Running-Specific, Periodized Strength Training Attenuates Loss of Stride Length During Intense Endurance Running

Jonathan Esteve-Lanao,[1] Matthew R. Rhea,[2] Steven J. Fleck,[3] and Alejandro Lucia[1]

[1]*European University of Madrid, Madrid, Spain;* [2]*Department of Interdisciplinary Health Sciences, AT Still University, Mesa, Arizona;* [3]*Sport Science Department, Colorado College, Colorado Springs, Colorado*

Abstract

Esteve-Lanao, J, Rhea, MR, Fleck, SJ, and Lucia, A. Running-specific, periodized strength training attenuates loss of stride length during intense endurance running. *J Strength Cond Res* 22: 1176–1183, 2008—The purpose of this study was to determine the effects of a running-specific, periodized strength training program (performed over the specific period [8 weeks] of a 16-week macrocycle) on endurance-trained runners' capacity to maintain stride length during running bouts at competitive speeds. Eighteen well-trained middle-distance runners completed the study (personal bests for 1500 and 5000 m of 3 minutes 57 seconds ± 12 seconds and 15 minutes 24 seconds ± 36 seconds). They were randomly assigned to each of the following groups (6 per group): periodized strength group, performing a periodized strength training program over the 8-week specific (intervention) period (2 sessions per week); nonperiodized strength group, performing the same strength training exercises as the periodized group over the specific period but with no week-to-week variations; and a control group, performing no strength training at all during the specific period. The percentage of loss in the stride length (cm)/speed ($m \cdot s^{-1}$) (SLS) ratio was measured by comparing the mean SLS during the first and third (last) group of the total repetitions, respectively, included in each of the interval training sessions performed at race speeds during the competition period that followed the specific period. Significant differences ($p < 0.05$) were found in mean percentage of SLS loss between the 3 study groups, with the periodized strength group showing no significant SLS change (0.36 ± 0.95%) and the 2 other groups showing a moderate or high SLS loss (−1.22 ± 1.5% and −3.05 ± 1.2% for the nonperiodized strength and control groups, respectively). In conclusion, periodized, running-specific strength training minimizes the loss of stride length that typically occurs in endurance runners during fatiguing running bouts.

Key Words distance running, cardiovascular fitnes performance enhancement

Introduction

It has previously been shown that periodized strength training programs are overall more effective than nonperiodized training programs for increasing maximal strength (7,8,25–27). In recent years, growing interest has focused on evaluating different types of strength training periodization programs. However, little research has focused on analyzing the effects of periodized strength training on the performance of trained endurance athletes (28).

Traditionally, the main determinants of endurance performance have been believed to be maximal oxygen uptake ($\dot{V}O_2max$), lactate threshold, and muscle efficiency. Recent research also places a growing emphasis on anaerobic capacity/power (2,4,10,11,15,21,22,24). A decrease in power production could affect endurance running performance by reducing stride length.

In addition its role in important aspects of basic preparatory training, such as injury prevention and athlete preparation for the upcoming more intense training, strength training can have a beneficial effect on endurance performance, especially through an increase in the running economy of trained runners (14,23,29,32). The latter is attributable to improvements in neuromuscular characteristics, including motor unit recruitment and reduced ground contact time (16). Improvements in running economy can be achieved through maximal (14) or power (23,29,32) strength training. Field studies have used a high-load, low repetition model of weight training and/or plyometrics. However, in cross-country skiers (19) and swimmers (17,33,35), sport-specific strength training exercises (e.g., rollerboard training for cross-country skiers or specific strength training devices used in the water for swimmers) seem to elicit greater gains in performance than

Address correspondence to Jonathan Esteve-Lanao, jonathan.esteve@uem.es.

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conventional weight training programs, indicating sport-specific strength training programs may elicit performance gains in runners.

In middle- and long-distance running events, increases in speed are produced by a linear increase in stride length. This is the result of applying more force during foot contact rather than increasing stride frequency (18,30,37). Previous investigations have identified kinematic changes indicating changes in running technique with fatigue (9,12), including decreases in stride length (7,31). Additionally, runners who are capable of keeping consistent running mechanics (i.e., with the lowest decrease in stride length) are those who are able to sustain competition speeds for longer time periods (9). To our knowledge, no study has been published examining the effect of a periodized, sport-specific strength training program on the stride length of competitive runners during intense running bouts.

It was therefore the purpose of this study to determine the effects of a sport-specific, periodized strength training program on endurance-trained runners' capacity to maintain stride length during interval training sessions performed at competition speeds. Given that strength training is known to improve muscle power and thus possibly runners' ability to maintain a constant kinematic style, the addition of a specific, periodized strength training program to a conventional endurance running program would theoretically enable runners to maintain stride length during fatiguing interval training sessions better than a training program including no strength training at all. Additionally, we also hypothesized that a periodized strength training program (that is, structured with specificity criteria, i.e., from higher to lower resistance and from general to specific exercises) would induce greater benefits (e.g., less decrease in stride length) than a non-periodized strength training program.

Methods

Experimental Approach to the Problem

The main characteristics of the study design are shown in Figure 1. Our study took place over a 16-week macrocycle (i.e., the spring season following the winter [cross-country] season) that was composed of a 4-week preparatory period followed by an 8-week specific period and a final 4-week competition period. Our strength training intervention (see below) took place during the specific period only. The preparatory and competition training periods were thus identical for the 3 study groups that are described below. Besides the differences in strength training that are described below, all the subjects performed the same running training sessions during the specific (intervention) period. We performed outcome measurements (stride length/speed [SLS] ratio and the percentage of SLS loss, see below) during the competition period only.

We used a randomized, controlled design. Trained middle-distance runners were randomly assigned to 1 of the following 3 training groups: experimental (periodized strength) group performing a specific periodized strength training program during the specific period of the macrocycle, a comparison (nonperiodized strength) group performing the same type of strength training exercises as the periodized group but in a nonperiodized fashion, and a control group performing no strength training at all during the specific period.

The participants were not informed about the specific purpose of the study, so that their natural running style (stride length and frequency) was not influenced by participation in the study, and they were not given any advice concerning running technique or feedback related to running mechanics during the training sessions of the intervention period. We determined stride length and frequency only during the interval training sessions (i.e., performed at estimated race speed) included in the competition period that followed the specific period (see below).

Subjects

Eighteen trained male middle-distance runners completed the study (age, 25 ± 4 years; weight, 63.7 ± 3.9 kg; height, 174 ± 4 cm; body mass index [BMI], 21.1 ± 1.2). All the subjects were well-trained and subelite (regional) level athletes, i.e., their personal bests in 1500 m and 5000 m ranged from 3 minutes 41 seconds to 4 minutes 15 seconds and from 14 minutes 30 seconds to 16 minutes 0 seconds, respectively (mean ± *SD* of 3

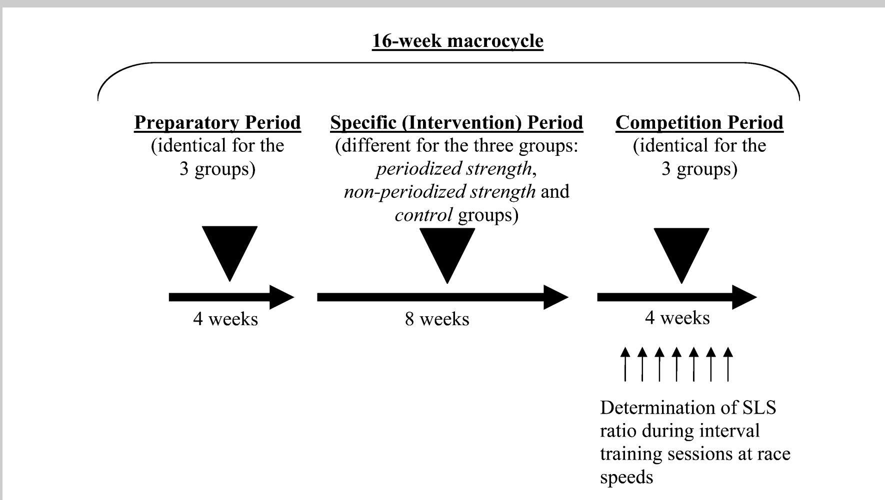

Figure 1. Schematic representation of the study design. SLS = step length (cm)/speed ($m \cdot s^{-1}$).

minutes 57 seconds ± 12 seconds and 15 minutes 24 seconds ± 36 seconds, respectively). All subjects had previous experience with strength training. Twenty-four runners were initially selected for the study before group assignment, but 6 of them were excluded because of lack of adherence to the assigned training program. The study was reviewed and approved by an institutional review board for research with human subjects.

Main Characteristics of Training and Periodization

The main organization of training in the 3 study groups is shown in Table 1. Total weekly running volume (i.e., combining aerobic, anaerobic, and basic conditioning training) ranged between 50 and 80 km per week over the 16-week macrocycle.

Preparatory Period (Mesocycle I, Identical for All Subjects)

During the preparatory (i.e., basic training) period, all the subjects from the 3 groups performed a total of 9 basic strength training sessions: 3 sessions were based on isometric work, i.e., 3 × 30 seconds, 3 × 45 seconds, 3 × 60 seconds with 4 exercises; 2 sessions using body weight type exercises (3–4 sets of 6–8 exercises reaching fatigue after 20–30 reps); and 4 resistance training sessions with machines and free weights exercises with sets not carried to failure (2–4 sets corresponding to ~25 repetitions maximum) at low velocities of movement (2 seconds/2 seconds concentric/eccentric actions) using machine (leg press, hamstring curls, calf raises) and free weights exercises (squats, power cleans, and snatches). The aforementioned sessions served as strength training familiarization sessions for the periodized strength and nonperiodized strength groups.

During the preparatory period, basic endurance training consisted of 4–5 weekly continuous running bouts (40–60 minutes) at ~70% of maximal heart rate (HRmax) (i.e., at an intensity corresponding to the lactate threshold [LT]). Adding up a total volume of 50–70 km per week. Subjects also started performing some interval training sessions (2 per week) at ~90% HRmax (i.e., at an intensity corresponding to the maximal lactate steady state) with 1-minute rest periods between reps, i.e., nine 3-minute reps, seven 4-minute reps, and six 5-minute reps.

Specific (Intervention) Period (Mesocycles II, III, and IV)

Subjects assigned to the periodized strength group performed 2–3 weekly strength training sessions during the first 2 weeks (mesocycle II) of the specific period (Table 2). These sessions progressively included eccentric contractions for hamstrings, fast eccentric/concentric contractions for calf muscles, concentric contractions for hip flexors until local failure between 20 and 30 reps, and squat, snatch, and clean training between

Table 1. Main organization of training in the 3 study groups.

Preparatory period	Specific (intervention) period (total duration: 8 wk)			Competition period
	Mesocycle			
I (4 wk)	II (2 wk)	III (3 wk)	IV (3 wk)	V (>4 wk)
Endurance training (identical for all groups)				
Basic LT	MLSS intervals Fartlek training	Peak velocity intervals MLSS long reps	Lac cap intervals Peak velocity long reps	Lac power short reps Competition pace/ competition
Strength (periodized group only)				
Basic strength training*	Circuit training, weight training	Oregon circuit, plyometrics, intermittent circuit, hills	Specific competition speed with belts (intervals)	Eventual strength training
Strength (nonperiodized group only)				
Basic strength training*	● 2–3 sessions per week mixing the following contents: ● 1–2 sessions of circuit training/basic weight training; ● 1 hill session; 0–1 session of speed work with belts (intervals)			Eventual strength training

MLSS = maximal lactate steady state (both obtained from field (track) lactate testing; Peak velocity = peak velocity obtained from a progressive running test on a track until exhaustion (starting at a pace of 4 min 30 s·km^{-1}; speed was increased by 0.2 km·h^{-1} every 200 m); Lac cap = lactic capacity; Lac cap intervals = intervals at 80–85% of personal best for the corresponding interval distance; Lac power = lactic power; Lac power short reps = reps at 90–95% of personal best for the corresponding interval distance; LT = lactate threshold.

*During the preparatory period, all subjects from the 3 groups performed the same 9 basic strength training sessions (see text for details).

Table 2. Strength training means in the periodized strength group during the specific period.

	Mesocycle							
	II		III			IV		
Week	1	2	3	4	5	6	7	8
Weight training	XX	X						
Circuit training	X	XX						
Oregon circuit			XX	X				
Intermittent circuit				X	X			
Plyometrics				X	X			
Hills				X	X			
Weighted belts						X	XX	XX

Each X represents a session in which the corresponding training mean was used. Total number of strength training sessions was 20.

15 and 20RM with sets not carried to momentary failure. During the first 2 weeks of the specific period, the periodized strength group also performed circuit training with light loads including standing up exercises moving legs and arms with low loads and high speed movements with work/rest ratios of 40 seconds/20 seconds (i.e., classic circuit training). Some examples of exercises are as follows: the "soldier," i.e., full squat + 1 push-up + stand up, skipping with dumbbells and ankle weights, "scarecrow" (hips and shoulders abductions and flexions while jumping at a fast pace with dumbbells); rope skipping and jumping; power cleans and snatches; jumping splits and one-quarter squat jumps with whole-foot contact or straight-knee jumps with metatarsus contact and holding dumbbells. Finally, high-intensity aerobic circuit training (classic and modified Oregon circuit) was also performed at this initial stage of the specific period, with 10 reps of 50 to 100 m. There were no resting periods during the aforementioned circuit resistance exercises, i.e., snatch, clean, squat, and split jumps with low loads were performed between the running reps.

Plyometric exercises (mainly horizontal jumps) were progressively added in mesocycle III (weeks 4 and 5) of the specific period in the periodized strength group, consisting of a fixed number of movements (10–15 movements) performed at the fastest possible speed. Starting in the middle part of this period (week 4, corresponding to mesocycle III), subjects in the periodized strength group performed hill and circuit power training (intermittent circuit) with short exercise/rest periods (15 seconds/15 seconds, 25 seconds/15 seconds). These sessions included specific exercises such as running with weighted vests or while pulling a load, skipping, and vertical/horizontal jumps.

In the last part of the specific period (weeks 6–8 or mesocycle IV), resistance training consisted of running reps at increasing speeds while wearing 2- to 3-kg weighted belts (3–5% of body weight). Running speeds corresponded to the following metabolic intensities: maximal aerobic speed ($\dot{V}O_2max$) (total running time at $\dot{V}O_2max$: 12–15 minutes), and lactic capacity training (8–20 reps of 200–500 m at 80–85% of personal best for the corresponding distance (200–500 m). As illustrated in Table 1 (first and second rows under "Endurance Training"), training was altered beginning with short reps and short rest periods, later with longer reps and longer rest periods, and finally with longer reps and short rest periods.

The nonperiodized strength group performed all the aforementioned strength training means included in the program of the periodized strength group but with no week-to-week or sequential mesocycle variations during the specific period (2–3 sessions per week) (Table 3).

Finally, runners in the control group did not perform any type of strength training at all (not even plyometrics) over the entire specific period.

Competition Period (Mesocycle V, Identical for All Subjects)

During the competition period (final 4 weeks of the macrocycle), no specific strength training was performed by any of the 3 groups except i) some sporadic, light maintenance resistance sessions (1 session every 2 weeks), similar to those included in the preparatory period and ii) some additional light plyometric training (1 session every 2 weeks). The aforementioned sessions were performed by all subjects. During this period, we measured speed and stride length as indicated below.

Speed and Stride Length Measurement During the Competition Period

The SLS ratio (see below) allowed for the determination of the effects of the different type of interventions (periodized and nonperiodized strength training, respectively, and control

Table 3. Strength training means in the nonperiodized strength group during the specific period.

	Mesocycle							
	II		III			IV		
Week	1	2	3	4	5	6	7	8
Weight training	X	X		X	X		X	X
Circuit training	X		X		X		X	
Oregon circuit								
Intermittent circuit plyometrics		X		X		X		
Hills	X		X		X		X	
Weighted belts		X		X		X		

Each X represents a session in which the corresponding training mean was used. Total number of strength training sessions was 20.

group performing no strength training) on the ability to maintain stride length during fatiguing running bouts, i.e., performed at competition speeds.

Only those running sessions performed at competition speeds during the competition period (i.e., interval training sessions such as 10 × 400, 5 × 800, 15 × 300, or 8 × 500 m) were recorded for analysis of speed and stride length. Running pace was set for every subject according to estimated race speed. Repetitions were usually performed until failure to hold the pace. If there was a competition close to testing, athletes performed the last high-intensity training session 4 days before the corresponding competition.

Recordings were performed using a digital video camera (JVC GR-DVL 9800E, Japan) at a frequency of 100 images per second (100 Hz). Subjects performed every repetition of the interval training sessions in the inside lane of a 400-m track (Figure 2). A reference system was placed over a 10-m interval at a distance of 50 m from the end of the repetition. Four devices similar to a pole were held vertical on both the inside and outside of the lane to delineate the 10-m interval over which stride length and running speed measurements were obtained. The camera was placed perpendicular to the lane at a distance of 25–30 m away from the middle of the 10-m interval. Running speed was measured ($m \cdot s^{-1}$) from the time spent in the reference zone with a 0.01 second accuracy. Stride frequency was calculated from the time to cover 4 ground contacts with the left foot (6 strides). The criterion for the attainment of ground contact was "initial contact of the foot." Average stride length was then calculated using speed and frequency in the 10-m interval of measurement. All measurements were made by the same researcher. Preliminary reliability analysis (repeated video recordings on 3 separate occasions) was

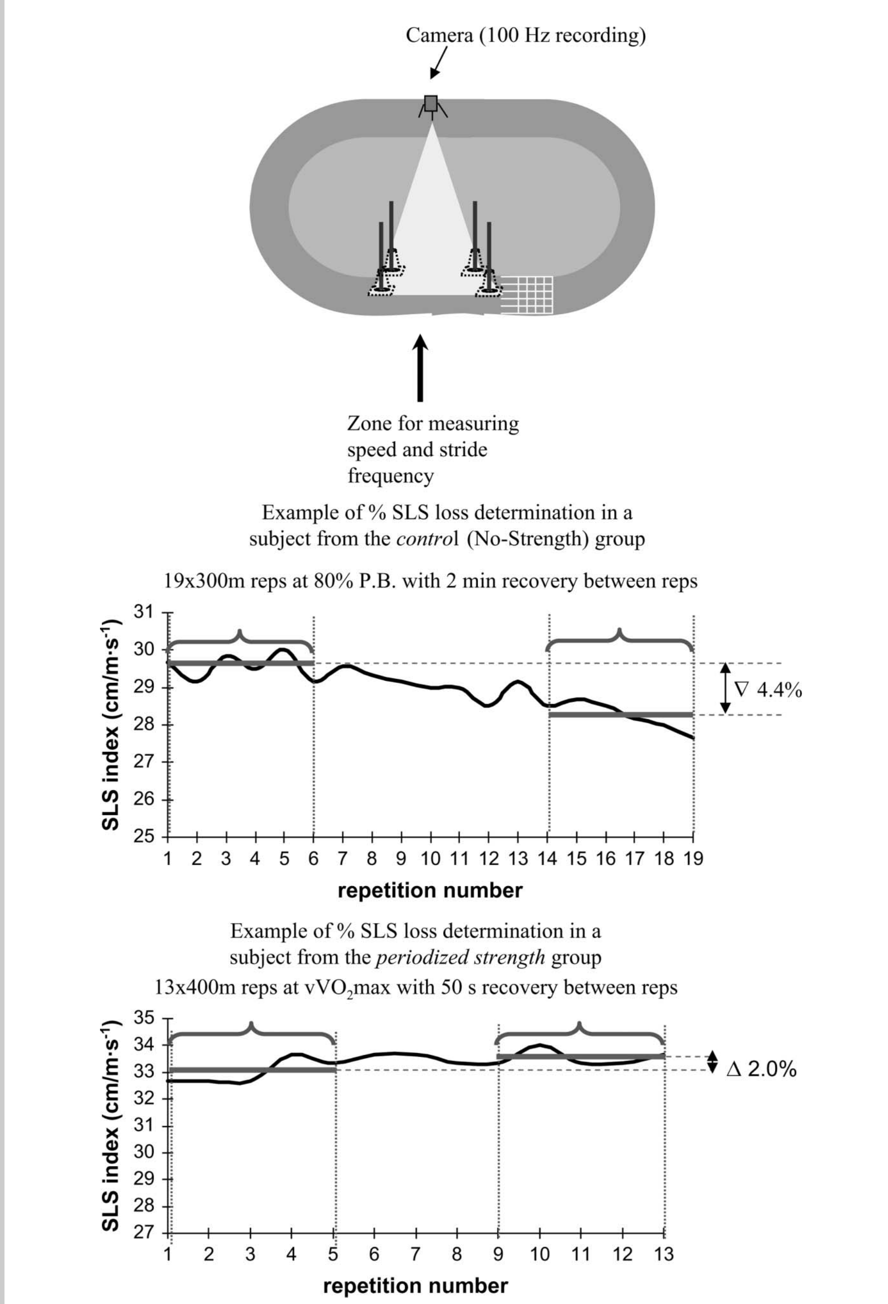

Figure 2. Determination of the stride length (cm)/speed ($m \cdot s^{-1}$) (SLS) ratio and percentage of loss in SLS during the competition period. We determined the percentage of loss in SLS by comparing the mean SLS ratio corresponding to the first and third (last) parts, respectively, in each of the recorded interval training sessions that were performed at race speeds during the competition period (see text for details). In the first example, the ∇ symbol denotes actual loss in SLS, i.e., loss in SLS when comparing the mean SLS value corresponding to the first third of the interval training session (reps 1–6) and the mean SLS value corresponding to the last third of the session (reps 14–19). In the second example, the Δ symbol denotes no loss (and actual increase) in SLS, i.e., increase in SLS between the mean SLS value corresponding to the first third of the interval training session (reps 1–5) and the mean SLS value corresponding to the last third of the session (reps 9–13). P.B. = personal best; $v\dot{V}O_2max$ = maximal aerobic speed.

performed in 10 runners over a 3-month period by the same researcher, showing no statistical differences ($p < 0.01$) and high intraclass correlation coefficient ($R > 0.95$) for the 3 repeated measurements each of speed, frequency, and stride length.

In order to obtain accurate data, we did not include recordings corresponding to speeds $>7.0\ m\cdot s^{-1}$ because the relationship between stride length and running speed starts to plateau above the aforementioned limit (18,30). An average of 6 sessions was obtained per runner. We collected a total of 111 training sessions for all subjects, ranging between 4 and 20 reps per subject per training session. The running rep distance was the same within each recording session.

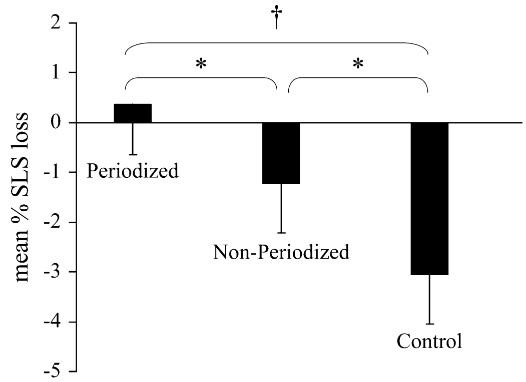

Figure 3. Comparison of the mean percentage of stride length (cm)/speed ($m\cdot s^{-1}$) (SLS) loss between the 3 study groups. Periodized = periodized strength training group; nonperiodized = nonperiodized strength training group; Control = no strength training group. *$p < 0.05$ for between-group comparisons; †$p < 0.014$ for between-group comparisons.

We calculated the SLS ratio corresponding to the first and third (last part) of each interval (i.e., race speed) training session. We obtained the percentage of loss in SLS by comparing the mean values of the SLS ratio corresponding to the first and third parts of each session. (See Figure 2 for an example.) We finally determined the mean percentage of SLS loss, i.e., of all recorded training sessions, for each runner.

Statistical Analyses

The Kolmogorov-Smirnov test was applied to ensure a gaussian distribution of the data. After ensuring that the criteria of homogeneity of variance was met across the 3 groups using Levene's test, a 1-factor (group) analysis of variance (ANOVA) was used to determine differences in mean percentage of SLS loss between groups (periodized strength, nonperiodized strength, and control). The Tukey test was used as a post hoc test. Data are reported as mean ± *SD*. The level of significance was set at $p \leq 0.05$ for all statistical analyses.

Results

The data followed a normal distribution (Kolmogorov-Smirnov $Z = 0.90$; $p = 0.512$), and the criteria of homogeneity of variance were met ($p = 0.067$ for Levene's test). The statistical power for group comparisons was 0.995. The ANOVA test showed a significant group effect ($p < 0.001$) for the mean percentage of SLS loss. We found significant differences for all post hoc comparisons between the 3 study groups: $p = 0.014$ and $p < 0.001$ for periodized strength versus nonperiodized strength and control group, respectively, and $p = 0.015$ for nonperiodized strength versus control group) (Figure 3). The periodized strength group showed no significant change in SLS (i.e., no actual loss in mean SLS), whereas the 2 other groups showed SLS loss.

Discussion

This is the first study to determine the effects of a running-specific, periodized strength training program on the capacity of endurance-trained runners to maintain stride length (SLS) during interval training sessions performed at competition speed. The main finding of this study was that this type of training program resulted in no loss of stride length during interval training sessions, as opposed to nonperiodized strength training and no strength training, after both of which we observed losses in stride length from the start to the end of interval training sessions. The periodization training program employed a wide variety of strength training methods, from auxiliary Olympic lifting exercises to circuit training and specific speed training in overloaded conditions, in a sequence to maximize strength during running-specific movements.

The effects of strength training on endurance performance have been previously assessed (1,3,5,6,13,19,20,23,26,34,35). The performance improvements brought about by this type of training seem to be associated with improved running economy (i.e., lower oxygen cost for a specific running speed) and a greater ability to sustain muscle power. A relevant study by Nesser et al. (19) compared 4 different training approaches in junior cross-country skiers: a traditional training group training with body weight only using a circuit of traditional exercises (until fatigue or with 30 seconds/30 seconds rest/exercise ratio); a nonskiing-specific weight training group using free weights and pulley-type exercises at slow velocities of movement (3–8 RM) and long rest periods between sets and exercises to focus on strength development and 10–12 RM resistance exercises performed explosively to focus on power development, a specific pulley ergometer ("rollerboard") training group using the same loads as the weight training group; and a skiing-specific training group that performed short uphill rollerskiing sprints, plyometric exercises specific to cross-country training, and uphill bounding with poles. Results reflected the importance of overload under specific conditions since the major improvements in strength and power together with the best competition performances were achieved in the rollerboard group. The worst competition results were obtained in the nonskiing-specific weight training group, which also showed the least improvement with training in both power and strength performance determined with specific ergometer (rollerboard) tests.

In swimmers, it also seems that combining normal swim training with specific strength exercises performed in water (with special ergometers such as a biokinetic swim bench, hydrochannel, or other implements used in the water that are specific to swimming) elicits greater improvements in performance than swimming alone or combining both normal swim training with traditional dry-land strength training (17,33,35). In a preliminary report on recreational runners, Turner et al. (36) found significant improvements in running economy with additional plyometric training versus a control group that did not perform any type of strength training. In contrast, no improvement was observed in 1-time maximal jumping tests, which could be attributable to the fact that jumping tests involve single maximal efforts as opposed to the multiple intense efforts used during plyometric training sessions. A recent study (29) conducted with very high level runners showed significant improvements in running economy due to the addition of plyometric training (3 sessions per week for a total of 9 weeks) but also showed no differences in strength and power measurements.

Collectively, the aforementioned results of previous research with runners and other endurance athletes indicate that one would expect that a strength training program specific to running would minimize the loss in SLS during interval training sessions. While previous research concerning periodized weight training indicating that periodized training is more effective than nonperiodized training in causing maximal strength gains (7,8,25–27) and thus would minimize SLS to a greater extent than nonperiodized training. Our results do suggest that the periodized strength training program did affect the strength of the runners to a greater extent than a nonperiodized program, resulting in the periodized group having smallest loss of SLS during the interval training sessions. The sport-specific periodized program showed no significant change in SLS, while both the nonperiodized strength training and no weight training (control) groups showed a significant decrease in SLS. The greater effect on strength of a periodized strength training program may have resulted in the significant difference in SLS loss between the periodized and nonperiodized groups, while the effect on strength of a sport-specific strength program may explain the significant difference in SLS loss between the nonperiodized and the no strength training groups.

In summary, the present study's results indicate that a sport-specific periodized strength training program attenuates the loss of SLS in middle-distance runners during interval running sessions compared to a nonperiodized strength training program and no strength training, while a nonperiodized program does result in a loss of SLS, but the loss is less than with no strength training.

Practical Applications

Our study showed that loss of stride length during an interval training session, a variable that is a key determinant of endurance running performance, can be minimized with a periodized sport-specific strength training program. This type of training intervention seems to minimize the detrimental effects that fatigue has on muscle power levels. It is suggested that running coaches periodically monitor the SLS ratio, a variable that represents a simple measurement of stability in mechanics during running. Specifically, the percentage of loss of SLS over an intense (competition speed) interval running session can be used as an index of muscle fatigue or inability to maintain force levels while running at race pace. Further studies could directly measure strength training effects under specific conditions (e.g., using the SLS index), as well as its relationship with actual performance and with those factors influencing performance, such as power and running economy.

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