EFFECTS OF PLYOMETRIC TRAINING ON ENDURANCE AND EXPLOSIVE STRENGTH PERFORMANCE IN COMPETITIVE MIDDLE- AND LONG-DISTANCE RUNNERS

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ABSTRACT
Ramírez-Campillo, R, Álvarez, C, Henríquez-Olguín, C, Baez, EB, Martínez, C, Andrade, DC, and Izquierdo, M. Effects of plyometric training on endurance and explosive strength performance in competitive middle- and long-distance runners. J Strength Cond Res 28(1): 97–104, 2014—The purpose of this study was to examine the effect of a short-term plyometric training program on explosive strength and endurance performance in highly competitive middle- and long-distance runners. Athletes were randomly assigned to a control group (CG, n = 18, 12 men) and an explosive strength training group (TG, n = 18, 10 men). Drop jump (DJ) from 20 (DJ20) and 40 cm (DJ40), countermovement jump with arms (CMJA), 20-m sprint time, and 2.4-km endurance run time test were carried out before and after 6 weeks of explosive strength training. Also, the combined standardized performance (CSP) in the endurance and explosive strength test was analyzed. After intervention, the CG did not show any significant change in performance, whereas the TG showed a significant reduction in 2.4-km endurance run time (−3.9%) and 20-m sprint time (−2.3%) and an increase in CMJA (+8.9%), DJ20 (+12.7%), and DJ40 (16.7%) explosive performance. Strength training group also exhibited a significant increase in CSP, although the CG showed significant reduction. We conclude that properly programmed concurrent explosive strength and endurance training could be advantageous for middle- and long-distance runners in their competitive performance, especially in events characterized by sprinting actions with small time differences at the end of the race.

KEY WORDS explosive strength, jump height, concurrent training, endurance performance

INTRODUCTION

Endurance performance ability or the ability to travel a long distance (i.e., from 800 m to 10,000 m) in the shortest time possible (also called velocity performance) (5) depends on several factors, like VO2max, lactate threshold, and running economy (5). Maintained submaximal velocity (e.g., 20.4–23.7 km·h⁻¹) in middle- and long-distance running events, however, may also require optimal neuromuscular characteristics related to voluntary and reflex neural activation, muscle force and elasticity, running mechanics, and anaerobic characteristics (12,27,35). In fact, some studies (3,18) have shown that anaerobic characteristics can differentiate well-trained middle- and long-distance runners according to their running performance, although longitudinal studies are necessary to corroborate this association. Recently, it has been reported that when proper strength training is used simultaneously with endurance training, improvements in strength and endurance performance is possible in world-class endurance athletes (10,11). On the other side, concurrent strength and endurance training have proven detrimental to endurance performance (21). However, no middle- and long-distance runners participate in these studies.

Whereas a traditional (heavy) resistance training program results mainly in neural and hypertrophic adaptations (12,14) leading to a dilution of the mitochondrial volume density (22); explosive strength training may lead preferentially to
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adaptations such as increased rate of activation of motor units (12,14). Explosive strength training may involve body weight jumping type exercises (23), also called plyometric exercises, commonly used to increase explosive strength by means of the stretch-shortening cycle (SSC) (31). This type of training is a highly effective neuromuscular stimulus, with the advantage of requiring reduced physical space, time, and equipment to complete the training sessions (8).

In a recent systematic literature review (39) it has been show that short-term plyometric training has a positive effect on endurance running performance or running economy, although this observation was based only in 4 eligible studies; in addition, we find several following limitations in these studies: (a) low number (less than 10) of subjects in experimental groups (26,28,34,36); (b) relatively low level of endurance performance (28,34,36); (c) poor description (28) or no application of plyometric training program (26); (d) relatively elevated plyometric training volume (more than 2000 jumps in 6 weeks) and concomitant low endurance training efficiency (only 0.0013% per jump) (36); (e) no time trial applied (34); (f) inclusion of triathletes as experimental subjects (26).

In addition, equivocal reports exist for the effect of concurrent explosive strength and endurance training on adaptive changes in aerobic capacity, endurance performance, and explosive strength performance (1,7,16,19,24,25,29). Therefore, although it is possible that concurrent explosive strength and endurance training can enhance explosive strength capabilities or endurance running performance, because of the limited number of longitudinal studies where explosive strength training was applied to middle- and long-distance runners, and the limitations explained above of these few studies, the effect of a concurrent explosive strength and endurance training program on explosive strength and endurance running performance of highly trained middle- and long-distance runners is not clear. Therefore, the objective of this study was to determine the effects of plyometric training, simultaneously applied with endurance running training, on a time trial running endurance performance test and explosive strength adaptations in a sizeable sample of highly competitive middle- and long-distance runners. It was hypothesized that simultaneous plyometric and running endurance training will induce significant changes in running endurance and explosive strength performance in competitive middle- and long-distance runners.

METHODS

Experimental Approach to the Problem

This study was designed to address the question of how a short-term plyometric training program of moderate frequency (2 session/week) using moderate volume affects explosive strength and running endurance performance in competitive middle- and long-distance runners. To do this, we compared the effects of 6 weeks of plyometric treatment in 2 groups of athletes. Some initial tests were executed to establish a baseline. This was a randomized controlled trial. From the initial sample of 53 middle- and long-distance runners, who volunteered to take part in this study and had the necessary requirements to integrate the study, and following a random distribution of the athletes in the investigation groups, only 36 applied as their initiative (control [CG, n = 18, 12 men], and plyometric training [TG, n = 18, 10 men]). The assigned groups were determined by a chance process (a random number generator on a computer) and could not be predicted. This procedure was established according to the “CONSORT” statement, which can be found at: http://www.consort-statement.org. Participants were randomly assigned into 1 of 2 intervention arms. Randomization was done using R software version 2.14 (R Foundation for Statistical Computing). The rate of runners who completed the plyometric training program was 89%.

From the 36 athletes who initially took part in the study, 1 man from the TG and 3 (1 women and 2 men) from the CG did not complete the postintervention measurements due to several following reasons: injury (nonplyometric training related), change of residency, and pregnancy. No injuries related to the plyometric training program were reported.

Subjects

For the intervention, a group of competitive middle- and long-distance runners (22 men 14 women; 22.1 ± 2.7 years of age) were recruited. They had a minimum of 2 years of competitive experience at national and international level, with personal best times that ranged from 3:50 and 4:27 (minutes:seconds) at the 1500 m (men and women, respectively) to 2:32 and 2:52 (hours:minutes) at the Marathon (men and women, respectively). Subjects had no explosive strength training experience in the last 6 months. Athletes completed (mean ± SD) 6.94 ± 1.8 running endurance training units per week, for a total running weekly volume of 672 ± 18.9 km (TG 64.7 ± 18.8 km; CG 70.0 ± 19.3 km; no significant difference between groups), where high intensity interval training bouts of long (i.e., >1 minute) duration were the preferred training method. This training load was added to their respective competitive schedule. Although the VO2max was not measured, the whole group of athletes (including women) underwent a 2.4-km time trial running performance test in a mean of 7.9 ± 0.8 minutes before intervention, suggesting a high level of fitness in comparison with previous reports (28,34–36). Exclusion criteria included athletes with (a) potential medical problems or a history of ankle, knee, or back pathology in the 3 months preceding the study; (b) medical or orthopedic problems that compromised their participation or performance in this study; (c) any lower extremity reconstructive surgery in the past 2 years or unresolved musculoskeletal disorders, and (d) athletes who were taking and had previously taken anabolic steroids, growth hormone, or related performance-enhancement drugs of any kind. However, individuals were not eliminated if they had been taking
vitamins, minerals, or related natural supplements (other than creatine monohydrate). Institutional Review Board approval for our study was obtained, and all athletes were carefully informed about the experiment procedures and about the possible risks and benefits associated with participating in the study, and an appropriate signed informed consent document was obtained pursuant to law before any of the tests were performed. We comply with the World Association’s Declaration of Helsinki. Sample size was computed according to changes observed in plyometric (i.e., jumping) performance ($\delta = 3.2\%$; $SD = 0.9$) in a group of endurance runners submitted to training for 6 weeks (28). A total of 15 participants per group would yield a power of 80% and $\alpha = 0.05$.

**Anthropometric Characteristics and Testing Procedures**

All anthropometric measurements were completed between 10:00–11:00 hours, whereas performance measurements were completed between 11:00 and 16:00 hours. Height was measured using a wall-mounted stadiometer (Butterfly, Shanghai, China) recorded to the nearest 0.5 cm. Body mass was measured to the nearest 0.1 kg using a digital scale (BC-554 Ironman Body Composition Monitor; Tanita, IL, USA). The body mass index (BMI) was determined by dividing body mass by the square height of the athlete (kg·m$^{-2}$). The athletes were carefully familiarized with the test procedures during several submaximal and maximal actions a few days before the measurements were taken (2 sessions per week during 2 weeks). The athletes also completed several explosive type actions to become familiar with the exercises used during training. In addition, several warm-up muscle actions were performed before the actual maximal and explosive test actions. All tests were carried out before and after 6 weeks of plyometric training. The performance tests were performed in 2 consecutive days. On day 1, the following tests were completed: measurement of height (m), body mass (kg), height in the countermovement jump with arms (CMJA) (cm), and drop jump (DJ) from 20 and 40 cm for maximal jump height divided by contact time (cm·ms$^{-1}$). On day 2, the 20-m sprint test and 2.4-km running endurance test were completed. Standard warm-up (5 minutes of submaximal running with several displacements and 2 submaximal jump exercises of 20 vertical jumps and 10 longitudinal jumps) were executed during each testing day. Also, athletes were instructed to use the same sports clothing during the preintervention and postintervention testing, to have a good night of sleep before each testing day, to avoid drinking or eating at least 2–3 hours before measurements. All subjects were motivated to give their maximum effort during performance measurements, and all performance test were executed at least 48 hours after a hard training session.

**Drop-Jump.** The athletes performed DJs from a 20 and 40 cm high platform for maximum jump height and minimum contact time, to assess plyometric performance requiring fast SSC action. The objective was to maximize the ratio between height and ground contact time (cm/ms), using an electronic contact mat system (Globus Tester, Codogne, Italy). A protocol previously described (4) was used to test athletes. The intraclass correlation coefficient (ICC) was 0.93 (0.91–0.95) for 20 cm DJ and 0.92 (0.90–0.94) for 40 cm DJ.

**Countermovement Jump With Arms.** A CMJA was used in to assess plyometric (i.e., maximal jump height; cm) performance requiring slow SSC action and the coordination between lower and upper body muscles. The CMJA test was performed using an electronic contact mat system (Globus Tester, Codogne, Italy). Jump height was determined using an acknowledged flight time calculation (2,6). During de CMJA, the athlete was instructed to use arms freely, foot and shoulders wide apart; athletes performed a downward movement with no restriction on the knee angle achieved (36) followed by a maximal effort vertical jump. All athletes were instructed to land in an upright position and to bend their knees after landing. Three trials were completed, with 30 seconds of rest between them, and the best performance trial was used for the subsequent statistical analysis. The ICC was 0.92 (0.89–0.95) CMJA measurements.

**20-m Sprint Time.** Sprint times (s) were recorded for 20 m distances to assess horizontal explosive strength performance requiring fast SSC action during running, a measure previously used to assess plyometric performance in endurance runners (28). A protocol previously described (4) was used to test athletes. Briefly, the 20-m sprint test was conducted indoors on a wooden running surface. The sprint time was measured to the nearest 0.01 seconds using infrared reds photoelectric cells (Globus Italia, Codogne, Italy) positioned at 20 m. Three trials were completed, and the best performance trial was used for the subsequent statistical analysis. Three minutes of rest were permitted between 20-m trials. The ICC was 0.95 (0.94–0.98) for 20-m sprint measurements.

**2.4-km Running Endurance Test.** This was the only test that took place outdoors. The wind velocity at all times was between 5.5 to 9.9 km·h$^{-1}$, the relative humidity was 50–66%, and the temperature was 13–14°C (Chilean Meteorological Service, Santiago, Chile). Athletes were instructed to run for maximal performance. The head coach took results as a guide to select athletes for competition, so motivation was considered maximal. Athletes individually completed 6 laps in a 400-m outdoor polyurethane track. Because the middle- and long-distance runners recruited for the study compete in different distances, we choose a standard distance for all athletes (2.4 km), as all of them were accustomed to this test as part of their annual general fitness assessment battery. For the specific warm-up, 2 submaximal laps around the track were completed, and 4 minutes later athletes had 1 maximal attempt to complete the test.
Combined Standardized Performance. The combined standardized performance (CSP) was analyzed. To obtain CSP, dependent performance variables were standardized by means of the Z score equation: 

\[ z = \frac{(r - \bar{X})}{SD} \]

where \( z \) is the raw score (e.g., 33 cm in the CMJA), \( r \) is the population mean, and \( SD \) is the population standard deviation. The performance variables standardized were 20 m, 2.4 km, CMJA, DJ20, and DJ40. The mean of each standardized performance variable was obtained, then combined, and finally divided by the total number of performance variables standardized. Where a smaller number represents a better result (such as running performance), the standardized value (i.e., \(-0.8\)) was reversed (0.8 in the example), and thus a positive value represent a positive performance regarding the total group of athletes. The higher the value, the better the athlete's performance with the group of 36 individuals that took part in the study.

Treatment

The plyometric training intervention period lasted for 6 weeks, as this time frame had shown to be adequate for significant endurance related adaptations (28,36,37), and was carried out during the initial part of the competition season. No reduction in running endurance training volume was applied to the TG (i.e., the TG and CG kept their usual volume of running endurance training during the intervention). The athletes were instructed to maintain their usual dietary habits for the entire duration of the study and they did not perform plyometric exercise between sessions in the TG. Before the initiation of the plyometric training period, the athletes were instructed as to the proper execution of all the exercises to be done during this period. The plyometric training took place 2 days per week (with at least 48 hours of rest between sessions) because this training frequency had been shown to induce significant explosive-related and endurance-related adaptations in endurance athletes (36), with significant superior efficiency as compared with higher training frequencies (6). Plyometric training sessions lasted less than 30 minutes and were completed immediately before the endurance training. Standard warm-up (i.e., 5 minutes of submaximal running and several displacements, 20 submaximal vertical jumps and 10 submaximal longitudinal jumps) was used before the main part of the training session. The plyometric exercises consisted only of DJs (bounce drop jumps), with a total of 60 DJs per session (2 series of 10 jumps from a 20 cm box, 2 series of 10 jumps from a 40 cm box, and 2 series of jumps from a 60 cm box), for the TG. This volume had been used in previous studies, obtaining significant positive results (4,6). The rest period between repetitions was of 15 seconds, as previously recommended (31), and between series was of 2 minutes. The control group did not perform plyometric training and underwent the same testing protocols as the TG.

Athletes from the TG used the same surface (i.e., wooden floor) to complete all the plyometric training sessions. Athletes were instructed to place their hands on their hips and step off the platform with the leading leg straight to avoid any initial upward propulsion, ensuring a drop height of 20, 40, and 60 cm. They were instructed to jump with maximal intensity for maximal height and minimum contact time in every jump. These instructions were intended to maximize explosive strength requiring fast SSC. A researcher was always present during training sessions, motivating athletes to give their maximum effort in each jump.

Statistical Analyses

Statistical analyses were performed by STATISTICA software (version 8.0; StatSoft, Inc., Tulsa, OK, USA). Descriptive statistics (mean ± SD) for the different variables were calculated. Normality and homoscedasticity assumptions for all data (pre and post) were checked respectively with Shapiro-Wilk and Levene Tests. To determine the effect of intervention on plyometric and running endurance adaptations, a 2-way variance analysis with repeated measurements (2 groups × 2 times) was applied. When a significant F value was achieved across time or between groups, Tukey post hoc procedures were performed to locate the pairwise differences between the means. Pearson r product-moment correlation was used to correlate the initial value of the dependent variables and their relative modification after the intervention. The α level used for all statistics was 0.05.

Results

Because after the analysis of variance no significant differences were detected between men and women in percentage change in any of the test variables from before to after training, both genders were pooled in each group, as previously suggested (33).

At baseline, no significant differences between the TG and CG were evident in any anthropometric or performance variables (Table 1).

During the 6 weeks of plyometric training, no statistically significant (\( p > 0.05 \)) changes were observed in the height, body mass or BMI in the groups (Table 1).

After 6 weeks of treatment, a significant reduction was observed in 2.4 km (\( p < 0.01 \)) and 20 m (\( p < 0.01 \)) time test in the TG. Also, after training, the TG shows a significant difference in 2.4 km (\( p < 0.05 \)) and 20 m (\( p < 0.05 \)) time test in comparison with the CG (Table 1).

The TG showed a significant increase in CMJA (\( p < 0.001 \)), DJ20 (\( p < 0.001 \), and DJ40 (\( p < 0.001 \)) explosive strength jumping performance after intervention. Also, after training, the TG shows a significant difference in CMJA (\( p < 0.01 \)), DJ20 (\( p < 0.01 \), and DJ40 (\( p < 0.05 \)) explosive strength jumping performance in comparison with the CG (Table 1).

In the TG, a significant correlation was observed between the initial 2.4-km time performance and the relative modification in DJ40 explosive strength performance (\( r = -0.82; p < 0.001 \)).

No significant differences were observed between groups before intervention in CSP. The TG shows a significant
<table>
<thead>
<tr>
<th></th>
<th>CG (n = 15; 10 men)</th>
<th>TG (n = 17; 9 men)</th>
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</thead>
<tbody>
<tr>
<td><strong>Body mass (kg)</strong></td>
<td></td>
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<tr>
<td>Combined</td>
<td>59.8 ± 6.1</td>
<td>60.0 ± 3.8</td>
</tr>
<tr>
<td>Men</td>
<td>63.2 ± 1.5</td>
<td>61.1 ± 3.4</td>
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<tr>
<td>Women</td>
<td>56.4 ± 1.8</td>
<td>59.1 ± 3.7</td>
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<tr>
<td><strong>BMI (kg/m^2)</strong></td>
<td></td>
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<tr>
<td>Combined</td>
<td>21.5 ± 0.8</td>
<td>21.9 ± 1.4</td>
</tr>
<tr>
<td>Men</td>
<td>21.6 ± 0.7</td>
<td>21.7 ± 1.3</td>
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<tr>
<td>Women</td>
<td>20.9 ± 0.9</td>
<td>22.0 ± 1.3</td>
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<td><strong>20 m (s)</strong></td>
<td></td>
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<tr>
<td>Combined</td>
<td>3.97 ± 0.2</td>
<td>3.92 ± 0.3</td>
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<tr>
<td>Men</td>
<td>3.87 ± 0.1</td>
<td>3.80 ± 0.1</td>
</tr>
<tr>
<td>Women</td>
<td>4.20 ± 0.1</td>
<td>4.03 ± 0.3</td>
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<tr>
<td><strong>2.4 km (min)</strong></td>
<td></td>
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<tr>
<td>Combined</td>
<td>8.0 ± 0.9</td>
<td>7.6 ± 0.7</td>
</tr>
<tr>
<td>Men</td>
<td>7.2 ± 0.7</td>
<td>7.2 ± 0.2</td>
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<tr>
<td>Women</td>
<td>8.7 ± 0.3</td>
<td>8.3 ± 0.4</td>
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<tr>
<td><strong>CMJA (cm)</strong></td>
<td></td>
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<tr>
<td>Combined</td>
<td>34.1 ± 7.1</td>
<td>36.1 ± 5.6</td>
</tr>
<tr>
<td>Men</td>
<td>37.0 ± 5.8</td>
<td>38.1 ± 3.7</td>
</tr>
<tr>
<td>Women</td>
<td>28.2 ± 0.3</td>
<td>33.9 ± 6.0</td>
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<tr>
<td><strong>DJ20 (cm/ms)</strong></td>
<td></td>
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<tr>
<td>Combined</td>
<td>0.157 ± 0.037</td>
<td>0.157 ± 0.037</td>
</tr>
<tr>
<td>Men</td>
<td>0.169 ± 0.038</td>
<td>0.167 ± 0.042</td>
</tr>
<tr>
<td>Women</td>
<td>0.143 ± 0.026</td>
<td>0.145 ± 0.050</td>
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<tr>
<td><strong>DJ40 (cm/ms)</strong></td>
<td></td>
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<tr>
<td>Combined</td>
<td>0.166 ± 0.047</td>
<td>0.156 ± 0.041</td>
</tr>
<tr>
<td>Men</td>
<td>0.179 ± 0.041</td>
<td>0.168 ± 0.032</td>
</tr>
<tr>
<td>Women</td>
<td>0.152 ± 0.037</td>
<td>0.139 ± 0.048</td>
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</table>

*BMI = body mass index; CMJA = countermovement jump with arms; DJ = drop jump.
†Values between parentheses reflect 90% confidence limits.
‡Denotes significant difference with the corresponding before value (p ≤ 0.01).
§Denotes significant difference with the CG (p ≤ 0.05).
¶Denotes significant difference with the corresponding before value (p ≤ 0.001).
©Denotes significant difference with the CG (p ≤ 0.01).
increase in their CSP (before 0.04 ± 0.89; after 0.11 ± 0.9), whereas the CG shows a significant reduction (before −0.06 ± 0.96; after −0.15 ± 0.96).

**DISCUSSION**

The aim of this study was to determine the effects of plyometric training, simultaneously applied with endurance running training, on a time trial running endurance performance test and explosive strength adaptations in a sizeable sample of highly competitive middle- and long-distance runners. The main finding of the present study was that the combination of high-intensity plyometric exercises (i.e., DJs) and running endurance training induce significant increases in explosive strength and running endurance performance after 6 weeks of moderate volume plyometric training in competitive middle- and long-distance runners. These results suggest that to optimize running endurance performance and explosive strength adaptations in middle- and long-distance runners, a plyometric training program should be added to their regular running training program.

The TG exhibited a relative reduction in 2.4-km time 3 times greater than that of the CG (−3.9% vs. −1.3%, respectively). Although the running performance has a structural basis (38) (i.e., low BMI are commonly observed among middle- and long-distance runners), interestingly, the increased running endurance performance in the TG was achieved even when their BMI attained an almost significant increase ($p = 0.067$). Thus, although it is possible that the TG experienced a negative modification (i.e., increased BMI), this group of endurance athletes achieved a significant increase in their running endurance performance possibly by means of adaptations induced by plyometric training, like improved neuromuscular and anaerobic characteristics (12,14), that in addition to $\tilde{V}_{\text{O}_{2}}\text{max}$, lactate threshold, among others “aerobic” indicators may have a crucial role in the performance of endurance athletes (3,12,18,27). This result agree with those of previous authors (28,36), although equivocal reports exist for the effect of concurrent strength and endurance training on adaptive changes in aerobic capacity, endurance performance, and explosive strength performance (21); however, several limitations of these studies preclude possible generalization of their results to the training programming of highly competitive middle- and long-distance runners. In some of these studies, they had reduced the volume of endurance training by 20% (24,25) or even 48% (29). In our intervention, the total explosive strength training time took less than 60 minutes per week, which is less than 3 times the time reported in a study where reduced endurance performance was observed (21). Interference also may occur when the overall volume and/or frequency of training is higher over a longer period of time (13).

Aside from the increased running endurance performance, the TG achieved a significant increase in 20-m sprint performance, whereas no significant modification was evident in CG. Similar results had been reported previously (28,30,32). An increase in 20-m sprint performance had been correlated with an improved running economy, which may translate in an increased running velocity during endurance events (28). Also, the TG achieved a significant increase in explosive strength performance requiring slow SSC action (i.e., CMJA) after the intervention (no significant change was evident in the CG). Additionally, our results also show that the TG achieved a significant increase in explosive strength performance requiring fast SSC action (i.e., DJ20 and DJ40) after intervention, which, to the best of the author’s knowledge, this is the first study to investigate this in highly competitive middle- and long-distance runners. An increased in explosive strength performance requiring fast SSC action may reduce the time the athlete’s foot spends in contact with the ground during running (28), favorably affecting performance during running endurance events.

A significant relationship observed between initial 2.4-km time performance and relative modification in DJ40 suggest that athletes with the best initial running endurance performance may obtain more explosive strength adaptations trough plyometric training, which may be an advantage for their endurance performance during running (3,18). This finding can have important practical applications, but more studies are necessary to corroborate this result.

When the performance of athletes in the 20 m, 2.4 km, CMJA, DJ20, and DJ40 tests was standardized by means of the Z score, the TG show a significant increase, whereas the CG experienced a significant reduction. In our study, the CSP reflect not only one performance variable but include running endurance and explosive strength performance variables, both of which may have a role during competitive endurance events (3,18), therefore, the CSP may me a convenient tool to evaluate, in a more comprehensive way, the performance state of the athlete. Also, the CSP reflect the performance of a subject in comparison with a group. Thus, a change in CSP may reflect a change in the performance (involving several critical variables) of an athlete in comparison with their competitors. Accordingly, the study of performance through a CSP analyses may be an interesting tool to investigate competitive athletes in relation with their peers.

In conclusion, after 6 weeks of high-intensity moderate volume plyometric training, highly competitive middle- and long-distance runners obtained significant running endurance and explosive strength adaptations, and these adaptations were compatible with their regular running endurance training program.

**Practical Applications**

From a practical point of view highly competitive middle- and long-distance runners can induce both significant explosive strength adaptations and specific endurance running performance enhancements by incorporating plyometric training in their training schedule. Subjects achieved significant adaptations with plyometric training of short duration (i.e., 6 weeks) that took less than 1 hour per week to
be completed (i.e., low volume and moderate frequency of training). Explosive strength drills demonstrated adaptability to a specific population, integration within practice, and relative inexpensive equipment requirements (i.e., wood boxes). In fact, plyometrically trained subjects (and their coaches) reported positive feelings regarding our intervention and the will to incorporate this type of training as part of their regular training program. In a follow-up contact, coaches reported the inclusion of plyometric drills as part of the regular preparation of their athletes.

Concern has been expressed by some researchers with regard to the training surface used during plyometric training due to its (speculated) high harm/injury index. To the best of the author’s knowledge, when adequate controlled plyometric training intervention had been applied, no injuries had been reported. In fact, plyometric training had been advocated as a preventive injury strategy (9,20) and even as a rehabilitation tool (15). It is important to notice that in the present investigation no injuries were reported. More so, subjects reported little subjective muscle pain after the training sessions (data not shown), even when a hard training surface was used. Also, previous results from our laboratory (4) had shown that a reduced volume of plyometric training, combined with a relatively hard training surface, represents an optimal stimulus to induce significant neuromuscular adaptations.

When different components of motor performance are concurrently being developed, caution must be taken so that the fatigue achieved during training one component does not adversely affect the development of the other(s). Our results showed that explosive strength and running endurance training can be completed in the same training session, which may facilitate the incorporation of this method in the training program schedule.

Finally, properly programmed concurrent plyometric and running endurance training could be advantageous to middle- and long-distance runners for their competitive performance, especially in events characterized by sprinting actions with small time differences at the end of the race (17). In this regard, although our results show that the performance increment in 2.4-km time trial was significant in the TG, it is possible that a more “competitive” running endurance test (i.e., were subjects must struggle for the winning place at the ending of the race, implicating some form of sprint running) can be more representative of the “true” adaptations in competitive middle- and long-distance runners performance after a combined plyometric and endurance running combined training program. This can be considered in future researches.

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References

Explosive Strength Training in Distance Runners


