

TARGET-FLOW INSPIRATORY MUSCLE TRAINING IMPROVES RUNNING PERFORMANCE IN RECREATIONAL RUNNERS: A RANDOMIZED CONTROLLED TRIAL

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Abstract: Inspiratory muscle training (IMT) has been shown to possibly improve exercise performance, but reports on IMT and running performance are rare. The objective of the present study was to examine the effect of target-flow IMT on running performance in recreational runners. Sixteen healthy recreational runners (five females) were recruited for the present study. They were randomly allocated into either an experimental or control group. Participants in the experimental group underwent a 6-week target-flow IMT programme, while those in the control group underwent a 6-week shoulder circumduction exercise programme. Running performance during a 1,500-m time trial run was assessed before and after the intervention period. After the intervention period, only the experimental group demonstrated an increase in inspiratory muscle strength (by 16.15 ± 7.44 cmH₂O; $p < 0.05$) and reduced completion time in the 1,500-m time trial (by 9.63 ± 5.42 seconds; $p < 0.05$). Exertion sensation was reduced by 1.63 ± 0.74 points ($p < 0.05$). No changes were observed in maximal aerobic capacity and pulmonary function in either group after the intervention period. A 6-week target-flow IMT programme enhanced running performance in recreational runners.

Key words: inspiratory, muscle, running, target-flow, training

Introduction

Intensive physical activity, such as endurance running, leads to an increase in ventilation and work of breathing, and oxygen consumption can increase by as much as fivefold [1]. Trained athletes engaged in endurance running require a maximal aerobic capacity ($\dot{V}O_{2\max}$) of $61\text{--}73$ mL O₂ · kg⁻¹ · min⁻¹ [2]. Respiratory muscles play an important role in the maintenance of adequate alveolar ventilation for high-demand oxygen consumption [1]. During intensive running, the increase in respiratory muscle work may account for 15% of the total oxygen consumption in trained athletes [1], thereby reducing

the amount of oxygen available for skeletal muscles and reducing performance, resulting in a decline in running speed.

Common methods used to improve running economy are altitude exposure and strength training [3]. Inspiratory muscle training (IMT) has recently been incorporated into training programmes for athletes to improve their endurance performance [1]. Historically, IMT has been used as part of a pulmonary rehabilitation programme for patients with respiratory problems to reduce work of breathing and improve exercise tolerance and performance [4,5]. Volianitis et al [6] adopted an 11-week inspiratory resistive training programme using a



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threshold loading device, which imposed a training load of 50% of maximal inspiratory pressure (P_{imax}), for 30 repetitions twice daily. Competitive rowers improved their inspiratory muscle strength by 45.3%, shortened completion time in a 5,000-m trial by 3.1%, and showed a significant reduction in dyspnoea perception [6]. Isocapnic hyperpnoea, which required athletes to breathe against a respiratory load at a target ventilatory rate and maximal tidal volume, was shown to improve respiratory muscle endurance and shortened a cycling trial time by about 5% [7]. This training required a complicated apparatus and a training programme that required the athletes to breathe at maximal ventilatory effort for 30 minutes each session.

Compared with isocapnic hyperpnoea training, inspiratory resistive training is a convenient and inexpensive training method that is more suitable for recreational athletes in a metropolitan environment. Inspiratory resistive training adopting a constant target-flow device allows training at a high intensity level and can provide a reliable resistive loading of the inspiratory muscles. The effect of IMT in the form of inspiratory resistive training on running performance, however, has not been explored. The research question asked in this current study is whether target-flow IMT improves endurance running performance in recreational runners.

Methods

Design

This study adopted a randomized, placebo-controlled, pretest and post-test design. Prior to data collection, the study protocol was approved by the human subjects ethics committee of the involved university. The study procedures were explained to each subject, and informed consent was obtained prior to data collection. The subjects were then randomly assigned to either the experimental (IMT group) or control (shoulder exercise) groups. Randomization was done by asking the patient to draw a sealed opaque envelope that contained the allocation. One investigator was responsible for application of interventions, and data entry was performed by an assistant who was blinded to the subject group. The design is outlined in Figure 1.

Participants

Healthy recreational runners without known cardiopulmonary or musculoskeletal disorders and who had been participating in running sessions less than four times per week, with a weekly running distance less than 20 km, were invited to participate in the study [8]. Exclusion criteria included cardiopulmonary or musculoskeletal disorders, previous experience with IMT, or a running distance of more than 20 km per week. All subjects were instructed to maintain their usual running habits

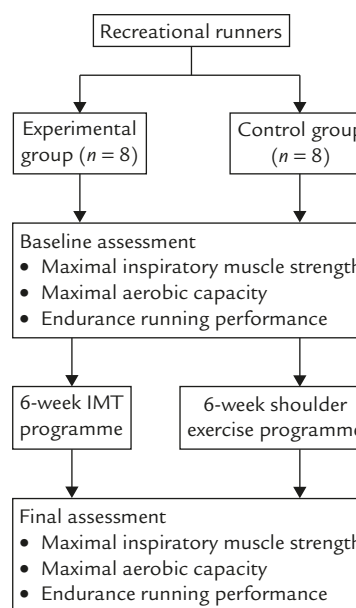


Figure 1. Flow chart of the study procedures. IMT = inspiratory muscle training.

throughout the study and were told they would be randomized into one of two training programmes.

Outcome measures

Prior to commencement of the training protocol, all subjects were invited to the laboratory for measurement of P_{imax} and maximal aerobic capacity ($\dot{V}O_{2max}$). They were also asked to perform a 1,500-m trial run. All measurements were repeated after 6 weeks.

Maximal inspiratory muscle strength test

The P_{imax} of each subject was measured by applying the American Thoracic Society guidelines [9]. The measurement circuit consisted of an inspiratory muscle trainer (DHD 22-7500; DHD Healthcare, Wampsville, NY, USA) and a pneumotachograph (RSS 100HR; Hans Rudolph, Shawnee, KS, USA) (Figure 2). The subject breathed in through the circuit three times, and the highest inspiratory pressure of the three trials was recorded as the P_{imax} of the subject.

Submaximal treadmill stress test

Subjects were asked to run on a treadmill (RunRace; Technogym, Gambettola, Italy), following the modified Bruce treadmill protocol [10] until they attained one of the following criteria for termination of the test: (1) subject experienced symptoms such as shortness of breath, which prevented them from continuing the test; (2) heart rate reached 85% of their predicted maximal heart rate; (3) respiratory exchange quotient reached 1.15; or (4) oxygen consumption increased less than 100 mL·min⁻¹ despite an increase in exercise intensity [11,12]. Heart rate was monitored by the Polar heart rate monitoring system (Polar S610i; Polar Electro, Kempele, Finland), and oxygen consumption was measured by a portable

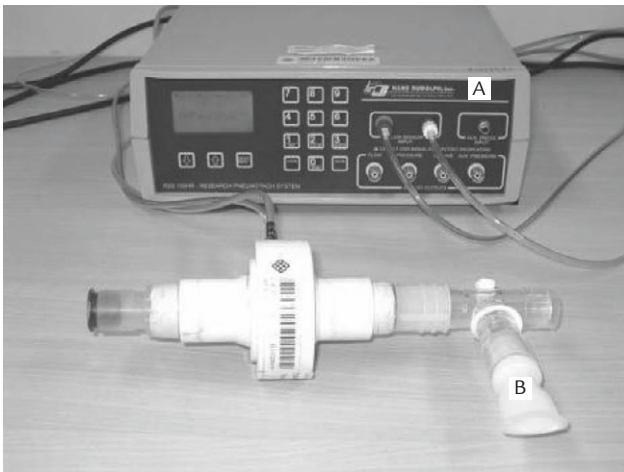


Figure 2. Circuit for determination of maximal inspiratory pressure. A=pneumotachograph; B=inspiratory muscle trainer.

breath-by-breath gas analysis system (K4b²; Cosmed, Rome, Italy).

1,500-m time trial run

Subjects were asked to run 15 times over a 100-m path in a park as fast as they could manage to attain the shortest time to complete this running task. The time required to complete the 1,500-m trial run (T1500) was recorded. A 20-point Borg scale was used to record the participant's subjective feeling of degree of exertion (RPE) at the end of the timed trial run. Heart rate (by Polar heart rate monitor) and oxygen consumption (measured by the K4b² system) were also measured during the timed trial run. Data recorded during the last minute of the run were averaged and subjected to analysis.

Intervention

Subjects allocated to the experimental group were given a dedicated IMT device composed of an inspiratory muscle trainer (DHD 22-7500; DHD Healthcare) and an incentive spirometer (Hudson lung volume exerciser; Hudson RCI, Durham, NC, USA) (Figure 3). They were asked to breathe in through the training device incorporating a designated resistance disc at an inspiratory flow that kept the ball at the top of the Hudson lung volume exerciser for at least 1 second (Figure 4). The level of inspiratory resistance was expressed as percentages of Pimax. All subjects commenced at 80% of their Pimax (determined at the laboratory). Subjects were asked to follow the protocol and breathe with the training device for 30 breaths at set inspiratory resistance twice a day for 6 weeks. To maximize training effect, training resistance was progressed from 80% Pimax for the first 2 weeks and to 90% Pimax for the remaining 4 weeks.

Subjects in the control group were instructed to complete a 6-week shoulder circumduction programme. Shoulder circumduction exercise was chosen, because

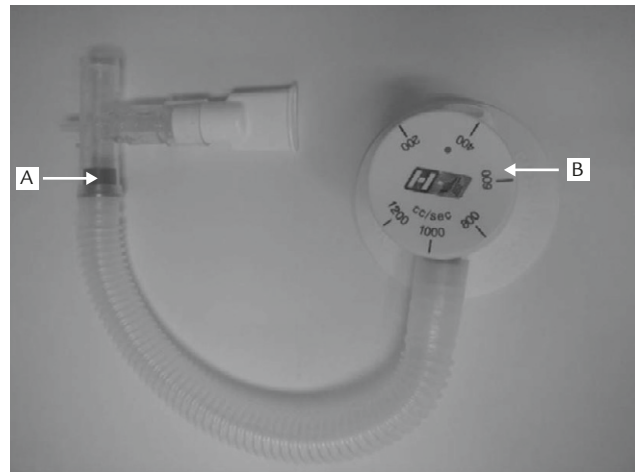


Figure 3. Set-up of the target-flow inspiratory muscle training system. A=resistor; B=incentive spirometer.



Figure 4. Side view of the incentive spirometer (Hudson lung volume exerciser). Indicator to be kept at the ceiling position for at least 1 second during training.

it induces respiratory resistance of less than 15% Pimax and has a negligible training effect on inspiratory muscles [6]. Subjects were asked to perform shoulder circumduction exercise for 30 repetitions twice a day for 6 weeks.

All subjects were instructed to maintain their running habit as usual throughout the study. They were given a logbook to record this exercise during the 6-week intervention period. Training frequency was also recorded in another logbook. A weekly phone call was made to monitor each subject's training compliance.

Data analysis

The study reported by Volianitis et al [6] produced a mean between-group difference of 15 seconds with a standard deviation of 7. Using an α value of 0.05 and a study power of 0.8 and allowing for a 10% drop-out rate, a sample size with six subjects in each group was considered appropriate. Independent *t* tests were used to analyse the between-group demographic and baseline

measurement data. Analysis of covariance was used to determine the effect of intervention by comparing post-training scores between groups with pre-training scores as covariates. Pearson correlation was also performed to identify the relationship between changes in inspiratory muscle strength and running performance. The significance level for all tests was set at 0.05, and data are expressed as mean (standard deviation). All data were analysed by Statistical Package for the Social Sciences version 12.0 (SPSS Inc., Chicago, IL, USA).

Results

Sixteen healthy subjects (11 male and 5 female) were recruited with a mean age of 26.00 ± 2.68 years, height of 1.67 ± 0.10 m, and weight of 59.06 ± 8.43 kg. The sex distribution (male to female ratio) for the experimental and control groups was 5:3 and 6:2, respectively. No subject withdrew from the study. There were no significant differences between group demographic variables or baseline measurements. Data in both groups were homogenous for comparison (Table 1).

Changes in Pimax

After the intervention period, Pimax in the experimental group increased by 16.15 ± 7.44 cm H₂O (95% confidence interval [CI], 9.93–22.37). No significant change in Pimax was noted in the control group. Compared with the control group, Pimax increased by 12.65 cm H₂O (95% CI, 5.80–19.71) after 6 weeks of IMT (Table 2).

Changes in running performance

T1500 decreased by 9.63 ± 5.42 (95% CI, 5.1–14.2) seconds, and RPE decreased by 1.63 ± 0.74 points (95% CI, 1.0–2.2) in the experimental group after 6 weeks of IMT. The oxygen consumption during the last minute of the 1,500-m run decreased by 4.14 ± 2.66 mL O₂ · kg⁻¹ · min⁻¹ (95% CI, 1.9–6.4) in the experimental group. No significant changes in T1500, RPE, and oxygen consumption were noted in the control group. As for the ventilatory system performance during running, no group had

Table 1. Demographic variables of the participants*

Demographic variables	EXP (n=8)	CON (n=8)
Age (yr)	26.13 (1.36)	25.88 (3.68)
Body weight (kg)	58.75 (9.93)	59.38 (7.33)
Height (m)	1.67 (0.10)	1.67 (0.11)
BMI (kg/m ²)	20.97 (1.85)	21.35 (2.27)

*Data are presented as mean (standard deviation). EXP=experimental group; CON=control group; BMI=body mass index.

Table 2. Mean (standard deviation) score, mean (standard deviation) difference within groups, and mean (95% confidence interval) difference between groups for all outcomes for the experimental group (EXP; n=8) and the control group (CON; n=8)

Outcome	Pre groups		Post groups		Difference within groups (post minus pre)		Difference between groups (post minus pre)*
	EXP	CON	EXP	CON	EXP	CON	
	EXP	CON	EXP	CON	EXP	CON	EXP minus CON
Pimax (cmH ₂ O)	79.45 (10.48)	80.36 (9.80)	95.60 (10.41)	83.75 (13.07)	16.15 (7.44)	3.39 (4.63)	12.65 [†] (5.80 to 19.71)
T1500 (s)	477.25 (45.58)	470.00 (53.95)	467.63 (46.09)	467.88 (56.88)	-9.63 (5.42)	-2.13 (3.72)	-7.74 [‡] (-12.63 to -2.85)
RPE (0 to 20)	17.00 (1.31)	16.50 (1.20)	15.38 (1.189)	16.38 (0.92)	-1.63 (0.74)	-0.13 (0.84)	-1.33 [†] (-2.09 to -0.57)
VO ₂ (mL O ₂ · kg ⁻¹ · min ⁻¹)	41.93 (3.74)	38.77 (8.05)	37.79 (5.47)	37.64 (9.39)	-4.14 (2.66)	-1.13 (3.07)	-3.47 [‡] (-6.64 to -0.31)
VE (L · min ⁻¹)	94.40 (20.75)	85.85 (14.98)	95.98 (19.66)	90.98 (22.78)	1.58 (9.49)	5.13 (11.38)	-3.76 (-15.86 to 8.35)
VE/VCO ₂	31.59 (3.43)	30.67 (2.19)	32.33 (4.83)	31.40 (3.00)	0.74 (4.47)	0.73 (2.04)	0.24 (-3.636 to 4.11)
VO _{2max} (mL O ₂ · kg ⁻¹ · min ⁻¹)	50.11 (4.85)	45.61 (7.81)	49.31 (8.16)	47.63 (12.08)	-0.80 (6.65)	2.02 (8.14)	-3.29 (-12.14 to 5.5)

*ANCOVA used for between group comparisons with baseline scores as covariate; †denotes a statistical significance at $p < 0.01$; ‡denotes a statistical significance at $p < 0.05$. Pimax = maximal inspiratory pressure; T1500 = time to complete a 1,500-m run; RPE = perceived exertion; VO₂ = oxygen consumption during the 1500-m run; VE = minute ventilation; VCO₂ = volume of exhaled carbon dioxide; VO_{2max} = maximal aerobic capacity.

Table 3. Correlation matrix among the changes in running performance and inspiratory muscle strength

	δT_{1500}	$\delta MRPE$	$\delta \dot{V}O_2$
δP_{imax}	-0.737*	-0.819*	-0.231
δT_{1500}		0.566 [†]	0.158
$\delta MRPE$			0.512 [†]

*Statistical significance at $p < 0.01$; [†]statistical significance at $p < 0.05$. δ =change of variables before and after the 6 week intervention period; T_{1500} =time to complete a 1,500-m run; $MRPE$ =mean rate of perceived exertion; $\dot{V}O_2$ =oxygen consumption during the 1500-m run; P_{imax} =maximal inspiratory pressure.

a significant change in minute ventilation ($\dot{V}E$) and ventilatory efficiency ($\dot{V}E/VCO_2$) after 6 weeks of IMT (Table 2). When degree of improvement of the experimental group was compared with the control, T_{1500} was reduced by 7.74 seconds (95% CI, 2.85–12.63), RPE was reduced by 1.33 points (95% CI, 0.57–2.09), and oxygen consumption was reduced by 3.47 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ (95% CI, 0.31–6.64; Table 2).

Changes in maximal aerobic capacity

No significant change in $\dot{V}O_{2max}$ was found in either group after the intervention period (Table 2).

The results of this study showed that improvement in inspiratory muscle strength (δP_{imax}) was positively correlated with the reduction in completion time (δT_{1500}) and RPE (δRPE). Furthermore, reduction in RPE (δRPE) was associated with a reduction in oxygen consumption ($\delta \dot{V}O_2$) and completion time (δT_{1500} ; Table 3).

Discussion

This study showed that a 6-week target-flow IMT programme improved P_{imax} and running performance in terms of a reduced time to complete a 1,500-m trial run. We speculate that the improved performance was related to improved respiratory muscle strength. The use of a target-flow inspiratory resistive device was aimed at overloading the inspiratory muscles. We hypothesized that this form of respiratory muscle loading would increase the proportion of type I fibres within the muscle cells, leading to increased inspiratory muscle strength [13]. The association between improvement in running performance and inspiratory muscle strength (as reflected by the improved P_{imax}) in the present study was, therefore, anticipated.

A previous study showed that subjects who received 4-week voluntary isocapnic hyperpnoea (VIH) training were found to have reductions in VE and oxygen consumption during running [13]. The authors suggested that reduction in work of breathing through a decrease

in VE accounted for the lowering of oxygen consumption during running. However, a study conducted by Harms et al showed that changes in work of breathing did not have an effect on the change of VE during exercise [14]. Furthermore, we cannot demonstrate any change in VE or ventilatory efficiency during exercise after IMT in the current study. Thus, reduction in oxygen consumption during running is not related to the change of VE or ventilatory efficiency alone.

IMT was proven to be effective in enhancing exercise performance in individuals [4,5]. The use of “proportional-assist” ventilation to unload the respiratory muscles during exercise could decrease the work of breathing and improve leg muscle perfusion [14]. IMT was also shown to attenuate the effects of vasomotor change in limb muscles (i.e. reduction in blood flow and acceleration of fatigue in muscle) at the same exercise intensity [15]. From the findings of these two studies, improvement in exercise performance after IMT could be a consequence of improved blood flow to working locomotor muscles and could delay the onset of peripheral muscle fatigue. After IMT, improvement in blood flow to skeletal muscles delays the onset accumulation of lactic acid and fatigue in working muscles. As a consequence, subjects can complete the running trial earlier by running at a higher speed for a longer duration. Unfortunately, the effect of IMT on blood flow and circulatory metabolites, such as blood lactate levels and peripheral vascular resistance, was beyond the scope of the present study. Future study is highly recommended to investigate the effect of IMT on this area.

The role of IMT in improving exercise performance has already been reported [6,16,17]. These studies adopted a similar training intensity of 50% P_{imax} for 30 repetitions, twice per day, which effectively enhanced inspiratory muscle strength as reflected by an 8–45% improvement in P_{imax} . The largest improvement (45.3%) appeared to be associated with the programme of longest duration (11 weeks) [6]. A 5-week programme induced an improvement of 8% [17]. The improvement of P_{imax} with our 6-week protocol was 20%, which was comparable to the 28% demonstrated by Romer et al [16]. The difference between our method and others was that we were able to adopt training at an intensity level of 80% P_{imax} during the first 2 weeks, which then increased to 90% over the last 4 weeks, while others used 50% P_{imax} throughout the training period.

The training device adopted in our study was different from others. We attached an incentive spirometer to an inspiratory resistive training system, making it a target-flow inspiratory resistive system. Both a target-flow IMT system and threshold loading device are convenient for implementation. Threshold loading devices available commercially are often designed for people with weaker lung function or with chronic pulmonary disorders. Often these devices offer a maximal training resistance of about

41 cm H₂O. With training intensity of 50% Pimax, a training resistance of 41 cm H₂O offered by these threshold loading devices is definitely insufficient to provide sufficient loading for improving inspiratory muscle strength in people of normal health, such as the participants in the current study with a mean Pimax of 81 cm H₂O or athletes with a higher Pimax reaching 130 cm H₂O [18]. The POWERbreathe (POWERbreathe, Warwickshire, UK) a device newly available, offers a higher training resistance for athletes but at a higher cost. The target-flow IMT system employed in this current study is economical and allows an easy progression to a high level of training intensity by simply increasing the inspiratory flow or inserting a resistor with smaller aperture.

Leddy et al [18] demonstrated that 4 weeks of progressive VIH training improved running performance, as reflected by a reduction in completion time by 1.2 minutes (4.1%) in a 4-mile time trial test, and an increase in breathing endurance, as reflected by an incremental increase in maximal voluntary ventilation of 19 L · min⁻¹ (10%) [18]. The authors considered the improved performance a result of improved ventilatory muscle endurance. This current study revealed an improvement of 2% in running performance and 20% improvement in inspiratory muscle strength after 6 weeks of training using the target-flow IMT device. Direct comparison with the findings of Leddy et al [18] is not appropriate, because the training methods and measured variables were different, although a similar pattern of improvement was observed. Isocapnic or normocapnic hyperpnoea training is usually carried out in the laboratory setting. It involves the use of a gas analysis system, oxygen infusion set-up, and a rebreathing system for monitoring and maintaining constant levels of carbon dioxide and oxygen in the body. Furthermore, an experienced person is required to supervise the training session throughout. In stark contrast, the use of the target-flow IMT system in the current study only involves the use of an inspiratory muscle trainer and an incentive spirometer. Supervision of training with the target-flow IMT system is unnecessary. Although the level of performance improvement was higher with VIH training (4%) compared with the 2% achieved by target-flow IMT, the low-cost set up of IMT adopted in this study appeared to be cost-effective when compared with the more expensive and complicated VIH system.

The relationship between RPE and Pimax or RPE and oxygen consumption has been established in previous studies [16,18]. This current study supports improved performance and Pimax and a reduction of RPE and rate of oxygen consumption during running with the use of an IMT as a training aid. The reduced rate of oxygen consumption in the experimental group suggests a greater running economy, and thus it was not surprising that those subjects felt they experienced a lower level of exertion.

Our 6-week target-flow IMT programme did not improve maximal aerobic capacity in our recreational runners. Maximal aerobic capacity of an individual is limited by several physiological factors, including the diffusing capacity of the pulmonary system, maximal cardiac output, oxygen carrying capacity of the blood, and properties of skeletal muscles [19]. Improvement in these physiological factors cannot be achieved through an improvement in inspiratory muscle strength alone. The American College of Sports Medicine recommends 20–60 minutes of continuous aerobic activity, such as swimming and jogging, for 3–5 days per week at an exercise intensity of 55–90% estimated maximal heart rate as being appropriate for fitness training of the cardiovascular system [20]. Our IMT protocol targeted muscle training rather than aerobic exercise, and each subject's personal training pattern was standardized to less than four times and no more than 20 km per week. An improvement in aerobic capacity was, therefore, not expected, and this correlates with the work of Sonetti et al [17], who showed that 5 weeks of IMT did not improve $\dot{V}O_{2max}$. Inspiratory resistive training has been suggested to be able to alter breathing mechanics and attenuate oxygen cost as well as blood lactate [21], and the effect of IMT on ventilation and metabolism warrants further investigation.

Limitations of the study

Because of a facility limitation, running was undertaken back and forth along a 100-m pathway 15 times, rather than around an oval track. Extra time was necessary for deceleration and turning. Furthermore, our subjects did not want to be seen wearing a face mask and K4b² system on a public running track. To permit proper comparison, future studies should adopt a proper 400-m oval track. Another limitation of this study was that we did not measure the humidity and temperature of the park during the conduct of the trial; however, measurements were conducted at the same time of the evening 6 weeks apart, and the external environment appeared similar.

Conclusion

This study demonstrated that a 6-week target-flow IMT programme can improve running performance in recreational runners. Analysis of blood lactate and blood flow to locomotor muscles with the use of a 400-m oval running track should be adopted in future studies.

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