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EFFECTS OF INTERVAL TRAINING-BASED GLYCOLYTIC CAPACITY ON PHYSICAL FITNESS IN RECREATIONAL LONG-DISTANCE RUNNERS

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ABSTRACT

Purpose. The aim of this study was to investigate the influence of 8-week-long interval training (targeting glycolytic capacity) on selected markers of physical fitness in amateur long-distance runners. **Methods.** The study involved 17 amateur long-distance runners randomly divided into an experimental (n = 8) and control (n = 9) group. The control group performed three or four continuous training sessions per week whereas the experimental group performed two interval running training sessions and one continuous running training session. A graded treadmill exercise test and the 12-min Cooper test were performed pre- and post-training. **Results.** $\dot{V}O_2$max and the rate of recovery increased in the experimental group. Relative oxygen uptake, minute ventilation, and heart rate speed decreased in low- (6 km/h) and medium-intensity (12 km/h) running. **Conclusions.** Both training modalities showed similar results. However, the significant differences in training volume (4–8 min interval training vs. 40–150 min continuous training) indicates that the modalities targeting glycolytic capacity may be more efficient for amateur runners prepare for long-distance events.

Key words: physical endurance, endurance training, interval training, maximal oxygen uptake, long-distance running

Introduction

There is a growing number of recreational runners involved in competition, such as in the world's most famous marathons in New York, Berlin, Chicago, or London [1, 2]. Running is a sport with no age or sex restrictions and unburdened by technical demands. In fact, the largest barrier to participation among working individuals is the time needed for regular exercise [3].

Of critical importance in long-distance running events such as the 10 km or marathon is meeting the body's energy demands. In such prolonged exercise, energy needed for the resynthesis of ATP is met primarily by aerobic processes that involve muscle glycogen and lipids [4]. The proportion of energy derived by aerobic ATP production increases with running distance (and therefore time), amounting to 97% in 10 km runs and 99% in marathons [4], whereas anaerobic pathways provide the remaining energy. The main factors behind performance in endurance events are maximal oxygen uptake ($\dot{V}O_2$max), the level of metabolic thresholds, anaerobic capacity, and efficiency [5]. The first three factors are determined by the time in which a certain level of aerobic and anaerobic metabolism can be maintained during exercise. The last defines what speed (or power) can be generated at a given level of oxygen consumption.

Maximal oxygen uptake is an excellent marker of aerobic capacity, as it reflects a series of physiological responses that directly influence work rate [6]. It is also an important factor in effectively negating the oxygen debt during post-exercise recovery [7]. According to Fick [8], $\dot{V}O_2$max is bound by the arteriovenous oxygen difference and cardiac output, itself determined by heart rate and stroke volume. In untrained populations, $\dot{V}O_2$max is significantly lower than in elite athletes [5]. The highest values of $\dot{V}O_2$max are achieved within 3–5 min of maximal activity and steadily decrease as exercise is continued. In running, the 10 km distance is performed at approximately 90–95% $\dot{V}O_2$max whereas the marathon was found to be run at approximately 75–85% $\dot{V}O_2$max. In such prolonged efforts, of critical importance are overall running economy, the body's ability to oxidize fat to meet the energy demands of muscle. the efficient utilization of lactate, and removal of fatiguing metabolites (H^+) [5].

Regular physical exercise can increase physical fitness. Costill [9] defined physical training as a conscious and targeted effort in developing an attribute of physical movement (whether health- or skill-related) that can be measured most easily in competition. The structural and functional effects of physical training depend on a myriad of factors, including the type of training stimulus and its frequency, intensity, and duration [4, 10], rest intervals, and the duration and type of recovery between training sessions [11, 12].

Among professional athletes, improving aerobic capacity is mainly determined by the adopted training intensity [13, 14]. While recreational athletes most commonly use a continuous training protocol at low or moderate intensity, Chtara et al. [15] and Friedlander et al. [16] confirmed that continuous training, also known as endurance exercise, contributes to increased at such

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low or moderate intensities in untrained populations. The literature also shows that individuals who regularly train in endurance sports such as cycling, marathon running, or cross-country skiing show improved pulmonary ventilation (via higher tidal volume and lower breathing frequency) in submaximal efforts [17].

Developments in exercise strategy have seen interval training becoming a widely adopted training modality in numerous sports, as it allows individuals to train at higher intensities while reducing exercise duration. Its defining feature is that it does not allow for full recovery, where subsequent repetitions of exercise are performed at increasingly higher levels of fatigue and lower blood pH [18]. According to Zatoń and Bugajski [19], the purpose of interval training is to augment the body's ability to tolerate exercise-induced metabolic acidosis while maximizing anaerobic glycolytic mobilization. Besides improved glycolytic capacity, interval training is believed to more effective in improving maximal oxygen uptake than continuous training [20–25]. Numerous studies [25, 26] have confirmed increased $\dot{V}O_2$max as a result of interval training, the effect of elevated cardiac output in terms of heart rate and stroke volume as well as increases in capillary blood flow, vascular conductance, arteriovenous oxygen difference, and mitochondrial enzyme activity. In addition to the above, research [21, 23] has credited interval training with increasing muscle glycogen stores, improving blood buffering capacity and work efficiency (lower $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$, respiratory quotient, and heart rate levels during non-maximal exercise), decreasing glycogen utilization in endurance efforts, lowering blood lactate in steady-state prolonged exercise, expanding chemoreceptor sensitivity to changes in blood hydrogen ion and potassium concentrations as well as carbon dioxide tension, increasing minute ventilation and the rate of expired carbon dioxide during exercise, and also developing oxygen uptake at the lactate threshold. Improved global oxygen delivery also correspond with changes in muscle fiber, in which type I fibers have greater oxidative capacity than IIa and IIx fibers. Interval training, by affecting glycolytic capacity, may also lead to increased mitochondrial activity in type II fibers and thus show characteristics similar to those of type I fibers [5]. Of considerable implication is the fact that endurance training is known to reduce maximum heart rate (HRmax) [27], which is one of the factors determining maximal oxygen uptake according to Fick's equation [8]. However, by exercising with repeated maximal efforts, as is present in interval training, it is possible to maintain a high HRmax. Combined with increased stroke volume, this allows for improved cardiac output and consequently $\dot{V}O_2$max [21].

This increase in absolute oxygen consumption as a result of such training stimuli introduces various adaptive changes, the most important of which is the ability to sustain a high running speed, even above 20 km/h, for long periods of time in long-distance events [5].

The effects of training on physical endurance capacity and other ergometric and physiologic variables can be assessed using various tests [28]. Depending on the studied variable, exercise testing can be direct or indirect. If conditions allow laboratory testing, a graded exercise test is most commonly performed to measure the contributions of the aerobic and glycolytic systems [29]. However, the expense and complexity of laboratory methods favors field tests such as the 12-min Cooper test, which was found to strongly correlate (0.92) with direct measurements of $\dot{V}O_2$max [30]. The Cooper test, in particular, offers an effective and low-cost alternative to estimating maximal oxygen uptake in the absence or infeasibility of other methods.

In light of the above, the aim of the present study was to investigate the influence of interval training (improving glycolytic capacity) on physical fitness in amateur long-distance runners and compare them against individuals who exercised using traditional continuous training.

Material and methods

The study recruited 17 male and female amateur long-distance runners preparing for a marathon race who belonged to a local running association. None of the participants had any competitive or professional experience with long-distance running and provided their informed consent to participate in the study. The sample was randomly divided into an experimental ($n = 8$; 3 women, 5 men) and control ($n = 9$; 3 women, 6 men) group. The characteristics of the groups are provided in Table 1.

Both groups were enrolled in an 8-week training program. Group E concentrated on glycolytic-based interval training, with two sessions held per week interspaced with a minimum of 48 hours of rest. At the end of the week (Sunday), this group ran with their running association approximately 20–30 km using continuous training. Each training session with preceded with a 15-min warm-up. The interval training sessions involved four 20–30 s repetitions of maximal intensity running (covering a distance of 90–200 m). Rest between each repetition was based on a 2:1 ratio of work to recovery and therefore ranged from 40 to 60 s. The number of sets performed ranged from 2 to 4, with 20 min of moderate intensity, varied active recovery provided between each set [31]. All exercise sessions were performed on a tartan track or running path. Distance covered in each repetition was recorded so as to compare subsequent repetitions in a set or the total distance within a set. If in either case work output decreased by 5% the training session was ended for that participant and a 5–10 min cool-down was performed. The total running time within a set (not including active recovery) ranged from 4 to 8 min. The control group continued to train as normal via continuous training. All of their training sessions were per-

Table 1. Anthropometric and performance characteristics of the control (C) and experimental (E) groups at study outset (± *SD*)

Group	Age (years)	Height (cm)	Mass (kg)	Training experience (years)	10 km time (min)	Marathon time (min)
E	34.25	176	76.3	2.1	47.5	238.7
	9.39	12	17.8	0.8	2.8	16.2
C	34.22	174	70.9	2.1	45	241.8
	15.95	7	10.3	0.9	5.5	13.2

formed together with the running association and lasted 40–150 min covering a distance of 8–30 km.

All participants completed two exercise tests pre- and post-training, the 12-min Cooper test and a graded exercise test, on two separate days (separated by a week) at a track and field stadium or at the Exercise Laboratory at the University School of Physical Education in Wrocław, Poland (PN-EN ISO 9001:2001 certified), respectively. On the day of the graded exercise test body composition and blood cell counts were also measured.

The Cooper test was performed on a 400 m tartan running track (Mondo, Italy) after the participants had been randomly divided into two groups outside of the initial division into experimental and control groups. Cones were set at 50 m intervals in order to help identify running distance and a whistle was used to mark the start and end of the 12 min. Each participant wore a S810 heart rate monitor (Polar Electro, Finland). Resting heart rate immediately after waking as well as maximal heart rate during the test and 5 min into recovery was recorded.

The graded exercise test was conducted on a SEG-TA7720 treadmill (InSportLine, Czech Republic). The conveyor belt was calibrated before testing by special computer software. Starting speed was 6 km/h and increased by 2 km/h every 3 min. Running speed was increased incrementally until volitional exhaustion or $\dot{V}O_2$max was reached, where no increase was noted despite an increase in running speed. Heart rate was recorded with the same heart rate monitor as before. Respiratory function was measured 3 min before the test and continued for 5 min after it was ended using a Quark b2 (Cosmed, Italy) metabolic analyzer on a breath-by-breath basis. Blood was drawn from the fingertip before the test during rest and 3 min after its completion. Acid–base balance variables, including blood pH and the partial pressures of oxygen (pO_2) and carbon dioxide (pCO_2), were analyzed using a RapidLab 248 blood gas analyzer (Bayer, Germany). Blood lactate (La^-) was controlled for using a LKM 140 lactate cuvette tester on a LP400 photometer (Dr. Lange, Germany).

All of the variables recorded during the graded exercise test were averaged over 30-second periods. was determined as the highest $\dot{V}O_2$max attained within an averaged 30-s interval. Relative values of %$\dot{V}O_2$max/kg and %HRmax were also calculated for data analysis by dividing the values obtained at 6 and 12 km/h by the maximums recorded in the graded exercise test. A rate of recovery (ROR) was calculated based on heart rate before and after the Cooper test [7].

Descriptive statistics for all variables were calculated. All calculations were performed using the Statistica 12.0 software package (StatSoft, USA) and Excel (Microsoft, USA) was used for data summary. The Wilcoxon signed-rank test means was used to compare the experimental (E) and control (C) groups. The significance level was set at α = 0.05.

Results

In both groups an increase in maximal oxygen uptake per kg of body mass was observed in post-training measures, from 49.48 ml/min/kg to 51.1 ml/min/kg in group E and from 51.98 ml/min/kg to 54.63ml/min/kg in group C (Figure 1). Pre- and post-maximal heart rate decreased slightly in group E but increased from 186 to 188 bpm in group C. Minute ventilation rose from 126.21 to 133.51 l/min and from 120.01 to 122.26 l/min in groups E and C, respectively (Figure 2). Increases were also noted in tidal volume, from 2.66 to 2.71 l in group E and from 2.26 to 2.35 l in group C. For the Cooper test, the distance covered also increased in both groups. Pre- and post-training results in group E were 2747.5 and 2783.8 m, whereas in group C they were 2757.8 and 2828.89 m, respectively. None of the above differences in either group were statistically significant. While the increase in ROR from 56 to 58 in group C, for group E participants the increase from 53 to 59.5 (Figure 3).

Pre- and post-training differences were also observed in the calculated relative measures. In group E, %$\dot{V}O_2$/kg relative to $\dot{V}O_2$max decreased from 45.62% to 41.03% and from 86.14% to 81.04% for running speeds of 6 and 12 km/h, respectively. In group C, /kg decreased from 52.84% to 43.89% at 6 km/h and from 84.27% to 80.02% at 12 km/h. Only the decrease at 6 km/h in the control group was significant (Figure 4). For %HRmax at 6 km/h, decreases were found both in group C, from 70.36% to 62.09%, and group E, from 67.18% to 60.89%. At 12 km/h these decreases were almost negligible, from 89.51% to 89.41% in group C, and from 88.74% to 89.28% in group E. Out of these decreases, only the one at 6 km/h in group C was statistically significant (Figure 5).

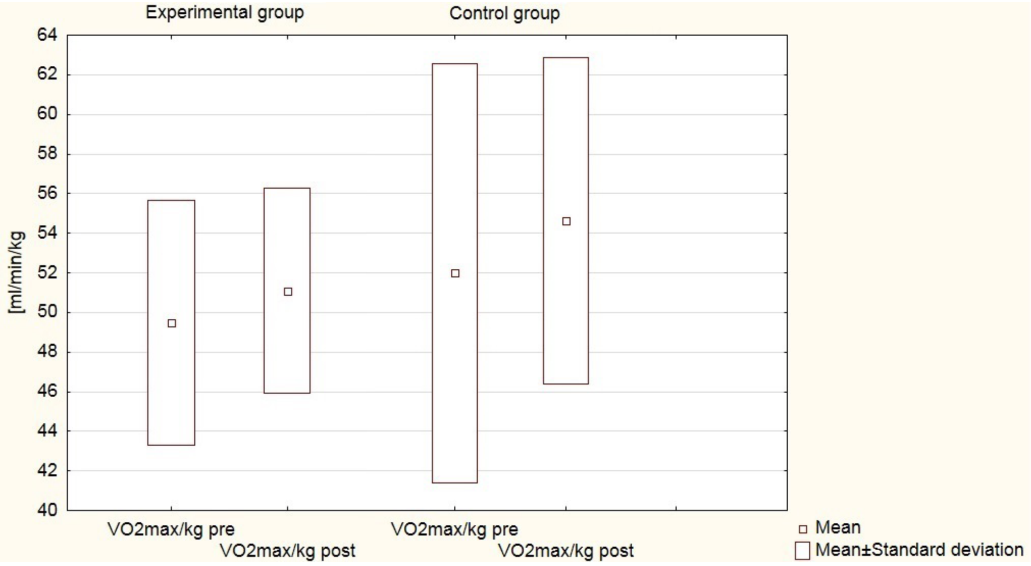


Figure 1. Graded exercise test pre- and post-training maximal oxygen uptake per kg of body mass per minute in groups E and C

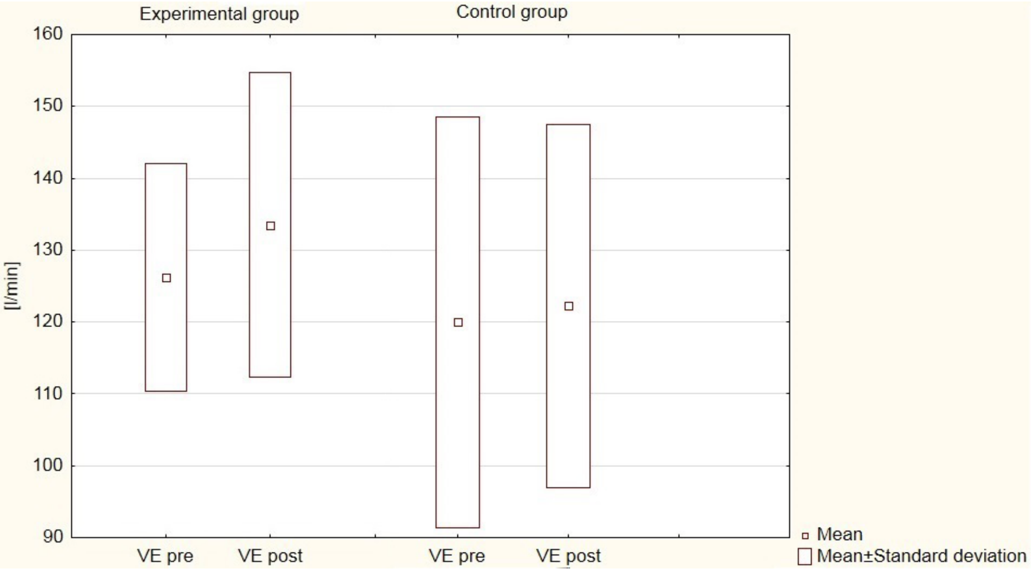


Figure 2. Graded exercise test pre- and post-training minute ventilation in groups E and C

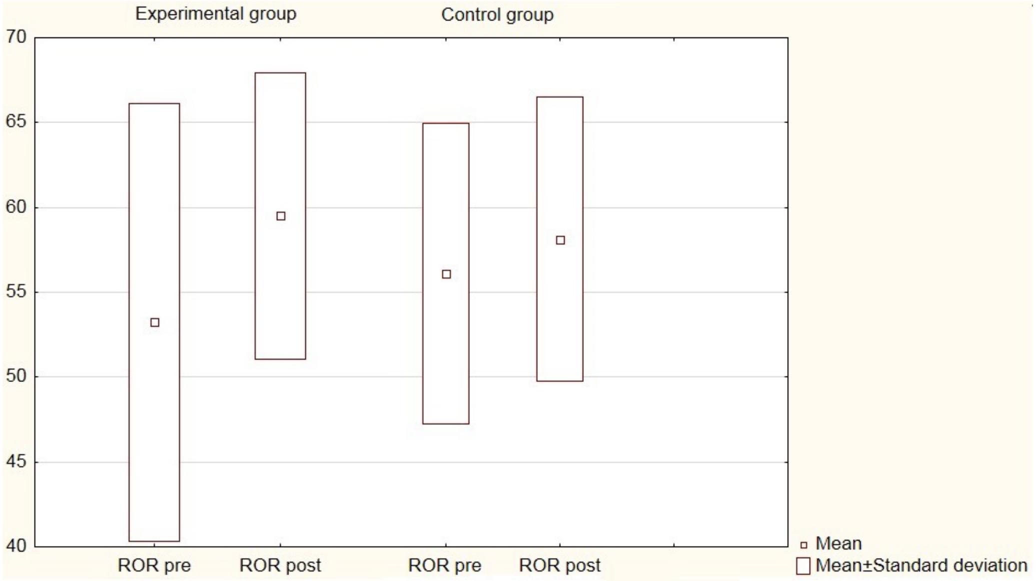
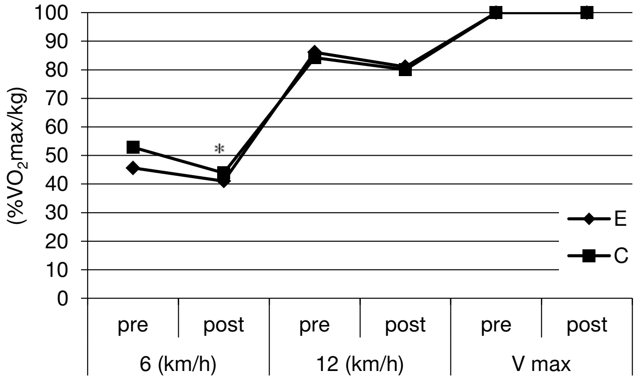
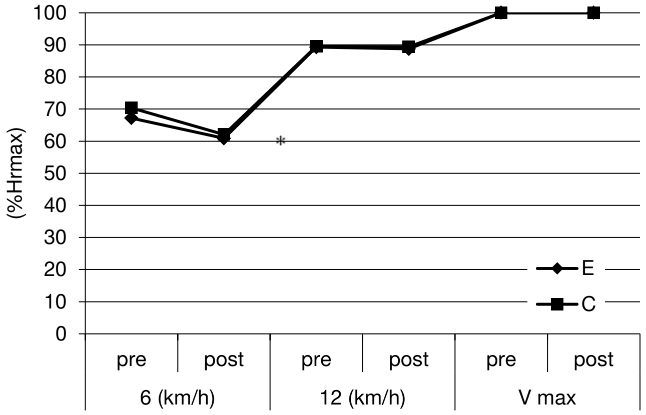


Figure 3. Cooper test rate of recovery (ROR) in groups E and C



* difference significant at $p < 0.05$

Figure 4. Pre- and post-training changes in relative maximal oxygen uptake per kg of body mass per minute at different running speeds in group E and C



* difference significant at $p < 0.05$

Figure 5. Pre- and post-training changes in relative heart rate at different running speeds in group E and C

Table 2. Graded exercise test acid–base balance characteristics pre- and post-training in groups E and C (± *SD*)

Group	Pre La$^-$	Post La$^-$	Pre pH	Post pH	Pre pCO$_2$	Post pCO$_2$	Pre pO$_2$	Post pO$_2$
E	11.1	10.85	7.17	7.21	32.94	34.93	87.3	85.34
	2.7	2.77	0.11	0.11	6.09	2.9	7.77	5.85
C	9.75	9.18	7.23	7.25	34.97	37.09	85.48	84.49
	3.41	3.33	0.08	0.07	2.38	3.43	6.95	5.84

Discussion

The results of our study indicate that the interval training protocol enhanced exercise capacity and post-exercise recovery as evidenced in the Cooper test. Similar functional improvements were reported by McKenna et al. [21] after 7 weeks of sprint interval training in untrained men. Their protocol involved 4 to 10 repetitions of 30-s maximal sprint cycling exercise separated by 4-min intervals. This rise in maximal oxygen uptake is credited to an increase in cardiac stroke volume and more efficient utilization of oxygen by skeletal muscle, inferred by the fact that the effects of training lead to a slight albeit observable decrease in maximum heart rate [5]. The latter adaptation of improved oxygen use is caused by higher muscle blood flow via increased capillary density as well as increased arteriovenous oxygen difference and mitochondrial enzyme activity [25, 26]. The lack of change in blood lactate content in the graded exercise test itself is indicative of improved buffer capacity and H+ clearance in working muscle [32], which is one of the main objectives of glycolytic-based interval training [19].

Of interest is that the present control group showed a greater increase in maximal oxygen uptake and tidal volume with a larger decrease in minute ventilation compared with the experimental group, although these differences were not statistically significant. The improvements of the above variables as an effect of endurance training at low and moderate intensities has been confirmed by numerous studies [15, 16, 33]. At the same time, we observed no reduction in maximum heart rate, itself associated with decreased sympathetic nervous system activity according to various sources [27]. Our results should be approached with caution largely due to the small sample size, which may have influenced the lack of statistically significant changes when comparing the absolute values in the experimental and control groups. However, relative maximal oxygen uptake and relative heart rate decreased in both groups in relation to the maximum values recorded in the graded exercise test. These differences were particularly evident during low-intensity effort (6 km/h), although only the decrease in the control group was significant. This effect nonetheless suggests improved movement economy in both groups, as lower relative values of oxygen consumption and heart rate (in relation to recorded maximums) were observed at an effectively similar workload.

The literature indicates that the magnitude of change in $\dot{V}O_2$max is dependent on various aspects that include, besides adaptations via oxygen transport and utilization, training intensity, duration, and frequency; overall physical fitness; and genetic factors [34]. Comparisons between different interval training and endurance training protocols have indicated greater increases in maximal oxygen uptake as a result of interval training [24]. For example, in Esfarjani and Laursen [24], a control group trained four times per week for 60 min at a speed corresponding to 75% of $\dot{V}O_2$max whereas their experimental groups performed a mix of interval and endurance training. Besides significant performance and physiological improvements noted in the experimental groups, 3000 m running time was also enhanced when compared with the control group. The authors concluded that such a training protocol results in improved aerobic and glycolytic capacity, which is consistent with the findings of Laursen et al. [22].

Burgomaster et al. [35] also compared interval training and traditional endurance training by drawing particular attention to the differences in training duration and volume. Their interval training group performed four to six maximal 30-s cycle ergometer bouts three times per week for 6 weeks; the endurance training group trained five times per week with 40–60 min of continuous cycling at 65% of VO_2max. When totaled, weekly training time in the former group was 1.5 hours versus 4.5 in the latter. Despite the large differences in training volume, the interval training group was found with similar positive training adaptations as the endurance training group, such as in increased oxidative capacity. A similar finding was reached by Gibala et al. [23], in which they administered a 2-week interval training protocol totaling only six training sessions. Burgomaster et al. [35] also noted no significant differences between their two groups in terms of glycogen utilization post-training after a 60 min constant load cycling test at 65% of , although they did demonstrate an increase in both the content and activity of enzymes responsible for beta oxidation, which was not observed in a previous study of theirs [36]. The results nonetheless suggest that the minimal time and volume component of interval training is enough to realize augmented metabolic adaptations such as by increased muscle lipid oxidation [35].

In light of the above, the similar changes we observed between the control and experimental group also need to be considered in terms of total exercise time. The present study involved 4 to 8 min bouts in one interval training unit, whereas the control group trained from 40 to 150 min. This reduction can make glycolytic-based interval training a far more attractive form of training by breaking away from the time-intensive and monotonous aspect of endurance training while providing similar improvements in aerobic and anaerobic capacity. The associated training adaptations make it a suitable modality when training for endurance events, such as marathon racing, and has been confirmed by numerous studies [35, 37]. At the same time, interval training may be an effective alternative for working individuals with limited time resources, it being one of the main barriers to performing regular physical activity in this population.

Conclusions

1. Interval training targeting glycolytic capacity develops physiological function similar to a traditional endurance training protocol in amateur long-distance runners.

2. This training modality increases maximal oxygen uptake, minute ventilation, tidal volume, distance covered in the Cooper test, and improves post-exercise recovery as well as running economy.

3. The low training volume (duration) of interval training make this form of training particularly important for individuals with limited time available for exercise.

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