Does Core Strength Training Influence Running Kinetics, Lower-Extremity Stability, and 5000-m Performance in Runners?

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Abstract

Sato, K and Mokha, M. Does core strength training influence running kinetics, lower-extremity stability, and 5000-m performance in runners? *J Strength Cond Res* 23(1): 133–140, 2009—Although strong core muscles are believed to help athletic performance, few scientific studies have been conducted to identify the effectiveness of core strength training (CST) on improving athletic performance. The aim of this study was to determine the effects of 6 weeks of CST on ground reaction forces (GRFs), stability of the lower extremity, and overall running performance in recreational and competitive runners. After a screening process, 28 healthy adults (age, 36.9 ± 9.4 years; height, 168.4 ± 9.6 cm; mass, 70.1 ± 15.3 kg) volunteered and were divided randomly into 2 groups ($n = 14$ in each group). A test-retest design was used to assess the differences between CST (experimental) and no CST (control) on GRF measures, lower-extremity stability scores, and running performance. The GRF variables were determined by calculating peak impact, active vertical GRFs (vGRFs), and duration of the 2 horizontal GRFs (hGRFs), as measured while running across a force plate. Lower-extremity stability was assessed using the Star Excursion Balance Test. Running performance was determined by 5000-m run time measured on outdoor tracks. Six 2 (pre, post) × 2 (CST, control) mixed-design analyses of variance were used to determine the influence of CST on each dependent variable, $p < 0.05$. Twenty subjects completed the study ($n_{exp} = 12$ and $n_{con} = 8$). A significant interaction occurred, with the CST group showing faster times in the 5000-m run after 6 weeks. However, CST did not significantly influence GRF variables and lower-leg stability. Core strength training may be an effective training method for improving performance in runners.

Key Words core exercise, running performance, stability

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Introduction

Core strength training (CST) is widely used in the strength and conditioning, health and fitness, and rehabilitation industries with claims of improving performance and reducing the risk of injuries (12,14). It is believed among those professionals that to improve athletic performance and prevent risk of injury, CST is one of the vital components in the strength and conditioning field. Despite the strong belief in these purported positive effects, limited scientific studies have shown no direct relationship between stronger core muscles and better athletic performance (3,16,17). Significant improvement in core strength has been documented as a result of CST, but the same research has failed to show significant changes in the athletic performance from CST (3,16,17). This type of research indicates that CST is a useful tool for strengthening core muscles, but the carryover to mechanics and performance needs further investigation. Core-related exercises such as Swiss ball training, balance training, weight training, and yoga have become popular physical activities even among general populations in recent years. Even though scientific studies have not shown any links to prove performance enhancement, CST is becoming common for all levels of athletes.

In a biomechanical analysis of running, abnormal ranges of vertical ground reaction forces (vGRFs) and horizontal GRFs (hGRFs) have been associated with overuse injuries (2,7,10,13). Aging, lack of joint stability, muscle weakness, harder running surfaces, and downhill running are found to be indications of increasing impact vGRFs as well (2,5–7,18). Stronger core muscles may help keep ground reaction forces (GRFs) within an optimal range. In addition, because previous lower-extremity injuries such as ankle sprain or overuse injuries often contribute to create muscular imbalance and poor proprioception, proper rehabilitation is needed to regain stability (4). Thereby, CST would be an option, and the CST may help improve dynamic stability of the lower extremity. Adequate dynamic stability in the lower extremity may have an important role in keeping vGRFs and hGRFs within the normal range.

Core strength training may have an important role in running performance, such as running within the normal range of GRFs at a given running velocity, and good dynamic stability of the lower extremity. Therefore, the purpose of this study was to determine the effects of 6 weeks of CST on GRF, stability of the lower extremity, and overall running performance in recreational and competitive runners. We hypothesized that CST would have the following positive influences: a) decrease peak impact vGRF (initial heel contact), b) increase peak active vGRF (push-off force), c) decrease the amount of time in breaking hGRF, d) increase the amount of time in propulsive hGRF, e) increase Star Excursion Balance Test (SEBT) scores, and f) decrease 5000-m run time.

Methods

Experimental Approach to the Problem

This study was 6-week training study completed during a marathon-training period. A test-retest design was used to identify the effects of CST. The CST group performed 4 sessions of 5 core exercises per week for 6 weeks. Laboratory testing lasted 0.5 hours on each subject in the control group and 1.0 hours on each subject in the CST group. The 5000-m run was timed at outdoor tracks on different days because of schedule restrictions.

Subjects

Twenty-eight recreational and competitive rear–foot-strike runners (10 men, 18 women) initially qualified and volunteered for this study (age, 36.9 ± 9.4 years; height, 168.4 ± 9.6 cm; mass, 70.1 ± 15.3 kg). They had no injuries at the time of data collection. They answered specific questions regarding their training strategies, pace, past injury history, and type of footwear used to identify their running background. The subjects were then randomly divided into 2 groups: control ($n = 14$) and CST ($n = 14$). Twenty-eight runners performed pretraining tests, and 20 participants completed the posttest ($n_{con} = 8$, $n_{cst} = 12$). Demographic information for the 20 participants is shown in Table 1. To detect any differences in physical and performance characteristics between the groups, an independent *t*-test was run. According to the test, body mass (using the posttest result) and average running pace (self-reported during the screening process) showed significant differences between the groups (see Table 1).

During the screening process, the core stability of each runner was assessed. The purpose of screening core stability before accepting participants was to eliminate potential participants who already possessed a high level of stability–a level III or better score based on the Sahrmann core stability test (scale = level I–V). Only 1 potential subject scored level III and was omitted from the study. The procedure of this core stability test follows that of Stanton et al. (17). Their pilot data exhibited a reliability coefficient of 0.95 with an *SEM* of 7.7% for this test. By assessing the core stability level, 28 qualified subjects possessed level I or level II core muscle strength before beginning the initial test. Each subject signed the university-approved informed consent form after explanation of the study procedures had been given.

Instrumentation

Force Plate. An AMTI force plate (Advanced Medical Technologies, Inc., Watertown, Mass) was used (sampled at 600 Hz) to measure GRF variables. The Peak Motus software (v. 8.2, ViconPeak, Centennial, Colo) was used to reduce the data with fast Fourier analysis. The GRFs were normalized mathematically to each participant's body weight (BW) for peak impact and active vGRFs: raw force (N) / 9.81 $m \cdot s^{-2}$ / BW. Duration of breaking hGRF and propulsive hGRF were standardized by percentage from a foot contact time: total foot contact time at 0.30 seconds = 0.15 seconds of breaking hGRF and 0.15 seconds of propulsive hGRF; thus, 50% and 50%.

Star Excursion Balance Test. The SEBT has been used in the clinical field to measure the functionality of the lower extremity (8,9,11,14). Olmsted et al. (14) describe the SEBT as an economical, simple, and reliable instrument to measure the dynamic stability of lower-body functionality. Kinzey and Armstrong (11) report a reliability coefficient of 0.86 after a practice session. Tapes were placed in 8 directions bisecting each other at 45° angles on the floor of the laboratory. The layout of the SEBT is shown in Figure 1.

Table 1. Demographic information (mean ± *SD*).

	Experimental group, $n = 12$	Control group, $n = 8$
Age (y)	37.75 ± 10.63	39.25 ± 10.81
Height (cm)	167.00 ± 10.00	167.00 ± 8.40
Body mass (kg)*	75.95 ± 16.89	63.03 ± 12.02
Average running pace (min:s)*	10:45 ± 1:11	9:26 ± 0:47
Average weekly mileage (miles)	20.75 ± 6.66	23.75 ± 6.41
Sahrmann core stability test (level)	1.54 ± 0.40	1.75 ± 0.38

*Significant difference between the groups, $p < 0.05$.

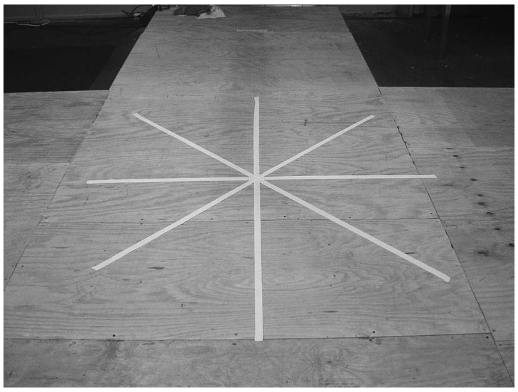

Figure 1. Layout of the Star Excursion Balance Test.

According to the methods used by Gribble et al. (9), only 3 out of 8 directions were used in this study to reduce the chances of fatigue during the test. The lengths of reaches in all 3 directions (0, 90, and 180° directions) from both feet were added and divided by each subjects' leg lengths to be comparable among them (e.g., if a subject scores 20 cm in front, 30 cm on the side, and 30 cm in the back from both feet, it is equal to a total of 160 cm; divided by the average leg length of 80 cm = 200%).

Procedures

All qualified subjects reported to the laboratory and selected outdoor tracks for testing on 2 occasions: a) pretraining and b) 6 weeks posttraining. Tests for GRF, lower-extremity stability, and running performance were performed identically at both sessions.

GRF Test

A reflective marker was placed on the lateral part of the left shoe to measure running velocity calculated by Peak Motus software version 8.2 (Vicon-Peak, Centennial, Colo). One 60-Hz camera (JVC Professional Products Company, Denver, Colo) was positioned on the left side of the force plate perpendicularly, to track the reflective marker. Subjects were instructed to contact the force plate with their left foot. Bennell et al. (1) have shown that the GRFs from the left and right feet during running were strongly correlated (0.73–0.96); thus, only left-foot kinetics were measured. The subjects warmed up by running at a self-selected pace outdoors, and then they returned to the laboratory to run across the force plate. The layout of the laboratory is shown in Figure 2.

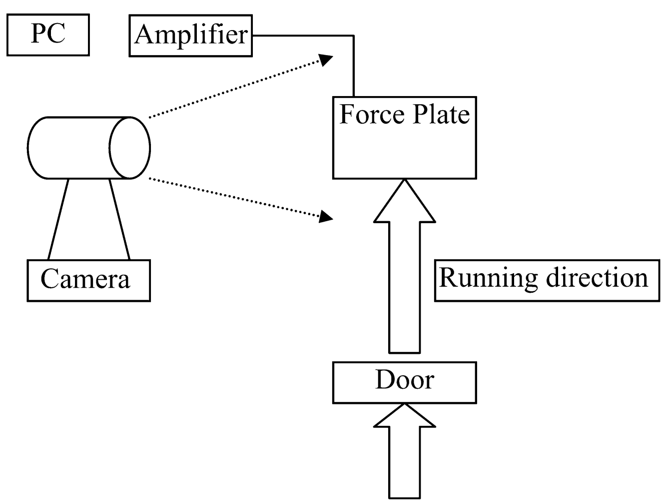

Figure 2. Layout of the laboratory.

This test simulated a real running situation; thus, if the subject reached the force plate with abnormal steps such as shuffling to achieve proper foot placement, the trial was repeated.

Star Excursion Balance Test

Before the SEBT, the investigator measured all subjects' leg lengths to calculate a ratio of the total score of the SEBT and leg length (total length / leg length = SEBT score) (8). Leg length was measured from medial malleolus to anterior superior iliac spine of each leg in centimeters by a tape measure, and the measurements were averaged if there was a minor leg length discrepancy. This ensured the accuracy of performance among the subjects to analyze the level of lower-extremity stability. The barefoot condition was required to eliminate extra balance and stability from the shoes during the test (8). First, each subject placed his or her left foot on the center of a 0–180° line. Then, each subject reached out his or her toes as far as possible to the direction of 0, 90, and 180° lines while maintaining balance. Next, each subject switched to his or her right foot and followed the same sequence. Kinzey and Armstrong (11) have indicated that instruction and demonstration improve the reliability of the test (from 0.67 to 0.87), along with practice sessions before the test; thus, adequate amounts of practice time also were provided. To maximize the reliability of the measurement, the following detailed instructions were given identically to all subjects: a) placing the foot on the line with the medial part of the stable foot while reaching laterally

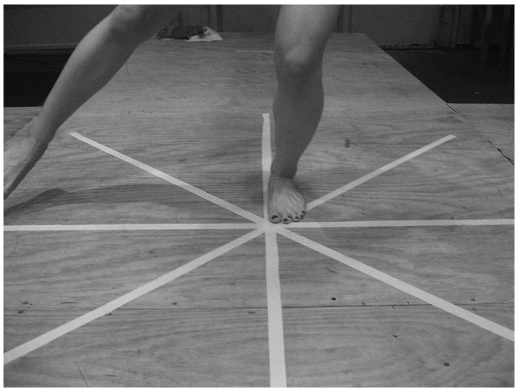

Figure 3. Stable foot (left) position for lateral reach.

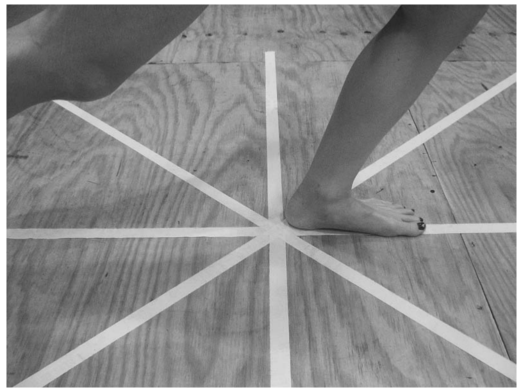

Figure 5. Stable foot (left) position for back reach.

(90°) (see Figure 3), b) placing the toes of the stable foot aligned on the line for the forward reach (0°) (see Figure 4), and c) placing the heel of the stable foot on the line for the backward reach (180°) (see Figure 5).

Subjects lightly touched the maximum reaching point while in a static position for at least 3 seconds to ensure their ability to stabilize their bodies (8). Each subject received 2 trials in each condition to reach his or her toes to the guided directions. The length between the toes of the reaching foot and the starting position of the stable foot were measured manually with a tape measure (8).

5000-m Run Test

A 5000-m run was done at accurately measured outdoor tracks. Because of the time availability of each subject, the 5000-m run was done on a separate day from the laboratory testing date (SEBT and GRF test). However, the 5000-m run was performed within 7 days of the laboratory testing date.

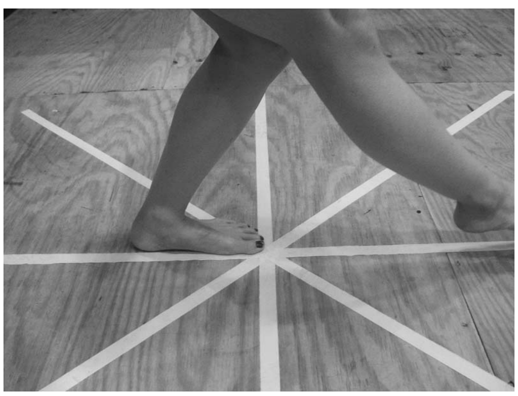

Figure 4. Stable foot (left) position for frontal reach.

After an adequate amount of warm-up including jogging and stretching, the 5000-m run was timed. The accurately measured track is 400 m per lap; thus, all participants ran 12.5 laps to complete a total distance of 5000 m. On completion of this trial, the 5000-m run time was recorded in minutes and seconds (e.g., 5000 m = 19 minutes 43 seconds). In addition, temperature and humidity level were also recorded during all subjects' running trials.

Core Strength Training

The control group did not receive the CST protocol; they were instructed to maintain their training routines and to report any alterations to the investigator. The CST group received the CST program that consists of 5 core-related exercises performed 4 times per week for 6 weeks. The following 5 exercises were visually demonstrated and verbally instructed by the investigator after the pretraining test: a) abdominal crunch on a stability ball to target abdominal muscles, b) back extension on a stability ball to target back extensor muscles, c) supine opposite 1-arm/1-leg raise to target back/hip extensor muscles, d) hip raise on a stability ball to target back/hip extensor muscles, and e) Russian twist on a stability ball to target abdominal muscles. These exercises have been used in previous studies to determine the effects of CST (3,16,17). The exercises are relatively well balanced, targeting core muscles (abdominal, hip flexor/extensor, and back extensor muscles). Even though those exercises are relatively novice level according to Stanton et al. (17), some of them are considered a challenge for those who have no experience in CST. All exercises were fully instructed and demonstrated by a certified strength and conditioning specialist to ensure the understanding of the proper mechanics after the pretraining laboratory test. In addition, the CST group received a hard copy of exercise instructions including pictures and training logs. Stability balls were provided to the experimental group because the treatment is intended for home training. They were instructed to fill out the training log after each session, and they also were contacted by the investigator at the end of each week to ensure adherence or to answer any concerns. Table 2 lists the volume of the training for the 6 weeks. According to Cosio-Lima et al. (3), the total session volume should increase to challenge strength improvement rather than performing the same volume throughout the treatment. Therefore, this study was designed to increase the volume of exercise sessions every 2 weeks.

Statistical Analyses

All dependent variables were entered into Statistical Package for Social Sciences (SPSS Inc., Chicago, Ill). Six 2 × 2 (group by time) mixed-design analyses of variance with repeated measures were performed to determine any significant effects of CST on the dependent variables. Significance was defined as $p \leq 0.05$.

Results

Table 3 shows that CST had no significant influence on lower-extremity stability scores measured by the SEBT or on any aspects of the GRF variables. However, there was a significant interaction in 5000-m run time, indicating that CST significantly improved running times in the CST group during 6 weeks.

Ground Reaction Force Test

As shown in Table 3, there are no significant effects on vGRF measures. The peak impact and the peak active vGRF were not influenced by the group or time, and there were no significant effects for the hGRF measures (see Tables 4 and 5). The duration of the breaking hGRF was slightly shorter, and the duration of the propulsive hGRF was slightly longer, in the CST group, regardless of 6 weeks of training.

Star Excursion Balance Test Scores

Table 6 shows that the SEBT scores increased in both groups during the 6 weeks. Although the SEBT score was shown to be nonsignificant on the basis of the interaction effect, the number did improve more (11.67-cm greater improvement) in the CST group during the 6 weeks of training.

Table 2. Training volume for the 6 weeks.

	Sets	Repetitions
First 2 weeks	2	10
Second 2 weeks	2	15
Third 2 weeks	3	12

5000-m Run Time

A significant interaction was found, $F(1,18) = 56.09, p < 0.05$. Table 7 shows that the CST group improved their average time compared with the control group.

Discussion

The purpose of this study was to determine the influence of CST on running kinetics, stability of the lower extremity, and performance in runners. It was expected that CST would positively influence running kinetics, stability of the lower extremity, and 5000-m run time.

Peak impact vGRF is a commonly measured variable in the biomechanics of running (5,7,10,13). If the impact of the initial foot strike is too low (<1.5 BW), this could cause a high loading rate relating to high active vGRF, but if it is too high (>3.0 BW), it could lead to overuse injuries by having a high force of heel impact (10,13,18). The normal range is approximately 1.6–2.3 BW, according to previous studies with similar running velocities (7,13). In this study, both groups had averages in the relatively normal range for peak impact vGRF ($n_{cst} = 1.65$ and 1.74 BW; $n_{con} = 1.99$ and 1.89 BW). Even though the CST group's number increased by 0.09 BW, it was not necessarily an excessive increase or range. Therefore, the increase for the CST group should not a concern for potential overuse injuries based on the impact force.

Peak active vGRF is also a common variable that is analyzed in running studies (5,7,10,13). High vGRFs were thought to negatively affect runners by putting high pressure on the mid- and forefoot, possibly leading to injury (10,13). The suggested range is from 2 to 3 BW, based on previous studies that have used relatively similar running velocities (10,13,18). On the other hand, if this force is too low, the runner may not be producing enough force to propel forward (7,13). In this study, the peak active vGRF was within the average range for all subjects, according to Novacheck (13). The results show that the peak active vGRF did not change significantly before and after the training period in the both groups (see Table 4). It is questionable to state that CST may have been the major role of this result for the experimental group. The purpose of incorporating CST was to increase core muscle strength to obtain better movement control, especially in the lower extremity, to optimize running kinetics. Although the results were the opposite of the hypothesis, the result may be a good indication for the CST group that their average 5000-m run time improved, whereas peak active vGRF did not change.

When a foot lands in front of the body while running (which often happens at downhill running and faster running velocity), it leads to a longer duration and higher force of breaking hGRF because the body becomes stiffer kinematically to accept greater foot impact (7). Reducing the duration of breaking hGRF would help carry forward momentum. Thus, increasing the duration of propulsive hGRF would help runners to carry forward momentum, making their

TABLE 3. Summary of the statistics on each variable.

	Interaction	Main effect: training	Main effect: group
Peak impact vGRF	NS	NS	NS
Peak active vGRF	NS	NS	NS
Time in the breaking hGRF	NS	NS	*
Time in the propulsive hGRF	NS	NS	*
SEBT	NS	*	NS
5000-m run time	*		

*Significant effect, $p < 0.05$. NS = not significant ($p > 0.05$); vGRF = vertical ground reaction force; hGRF = horizontal ground reaction force; SEBT = Star Excursion Balance Test.

running more economical in biomechanics terms (7,13). Gottschall and Kram (7) report that the ideal duration of breaking hGRF is approximately 50% or slightly lower. On the basis of the statistical analysis, there were no significant effects of CST on either variable in the CST group (see Table 3). Both groups slightly decreased their duration of propulsive hGRF after 6 weeks (n_{cst} = −3.45%; n_{con} = −1.37%).

The GRF data for both groups were potentially affected by inconsistent running velocity between pre- and posttraining GRF tests (n_{cst} = pretest 2.64 m·s^{-1}, posttest 2.81 m·s^{-1}; n_{con} = pretest 2.99 m·s^{-1}, posttest, 3.08 m·s^{-1}); this is one of the limitations of this study. Faster running velocity correlates with higher peak impact vGRF because of the harder initial foot contact (7,13). Even though all subjects were instructed to run across the force plate at the same speed and as naturally as possible (both pre and post), many subjects, especially in the CST group, ran faster during the posttraining GRF test.

Even though there is no scientific evidence for the effectiveness of having good balance and stability in athletic performance, health and fitness professionals believe that better stability of the lower extremity is extremely important to athletic performance, and also for daily living, in preventing potential injuries (11). Therefore, it is necessary to analyze whether CST would improve stability levels in dynamic movement based on the SEBT. The results show that SEBT scores improved in both groups because of possible test-retest effects, which may be why the interaction effects were not significant. However, the CST group improved their SEBT scores better than the control group (n_{cst} = +21.92 cm; n_{con} = +10.25 cm). Regardless of the nonsignificant outcome, a better SEBT score is a sign of improvement in dynamic stability for the CST group. Even though it is not known whether this improvement actually helps runners run faster or prevents potential running-related injuries, a more stable lower extremity should provide better and more consistent movement control.

The 5000-m run was conducted for performance analysis because the distance is one of the most popular distances for participating in local races (18). The results show significant improvement in the CST group after the training period (faster times by an average of 47 seconds), and the control group also improved their run times by an average of 17 seconds in the posttraining test. Even though minor limitations including climate difference between pre and post 5000-m runs and increasing weekly mileage during the 6-week period could have been factors for the faster time results, both groups were equally affected by those conditions. Core strength training may certainly be one of the causes that improved running times, especially in the CST group.

TABLE 4. Peak impact and peak active vertical ground reaction force (vGRF) for each group before and after training time (mean ± *SD*).

		Experimental group, $n = 12$	Control group, $n = 8$
Peak impact vGRF (BW)	Pretraining	1.65 ± 0.38	1.99 ± 0.38
	Posttraining	1.74 ± 0.46	1.89 ± 0.24
	Difference (pre-post)	±0.09	−0.10
Peak active vGRF (BW)	Pretraining	2.30 ± 0.36	2.49 ± 0.26
	Posttraining	2.31 ± 0.42	2.52 ± 0.24
	Difference (pre-post)	+0.01	+0.03

BW = body weight.

TABLE 5. Duration of breaking and propulsive horizontal ground reaction force (hGRF) for each group before and after training time (% as duration during a foot contact) (mean ± *SD*).

		Experimental group, *n* = 12	Control group, *n* = 8
Breaking hGRF (%)	Pretraining	47.30 ± 5.91	53.11 ± 4.77
	Posttraining	49.33 ± 6.81	54.48 ± 4.76
	Difference (pre-post)	+2.03	+1.37
Propulsive hGRF (%)	Pretraining	52.70 ± 5.92	46.89 ± 4.77
	Posttraining	49.25 ± 6.70	45.52 ± 4.57
	Difference (pre-post)	−3.45	−1.37

This study's design involved performing 4 training sessions per week, which was higher than in previous studies (3,16,17). Thus, the volume in the present study may have provided a strong enough stimulus to show significant effects in running performance. According to the qualitative feedback from the subjects in the CST group, some were conscious of using their core muscles to stabilize their running form. Thus, the significant improvement in 5000-m run time for the CST group may be a true effect of CST.

In summary, this study shows a significant effect on running performance from performing CST. Because previous studies using low training volumes (2 sessions per week for 6 weeks) did not show significant effects, this study might prove that a higher training volume is needed to show a significant effect. However, CST did not significantly affect the GRF variables or lower-extremity stability.

PRACTICAL APPLICATIONS

This study demonstrates that CST has an important role in improving running performance from a physical perspective by improving core muscle strength. Additionally, the CST group became more conscious of body position once they understood the importance of having good posture while running. However, it also seemed that the CST did not significantly influence running kinetics. Runners are interested in every possible way of improving running performance, such as purchasing lighter shoes and apparel, trying famous training plans, changing running mechanics, or taking endurance supplements. The CST is certainly one possible way for any type of runner to use supplemental strength training to optimize overall running efficiency. This information is valuable to strength and conditioning coaches, team coaches, and physical education teachers who are implementing CST into their routine and who understand the relationship between core strength levels and running performance.

The CST is a great training tool for those professionals who use it in the strength and conditioning field to improve or maintain strength levels in the midsection of the body. The CST also has been an effective training tool in the rehabilitation field for recovering from previous musculoskeletal injuries to regain muscular strength. This study used a relatively short training period (6 weeks), as have other studies in the past (3,16,17). A full year of continuous CST and

TABLE 6. Star Excursion Balance Test scores for each group before and after training time (% as a ratio of total reaching length / leg length; mean ± *SD*).

	Experimental group, *n* = 12	Control group, *n* = 8
Pretraining (%)	198.75 ± 26.70	199.13 ± 26.34
Posttraining (%)	220.67 ± 26.90	209.38 ± 26.89
Difference (pre-post)	+21.92	+10.25

TABLE 7. Five-thousand-meter run time for each group before and after training time (mean ± *SD*).

	Experimental group, *n* = 12	Control group, *n* = 8
Pretraining (min:s)	29:29 ± 2:38	26:30 ± 1:59
Posttraining (min:s)	28:42 ± 2:23	26:13 ± 1:54
Difference (pre-post)	−0:47	−0:17

occasional tests may show changes in the biomechanical characteristics of running performance.

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