Effects of Flywheel Strength Training on the Running Economy of Recreational Endurance Runners

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Abstract

Festa, L, Tarperi, C, Skroce, K, Boccia, G, Lippi, G, La Torre, A, and Schena, F. Effects of flywheel strength training on the running economy of recreational endurance runners. *J Strength Cond Res* 33(3): 684–690, 2019—Running economy (RE) has been defined as the most important determining factor in endurance performance in both elite and recreational runners. The purpose of this study was to evaluate the effect of flywheel strength training (FST) and high-intensity training (HIT) protocols on RE and strength parameters in a group of recreational runners. Twenty-nine recreational runners were recruited to take part in the study and were randomly assigned to FST ($n = 9$; 44.5 ± 6.0 years; $\dot{V}O_2max$ 48.8 ± 5.2 $ml\cdot min^{-1}\cdot kg^{-1}$), HIT ($n = 9$; 42.2 ± 8.6 years; $\dot{V}O_2max$ 50.3 ± 3.7 $ml\cdot min^{-1}\cdot kg^{-1}$), or low-intensity training (LIT) ($n = 11$; 45.4 ± 8.0 years; $\dot{V}O_2max$ 50.2 ± 6.8 ml min^{-1} kg^{-1}) groups. Before and after 8 weeks of an experimental period, maximal oxygen uptake ($\dot{V}O_2max$), ventilatory thresholds (VTs), maximal dynamic force (1 repetition maximum [1RM]), and anthropometric data were evaluated. The FST group showed significant increases ($p < 0.05$) in 1RM and RE. No differences were found in the other groups. Significative changes are found for all groups on average speed on 2 and 10 km ($p < 0.05$). Anthropometric data were unchanged after the training period. The results of this study indicate that in recreational runners, FST seems able to obtain improvements in RE and neuromuscular adaptation.

Key Words strength training, running economy, endurance, performance

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Introduction

Typically, endurance running events are strongly related to different physiological factors such as maximal oxygen uptake ($\dot{V}O_2max$), the $\dot{V}O_2max$ available fraction, defined as the intensity sustained for a long period ($F_{\dot{V}O_2max}$), and running economy (RE), defined as the $\dot{V}O_2$ required at a given absolute exercise intensity (5). Running economy seems to be a better predictor of endurance performance than $\dot{V}O_2max$ (21,26). Some authors have suggested that anaerobic and neuromuscular characteristics together with RE are able to affect endurance performance (22,23). For this reason, in recent years, strength-training programs have been indicated as powerful stimuli to improve mechanical efficiency, muscular coordination, motor unit recruitment patterns, and lower-limb stiffness regulation with an overall enhancement in RE (25). In the past, it was suggested that concurrent endurance and strength training might interfere with or inhibit the development of strength or rate force development if the periods of concurrent training were too long or the training volume or intensity was too high (13,14,16). The cause of the "interference effect" seems to be related to the divergent responses and adaptations when considering also the specificity of the training mode and its adaptations in the neuromuscular system within strength training. For example, maximal strength training with high loads (such as 70–90% of 1 repetition maximum [1RM]) and low repetitions per set generally result in neural adaptations responsible for muscle hypertrophy over prolonged training periods. Conversely, explosive resistance training with low to medium loads (such as 30–60% of 1RM) but high action velocity movements improves neuromuscular characteristics, especially the rapid activation of the muscles because of increased motor unit recruitment. Maximal strength training and explosive strength training paired with endurance training, as well as plyometric training, have been shown to be more effective in improving RE, strength, power, and muscle activation in recreational endurance runners compared with concurrent circuit and endurance training (7,11,19,20,23,30).

Table 1. Physical characteristics of runners.*†

Variables	FST ($n = 11$) 6 men and 5 women	HIT ($n = 9$) 6 men and 3 women	LIT ($n = 9$) 6 men and 3 women
Age (yr)	44.2 ± 6.0	42.2 ± 8.6	45.4 ± 8
Body mass (kg)	73.3 ± 9.4	70.9 ± 11.9	66.1 ± 11.7
Height (cm)	169.0 ± 9.1	171.1 ± 6.8	171.8 ± 9.6
$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	48.8 ± 5.2	50.3 ± 3.7	50.2 ± 6.8

*FST = flywheel strength training; HIT = high-intensity training; LIT = low-intensity training.
†Values are mean ± *SD*.

Guglielmo et al. (12) demonstrated that heavy weight training (load 6RM) was more effective in improving RE than explosive strength training (with intermediate resistance, load 12RM) over short (4 weeks) training periods in well-trained endurance runners. Moreover, Piacentini et al. (24) endorsed these results confirming that total body maximal strength training (85–90% of 1RM, 4 repetitions, 4 sets) twice a week for 6 weeks improved 1RM by 17%, and RE by 6.1% ($p < 0.05$) in master athletes.

Recreational runners represent most participants in marathon events, and their number grows year after year. These athletes train and compete regularly, and follow detailed, structured training programs despite having various work and family commitments. Adding 2 extra strength-training workouts a week is not feasible for most of them, if not as part of a regular running session.

Knowing the benefits of adding strength training to endurance training to improve neuromuscular performance and sport specific economy, we conducted this study to compare RE variations before and after a regular endurance training program performed once a week, consisting of specific, short flywheel muscle efforts on a Yo-Yo Leg Press vs. low-intensity training (LIT) or high-intensity training (HIT) programs. According to our hypothesis, a brief flywheel strength training (FST) session in addition to endurance training would lead to an improvement in RE and, consequently, in the endurance performance of recreational runners.

Methods

Experimental Approach to the Problem

In this study, an 8-week training period was chosen to analyze the effects of FST on RE because it was believed that most adaptations in RE would occur after 4–6 weeks of strength training and that longer protocols may not add further improvements to RE (31). A parallel, 3-group, matched, longitudinal (pre-test–post-test), experimental design was used for this study to investigate the possible effects on RE, anthropometric data (DEXA), $\dot{V}O_2max$, ventilatory thresholds (VTs), and 1RM after 3 different training programs: FST, HIT, and LIT.

Subjects

Twenty-nine recreational runners (27-57 years old) were divided into 3 experimental groups of similar age, body mass, height, and $\dot{V}O_2max$ (Table 1). The Department of Neuroscience, Biomedicine, and Movement, University of Verona Ethical Committee approved the protocol, and the participants gave their written consent before taking part (prot. No. 165038, June 28, 2016). To avoid the influence of an athlete's

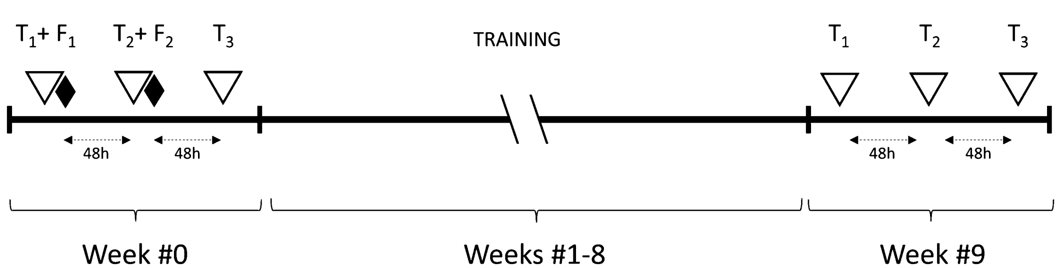

Figure 1. Timeline of research. Week #0 for test PRE, weeks #1–8 for training period, and week #9 for test POST. Test sessions (T) and familiarization trials (F).

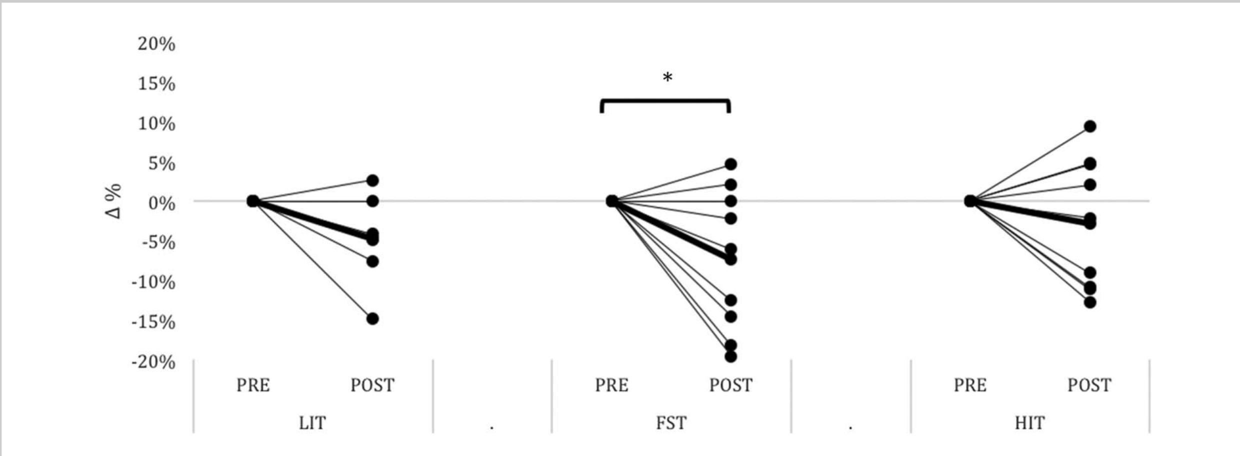

Figure 2. Percentage change in running economy on the 3 groups. Average in bold line, * $p \leq 0.05$.

current ability and preparation level, the participants included in this study had to fulfill the following criteria: they had to complete a half marathon not more than 2 months after the beginning of the study; and they had to have at least 3 years of endurance training experience.

Procedures

All subjects, during the week before the start of training (week #0), arrived at the laboratory for 3 sessions: aerobic capacity, RE (T_1 and T_2 in random order), and 1RM (T_3) (Figure 1). The sessions were separated by a 48-hour resting period, performed at the same time of day (at 19:00 ± 2 hours) in a climate-controlled laboratory (20–22° C, 55% humidity). The participants did not perform any physical activity during the 48-hour resting periods and were requested to refrain from using caffeine-containing food or beverages, consuming alcohol, and smoking cigarettes, or using any form of nicotine intake during this period. The daily diet was requested during the first session, and we have asked each subject to reproduce it for all experimental conditions. During the first session, the body composition was measured.

At the end of first and second sessions, 2 familiarization trials (F_1 and F_2) were performed by the Yo-Yo horizontal leg press machine for FST and by the isotonic horizontal leg press machine for all groups (Figure 1). The first trial consisted of 4 sets of 7 repetitions at moderate self-selected intensity on each machine while the second trial was of 4 sets of 4 repetitions at submaximal self-selected intensity.

The subjects repeated the same test program during the week just after the end of training (week #9).

Body Composition. In addition to standing height (measured using standard methods), body mass and body composition

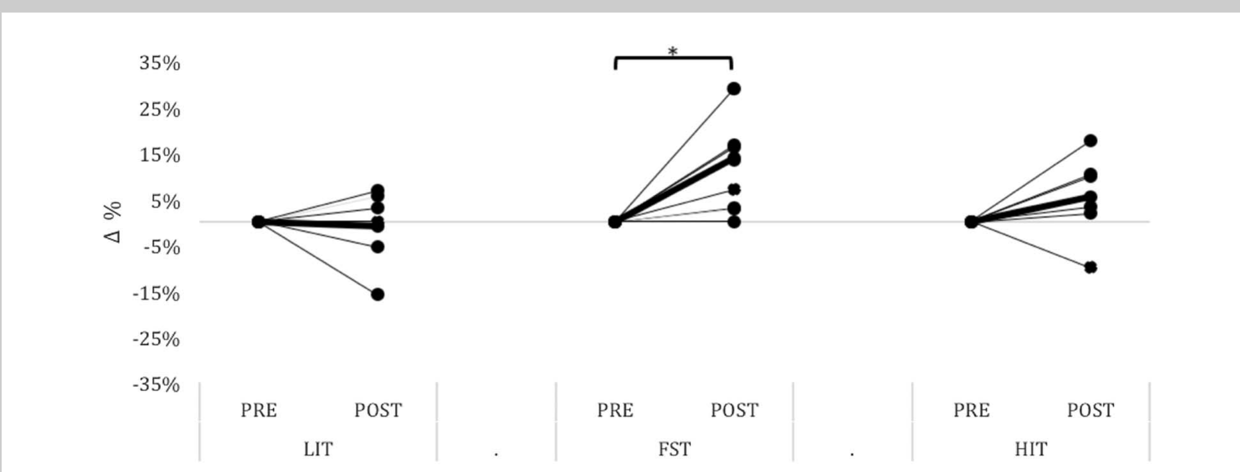

Figure 3. Percentage change in 1RM on 3 groups. Average in bold line, * $p \leq 0.05$. 1RM = 1 repetition maximum.

TABLE 2. Physiological results in low-intensity training (LIT) group (n = 11).*†

	Pre-training	Post-training	Difference	Lower bound	Upper bound	Effect size (d)
Body mass (kg)	66.1 ± 11.7	66.2 ± 11.7	0.1	−0.9	0.6	0.0
Fat mass (%)	21.1% ± 6.7%	20.3% ± 6.7%	0.8%	0.1%	1.5%	−0.1
$\dot{V}O_2$max (ml·min)	3,313.9 ± 765.3	3,400.9 ± 842.6	87.1	−281.8	107.7	0.1
v$\dot{V}O_2$max (km·h^{-1})	13.3 ± 2.0	13.6 ± 2.0	0.3	−0.7	0.2	0.2
VT_1 (km·h^{-1})	10.8 ± 1.6	11.5 ± 1.8	0.7	−1.2	−0.2	0.5‡
VT_2 (km·h^{-1})	12.2 ± 1.9	12.9 ± 2.0	0.7	−1.1	−0.3	0.5§
RE@75 (ml·m^{-1}·kg^{-1})	195.6 ± 28.8	197.2 ± 15.3	1.6	−17.6	14.4	0.1
Strength						
1RM leg press (kg)	136.9 ± 37.4	135.6 ± 39.1	1.4	−2.2	4.9	0.0
2-km avg speed (km·h^{-1})	13.7 ± 2.0	14.1 ± 2.2	0.4	−0.7	−0.2	0.3§
10-km avg speed (km·h^{-1})	12.2 ± 2.0	12.5 ± 2.0	0.3	−0.6	−0.0	0.2‡

*1RM = 1 repetition maximum.
†Values are mean ± *SD*. RE@75 measured on treadmill at 75% of vVT_1 with 1% inclination.
‡p value <0.05 significantly different from preintervention value.
§p value <0.01 significantly different from preintervention value.

were measured using DEXA (QDR explorer E, Hologic, MA, USA).

Aerobic Capacity. Maximal oxygen uptake ($\dot{V}O_2$max) and maximal running speed (v$\dot{V}O_2$max) were determined by an incremental treadmill running test at the laboratory. The protocol test was individualized for each subject to control the duration of each test. Therefore, the initial speed was determined by the subject's capacity, and it was increased by 0.5 km·h^{-1} every minute until exhaustion. The running surface slope was kept at a constant +1% throughout the test (Runrace Technogym, Gambettola, Italy). Heart rate, oxygen consumption, and ventilatory parameters were determined breath-by-breath using a Cosmed flow meter (Quark PFT, Cosmed,

TABLE 3. Physiological results in flywheel strength training group (n = 9).*†

	Pre-training	Post-training	Difference	Lower bound	Upper bound	Effect size (d)
Body mass (kg)	70.9 ± 11.8	69.7 ± 11.5	1.2	0.4	2.0	−0.1‡
Fat mass (%)	19.3% ± 2.5%	18.5% ± 2.6%	0.8%	−0.1%	1.6%	−0.1
$\dot{V}O_2$max (ml·min)	3,484.2 ± 739.0	3,558.2 ± 744.0	74.1	−217.9	69.8	0.1
v$\dot{V}O_2$max (km·h^{-1})	13.1 ± 1.3	13.7 ± 1.3	0.6	−0.8	−0.4	0.4§
VT_1 (km·h^{-1})	11.1 ± 0.9	11.7 ± 1.1	0.6	−0.9	−0.3	0.5§
VT_2 (km·h^{-1})	12.4 ± 1.1	13.1 ± 1.0	0.7	−1.0	−0.4	0.5§
RE@75 (ml·m^{-1}·kg^{-1})	222.8 ± 19.6	215.8 ± 19.8	6.9	−4.5	18.3	−0.3
Strength						
1RM leg press (kg)	130.0 ± 19.9	128.9 ± 25.9	1.1	−5.2	7.3	0.0
2-km avg speed (km·h^{-1})	14.0 ± 1.1	14.5 ± 1.1	0.5	−0.7	−0.4	0.4§
10-km avg speed (km·h^{-1})	12.0 ± 1.6	12.7 ± 1.4	0.8	−1.0	−0.6	0.5§

*1RM = 1 repetition maximum.
†Values are mean ± *SD*. RE@75 measured on treadmill at 75% of vVT_1 with 1% inclination.
‡p value <0.05 significantly different from preintervention value.
§p value <0.01 significantly different from preintervention value.

TABLE 4. Physiological results in flywheel strength training group.*†

	Pre-training	Post-training	Difference	Lower bound	Upper bound	Effect size (*d*)
Body mass (kg)	71.3 ± 9.4	70.2 ± 8.9	1.0	0.0	2.0	−0.1
Fat mass (%)	23.9% ± 5.7%	22.8% ± 6.3%	1.1%	0.2%	2.0%	−0.2
$\dot{V}O_2max$ (ml·min)	3,502.8 ± 768.1	3,475.7 ± 699.7	27.0	−53.0	107.1	0.0
$v\dot{V}O_2max$ ($km \cdot h^{-1}$)	12.8 ± 0.9	13.6 ± 1.2	0.8	−1.0	−0.5	0.5‡
VT_1 ($km \cdot h^{-1}$)	10.7 ± 0.8	11.5 ± 1.0	0.7	−1.0	−0.5	0.6‡
VT_2 ($km \cdot h^{-1}$)	12.0 ± 1.1	12.6 ± 1.2	0.6	−0.9	−0.4	0.4‡
RE@75 ($ml \cdot m^{-1} \cdot kg^{-1}$) Strength	220.1 ± 12.5	206.2 ± 21.0	13.9	3.6	24.3	−0.6§
1RM leg press (kg)	130.7 ± 28.3	135.9 ± 28.9	5.2	−7.9	−2.5	0.2‡
2-km avg speed ($km \cdot h^{-1}$)	13.4 ± 1.0	14.0 ± 1.4	0.6	−0.8	−0.3	0.4‡
10-km avg speed ($km \cdot h^{-1}$)	11.5 ± 1.0	12.2 ± 0.9	0.7	−0.9	−0.4	0.5‡

*1RM = 1 repetition maximum.
†Values are mean ± *SD*. RE@75 measured on treadmill at 75% of vVT_1 with 1% inclination.
‡*p* value <0.05 significantly different from preintervention value.
§*p* value <0.01 significantly different from preintervention value.

Rome, Italy). Before each test, the flow meter was calibrated with a 3-L syringe, and the analyzer was calibrated with certificated gas mixtures (16% O_2 and 5% CO_2) and environmental air (20.9% O_2 and 0.03% CO_2). The VT was defined as the intensity at which the ventilatory equivalent of oxygen ($\dot{V}E/\dot{V}O_2$) began to rise without a concurrent rise in the ventilatory equivalent of carbon dioxide ($\dot{V}E/\dot{V}CO_2$) (10). This method has been shown to be valid and reliable (3,4). Two experienced evaluators performed the threshold determinations independently. If there was disagreement between the 2 independent observers, a third was brought in.

One Repetition Maximum. Maximal strength was estimated by a 6RM test on a leg press machine. All subjects were positioned on a horizontal leg press (Technogym, Gambettola, Italy), and the knee angle (90°) was fixed to maintain the same position in all test occasions. After a 5-minute warm-up and an appropriate rest period, the subject performed the first session with a preliminary load of 15 repetitions. Thereafter, the load was increased every step by 30% until the athlete could not successively complete a 6RM repetition (1). The 1RM was estimated using a conversion table. The 1RM was measured for all subjects after 2 weeks of the familiarization period.

Running Economy. After 5 minutes of running warm-up at 60% of the velocity at first VT (vVT_1), the RE was determined by measuring submaximal steady state $\dot{V}O_2$ running for 5 minutes at 75% of vVT_1. During each test, heart rate and $\dot{V}O_2$ were monitored and recorded breath-by-breath with the Cosmed metabolimeter (Quark PFT; Cosmed, Rome, Italy), calibrated before each test as described above. The RE was defined as the mean $\dot{V}O_2$ collected at the last 2 minutes of test.

Training Protocol. Reference velocity (RV) was defined to differentiate training interventions. Reference velocity is the mean velocity between the first and second VTs (vVT_1 and vVT_2). All groups performed training sessions 3 times a week. The endurance program for FST and LIT was characterized by an intensity ranging between 70 and 105% of RV, while the intensity for HIT was at 95–140% of RV. An FST session was conducted once a week, before the endurance workout. After a standardized warm-up, the runners did 4 sets of 7 repetitions at maximum velocity on a Yo-Yo Leg Press (Yo-Yo Technology AB, Stockholm, Sweden), a new isoinertial system that maximizes the eccentric phase of muscular contraction. The intensity effort was controlled with Rate of Perceived Exertion after each set. If the subject gave a value in the range of 9–10, the effort was considered maximum. The rest interval between sets lasted 3 and a half minutes. To compare training the total training load (intensity × volume) was balanced using a modified version of the training-impulse (TRIMP) approach (9).

Statistical Analyses

Standard statistical methods were used to calculate the mean, *SD*, and *SE*. Group differences were analyzed using a 1-way analysis of variance (1-way ANOVA), and within-group differences (group-by-training interaction) were analyzed using repeated ANOVA measures. Differences between PRE vs. POST were reported as absolute values; the estimate precision was considered as 90% for confidence limits and effect size (*d*), and the benchmark for significance was set at $p \leq 0.05$.

RESULTS

Before the training period, the subjects did not differ in terms of any measured variable. After the 8-week program, there were no significant changes in body mass, fat-free mass

(FFM), lower-limb FFM, fat mass, or percentage of body fat. The FST group showed a significant 12.9% increase ($p \leq 0.05$) in 1RM after training. In fact, pre-mean and post-mean values were 144.2 ± 35.8 and 162.5 ± 37.3 kg, respectively, whereas no significant differences were observed in the HIT and LIT groups (Figures 2 and 3).

Running economy improved significantly ($p \leq 0.05$) in the FST group (6.3%) at 75% of VT_1. The HIT and LIT groups did not show any significant improvements in RE.

All groups show significance improvement ($p \leq 0.05$) on performance +3.7% and +6.1% for FST, +3.8% and +5.8% for HIT, and +2.9% and +2.5% for LIT in average velocity on 2 and 10 km, respectively. All results concerning the pre-training and post-training variations are summarized in Tables 2–4.

Discussion

The results of this study indicate that recreational runners may obtain improvements in RE and neuromuscular adaptation by using the FST.

In our study, FST was performed concurrently with a low-intensity endurance training program over 8 weeks (FST) and then compared with 2 different equivalent endurance training programs based on high- and low-intensity exercises, respectively. The significant 12.9% increases in maximal dynamic strength (1RM) in the FST group is lower than that found in previous studies (23,24), but in our study, it was obtained with smaller intervention. The usefulness of increasing the maximal muscle force in a runner is a debated topic in the scientific literature. Several authors have obtained it with strength exercises in addition to endurance training, others through the use of specific plyometric exercises with a strong component of eccentric muscle strength (2,8,15,18,27–29). Also, in our data, the maximal dynamic force (1RM) increased in FST, contrary to the other 2 groups (HIT and LIT). This result could be justified by the plasticity of muscle fibers in accordance with the results obtained by Piacentini et al (24). However, regarding anthropometric measurements, we have not measured changes in FFM in lower limbs. This means that the gains in terms of strength of the FST group are not due to a structural change, but mainly to neural adaptations such as increased activation, a more efficient recruitment, motor unit synchronization, and excitability of the motor neurons or decreased Golgi tendon organ inhibition (13), in agreement with the results obtained by Taipale et al. (30) using plyometric training. In other words, flywheel training increases the capacity to store and reuse elastic muscle energy, and this seems to have a protective effect against muscle damage because of the intense activity of races. Consequently, there is a 6.3% decrease in RE in FST, confirming the strong relationship between muscle force and RE (10,19,20). This has never been demonstrated before and confirms our initial hypothesis that 1 session a week of 4 sets of 7 repetitions at maximum velocity on the flywheel leg press (Yo-Yo Technology AB) could significantly improve RE in recreational runners.

Both FST and HIT groups showed a significant increase in velocity related to $\dot{V}O_2$max of 6.0 and 4.7%, respectively. None of the 3 experimental groups showed a significant increase in $\dot{V}O_2$max values. A significant increase in velocities, correlated with the ventilatory thresholds, was found in all groups. These increases were 6.8 and 5.3% for the FST group, 5.5 and 5.9% for the HIT group, and 6.2 and 5.9% for the LIT group respectively for the velocity at VT1 and VT2. Millet et al. (20) obtained the same results in their study on 14 triathletes. The protocol consisted of a 14-week regimen based on concurrent endurance and strength training programs. The strength training was based on intensities near the maximal and low numbers of repetitions (20). Millet's study showed that it is possible to obtain an improvement in the velocity of VTs and $\dot{V}O_2$max without improving $\dot{V}O_2$max values due to adaptations that occur at the muscle level. This can be partially confirmed by analyzing the different intensities of the 3 training programs. Flywheel strength training and LIT training programs were based on the intensity of 100% of RV. The average 112% RV intensity is capable of arousing the appearance of $\dot{V}O_2$max. Intensities used for our study could not improve central physiological adaptations, which are very important for an increase in $\dot{V}O_2$max. Although the high-intensity intervals were achieved approximately at 130% of RV, the HIT group did not obtain any significant increase in $\dot{V}O_2$max values because of a reduced duration of the intervals (6,17). The 2 VTs, the first and the second, were determined at 95 and 105% of VR, respectively.

The participants of our study achieved significant improvements in 2 track tests consisting of 2,000- and 10,000-m runs. We can correlate the 10-km performance with the velocity at the second VT. Traditionally, amateur athletes running at this intensity achieve the best results at this distance. This is confirmed with the 0.91 correlation between the 10-km performance and the value corresponding to the value of the second VT determined by laboratory testing. This interpretation cannot be verified in the 2,000-m tests. On the contrary, this test should measure results that are easily associable with improvement in $\dot{V}O_2$max. The significant increase in average velocity during field test on 2,000 m did not bring the same increase in $\dot{V}O_2$max values. By collecting feedback from the athletes at the end of the 2,000-m run, we found that the trial was hard to manage in terms of intensity, distance, and duration. Amateur runners are not used to maximal efforts mainly because they tend to run races of 10 km or more and therefore never run at the intensity close to their maximal. Furthermore, this type of sport often makes runners fear that they will not be able to finish the race. This fear could prevent athletes from achieving their possible maximum performance.

The results connected to endurance performance demonstrate that FST and HIT groups have similar improvements although the subjects of FST group improved their RE. The 2- and 10-km performances are mainly connected to the $\dot{V}O_2$max and the running velocity connected to the anaerobic threshold, while RE alters the performance lasting more than 1 hour.

The results of this study indicate in recreational runners a specific sensitivity to including muscle strength components in training as in HIT and in particular in FST. Flywheel strength training allows to improve functional abilities as RE and 1RM. This is attributable to a development in muscle strength, in particular because of the eccentric component. It is to be regarded as one of the determining factors of RE in endurance performance. The benefits in RE obtained by FST are, as known, proportional to effort duration and as found no different to HIT for 2 km, slightly better in 10 km and probably much better for long-distance runs.

Eight weeks of once-a-week training was an effective stimulus to induce adaptations, and therefore, it should be taken into consideration in the training programs of amateur athletes.

Practical Applications

The results of this study have shown the exercises with eccentric (or combined) components as compatible with training programs in recreational runners. They have been shown to improve RE and strength that can enhance performance. Therefore, strength-enhancing exercises with eccentric and concentric components should be considered by athletic trainers for training programs of recreational runner.

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