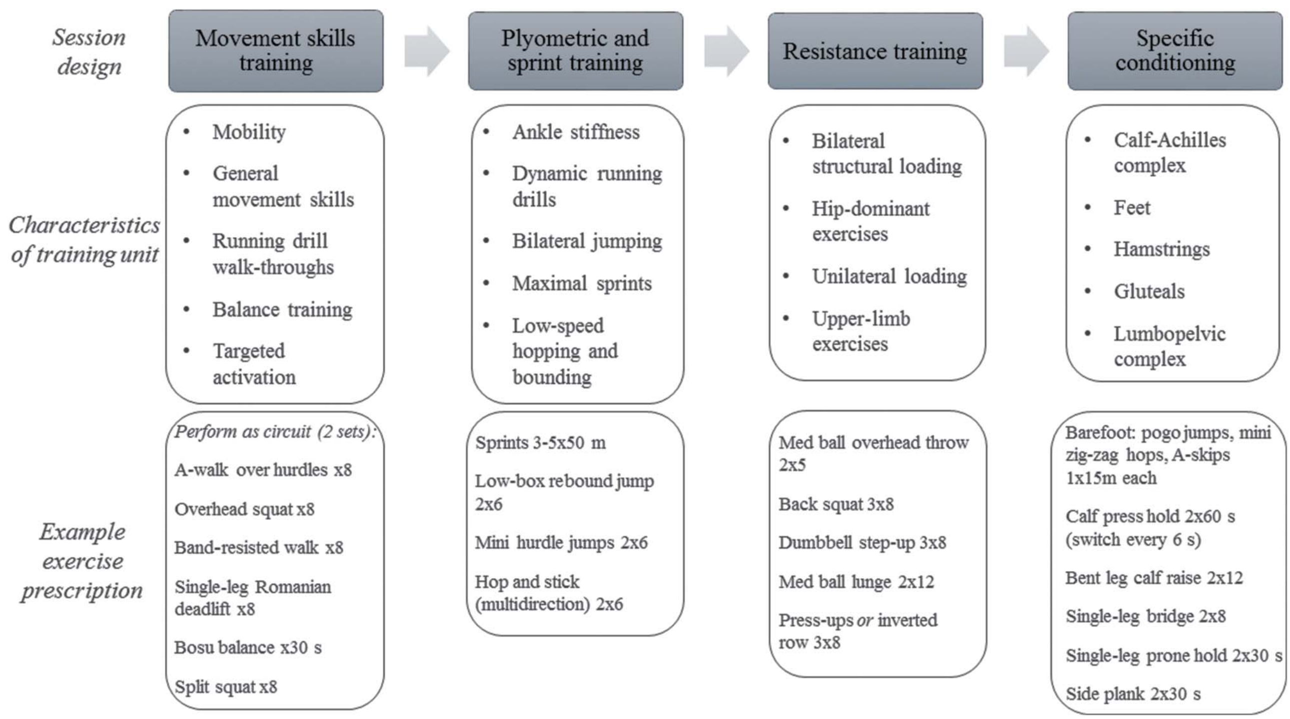

Figure 2. Recommended structure of a strength and conditioning session for adolescent endurance runners. Characteristics and example exercise prescription for individual training units are also shown. Prescription is sets × repetitions (unless stated).

a variety of ST modalities can be used to achieve similar outcomes. However, to maximize long-term adaptations in young athletes, it is suggested that a periodized approach is adopted with fundamental skills training and RT prioritized initially (9,25,47). Figure 2 provides an overview of the session design and characteristics of specific training units recommended for adolescent distance runners. A similar session design framework has also been used successfully in other investigations that used distance runners embarking on an ST program for the first time (9,17,58).

MOVEMENT SKILLS TRAINING

The inclusion of MST in the routine of adolescent distance runners is recommended, and is likely to reduce long-term injury risk (45,62,82). This form of conditioning is ideal to include as part of a movement preparation warm-up routine before running and ST sessions, or as an independent training unit (82). MST should include activities to enhance both general (fundamental) and specific (running-related) movement skill and control, balance and dynamic stability, and low-level RT targeting specific muscle groups, such as the gluteals (37).

PLYOMETRICS AND SPRINT TRAINING

Low-intensity plyometric-based exercises that aim to develop ankle stiffness, such as skipping, low-box rebound jumps, mini hurdle jumps, and short-range hopping tasks, offer a potent stimulus to the neuromuscular system and have independently been shown to enhance RE and time-trial performance (12,68,71,81,86). It is suggested that 30–60 foot contacts per session are used initially with adolescent distance runners (17). Sprint training has also been used in several investigations showing enhancements in maximal speed and performance-related factors (17,58,59,66). Three to 5 sets of short-distance (30–60 m) technical and maximal sprints performed 2–3 times per week is likely to provide benefits to adolescent endurance runners.

RESISTANCE TRAINING

RT, which should include both ERT and heavy RT, increases motor unit recruitment and firing frequency, and thus enhances a runner's ability to appropriately control and express force during ground contact. Although changes in fat-free mass seem to be minimal after an ST intervention in distance runners (16), a targeted RT program that aims to increase muscle mass specifically around the proximal region of the lower limb may enhance biomechanical and physiological factors, which positively influences RE (36). Exercises, such as squats, deadlifts, step-ups, and lunge patterns, which possess similar kinematic characteristics to running gait, are likely to provide the greatest transfer (8) and have been used in several previous investigations (9,17,58). Loaded jump squats, medicine ball throwing, and weightlifting are examples of suitable ERT activities that can also be used (8,9,59). Upper-limb exercises such as press-ups, rowing exercises, and overhead presses should also be incorporated to offset the vertical angular momentum created by the lower limbs and aid in controlling excessive rotation forces (42,69,77). One to 3 sets of each exercise performed in a moderate repetition range (8–12 repetitions) is likely to provide non–strength-trained individuals with a stimulus sufficient to drive neuromuscular adaptation while developing skill in each exercise (9,17,59). Higher loads (≥80% 1 repetition maximum) and lower repetition ranges (3–8 repetitions) are likely to be required to provide further overload in strength-trained adolescents, with volume of work moderated through an increase in sets.

SPECIFIC CONDITIONING

Many young endurance runners are motivated to include S&C activities to reduce injury risk more so than improve their performance (15). Youth endurance athletes have been identified as a high-risk group due to the rigorous training that they undertake during a critical period of their physical and emotional development (54,80). Indeed, injury incidence rate has been reported to be higher in adolescent elite endurance runners compared with athletes who participate in other endurance sports (88). Moreover, female adolescent runners tend to display higher rates of low bone mineral density and bone stress injuries compared with young female athletes in other sports (78). Overuse injuries occur over multiple running sessions when structure-specific cumulative load exceeds capacity (13). MST, PT, and resistance-based exercises are likely to contribute toward lowering risk of injury through enhancements in motor control and increased bone mineral density and tissue resilience (45,62,89). Exercises designed to expose specific muscles or tissues to a high magnitude of load are also likely to provide benefits to tendon stiffness (35) and tolerance to repetitive stress (7,19,61,84,89). It is recommended that such exercises are positioned in the final part of a session or performed separately because prefatiguing muscles in isolation is likely to be detrimental to performance in multijoint tasks (4). Specifically for distance runners, targeted conditioning exercises should focus on the specific structures that are vulnerable to injury, or the muscles that contribute toward controlling the positioning of joints within the lower limb, such as the intrinsic joints of the feet, the calf-Achilles complex, and gluteal and hamstring muscles (2,32,38,55,57,61). In addition, specific exercises that target proximal musculature around the lumbopelvic-hip complex ("core stability") are likely to offset the risk of several types of common overuse injuries in runners (23). Specifically, exercises that facilitate greater strength and control of the hip abductors and external rotators are likely to provide benefits (23,39).

CONCLUSION

Endurance running performance is constrained by several important physiological variables; however, anaerobic and neuromuscular factors have also been recognized as being important. For the young athlete, participating in a broad range of sporting and physical pursuits is recommended during early adolescence. Age-appropriate S&C should form an integral part of a well-rounded approach to the long-term physical development of all young sports performers. Participating in endurance running events can certainly form part of a program of activities during adolescence; however, it is suggested that young athletes should not solely specialize in endurance running until late adolescence. For the young endurance runner, adding ST sessions twice per week that includes RT, PT, and sprinting is likely to provide benefits to RE and maximal sprint speed that translate to improved performance. Moreover, these activities, plus MST and specific strengthening of tissues vulnerable to injury, are important for lowering the risk of overuse injury.

Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

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