Blood lactate and ventilatory responses to interval-and endurance-training in recreational runners

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Abstract.

The purpose of the present study was to compare threshold levels of blood lactate and ventilation after two different training programs of 9 weeks, that is, interval-run (IR) and endurance-run (ER). Twenty (20) recreational male runners from local running clubs volunteered to this study and completed maximal ramp cycle tests to determine maximal aerobic power (VO_2max) and blood lactate concentrations. Maximal cycle testing involved progressing in increments of 25 watts (W) every 2 minutes following a 4-min warm-up period at 0 W. The subjects were requested to maintain a pedaling frequency of 60 rpm. The test was continued till the subjects reached a point of exhaustion. After baseline tests, subjects were matched in terms of the VO_2max and placed in one of two training groups, an interval-run group (IR, mean age 40 years), and an endurance-run group (ER, mean age 41.7 years). Gas analysis was carried out every 20 sec for minute ventilation, oxygen consumption, carbon dioxide production using Metamax system. Calculation of ventilatory threshold (VT) employed the V-slope method. Blood samples were collected during exercise from the brachial vein for analyses of blood lactate using YSI 1500 Sport Lactate analyzer. The value of blood lactate concentrations corresponding to 4 mmol/L for determining the lactate threshold (LT) was chosen. After training, there were significant increases in VO_2max, the estimated LT-4 mmol/L, and VT in both groups. In addition, faster running performance of 10 km after a 9-week training program was observed in the IR and ER groups with no significant differences between the groups. However, the magnitude of the aforementioned improvements was greater in the IR than ER groups. Blood lactate concentrations in both groups lowered significantly at all given work rates after 100 W during the incremental graded exercise. However, the lactate concentrations at higher work rates were significantly lower in the IR than ER groups. It was concluded that both aerobic interval-training and endurance-training produce increases in performance and physiological parameters. However, it seemed that, for runners who are already trained, notable improvements in endurance performance can be achieved only through high-intensity interval training.

Maximal oxygen uptake (VO_2max) has been recognized as the most objective index for determining the potential of endurance exercise capacity[1]. In spite of the physiological significance of VO_2max, a wide variation in the relationship between VO_2max and running performance has been demonstrated[2]. A previous study[3] has shown that considerable variance existed in 10 km finish times between a group of highly trained runners with similar VO_2max which suggests that other variables must contribute to distance running success. Furthermore, it has been proposed that aerobic power is not the only determinant of endurance performance such as marathon race[4].

In highly trained subjects, endurance training at submaximal workloads does not appear to induce improvements in either endurance performance or corresponding physiological variables[5]. Traditionally, therefore, a training program for top runners has been emphasized both aerobic and anaerobic components. Runners can increase their maximal sustainable running speed by increases in the aerobic capacity with endurance-run training and in the anaerobic component with relatively fast speed-short distance training such as interval-run training.

The benefits of measuring blood lactate concentration to assess and improve aerobic capacity have been well documented[6,7]. It has been also suggested that metabolic parameters measured during submaximal exercise may be better indicators of endurance[8,9]. For this reason, the blood lactate response during submaximal run should be considered as an important indicator of endurance performance.

Marathon races in recent years have been in the stage where speed component is emphasized more than endurance component. A higher rate of running pace and a higher absolute rate of oxygen consumption without raising blood lactate above resting levels during marathon race are more beneficial to finish race faster.

The purpose of the present study is to determine the effect of interval training with regard to lactate threshold and ventilatory threshold in a group of recreational, but serious runners. In addition, the relationship between both thresholds and the performance times on 10000 m time trial was studied.

Materials and Methods

Subjects

The experiments were carried out in 20 male recreational runners from local running clubs who gave their informed consent. These subjects were pre-tested to establish baseline values for maximal oxygen consumption (VO_2max), lactate threshold (LT) and ventilatory threshold (VT).

After the baseline tests, subjects were matched in terms of the VO_2 max and placed in one of two training groups to achieve homogeneity between groups. One of the groups is an interval-run (IR) group and other is an endurance-run (ER) group.

Measurements

All subjects performed a maximal ergometric test (ramp protocol) on an electromagnetically braked bicycle ergometer. Exercise was performed on an electromagnetically braked cycle ergometer with the work rate controlled by microcomputer (Corival, Load). The cycle ramp test was initiated following 4-min unloaded warm-up at 0 W, and the work rate was then increased by 25 W every 2 min. The subjects requested to maintain a pedaling frequency of 60 rev/min. The test was continued till the subjects reached a point of exhaustion or could no longer maintain the pedaling frequency when the load was increased.

Metabolic parameters were recorded using a Metamax unit (Cortex

Ltd., Leipzig, Germany). A 20 min warm-up period was maintained for the equipment prior to each testing session. The turbine flow meter was calibrated with a 3-liter calibration syringe, and the O_2-and CO_2-sensors were calibrated either with room air and a calibration gas (16% O_2, 4% CO_2, 80% N_2) prior to each testing session. The respiratory measurements were taken continuously with an on-line computerized method. Minute ventilation (V_E), oxygen consumption (VO_2), carbon dioxide production (VCO_2) and respiratory exchange ratio (RER) were measured every 30 seconds. Heart rate (HR) was monitored employing a five lead electrocardiogram interfaced to the Metamax system. The samples of venous blood were withdrawn at rest and every 2 minutes during the tests for analyses of blood lactate. Blood samples were analyzed immediately for lactate concentration in duplicate using YSI 1500 Sport Lactate analyzer (YSI, Yellow Springs, Ohio, USA). The value of blood lactate concentration corresponding to 4 mmol/L for determining the lactate threshold (LT) was chosen following the indications of

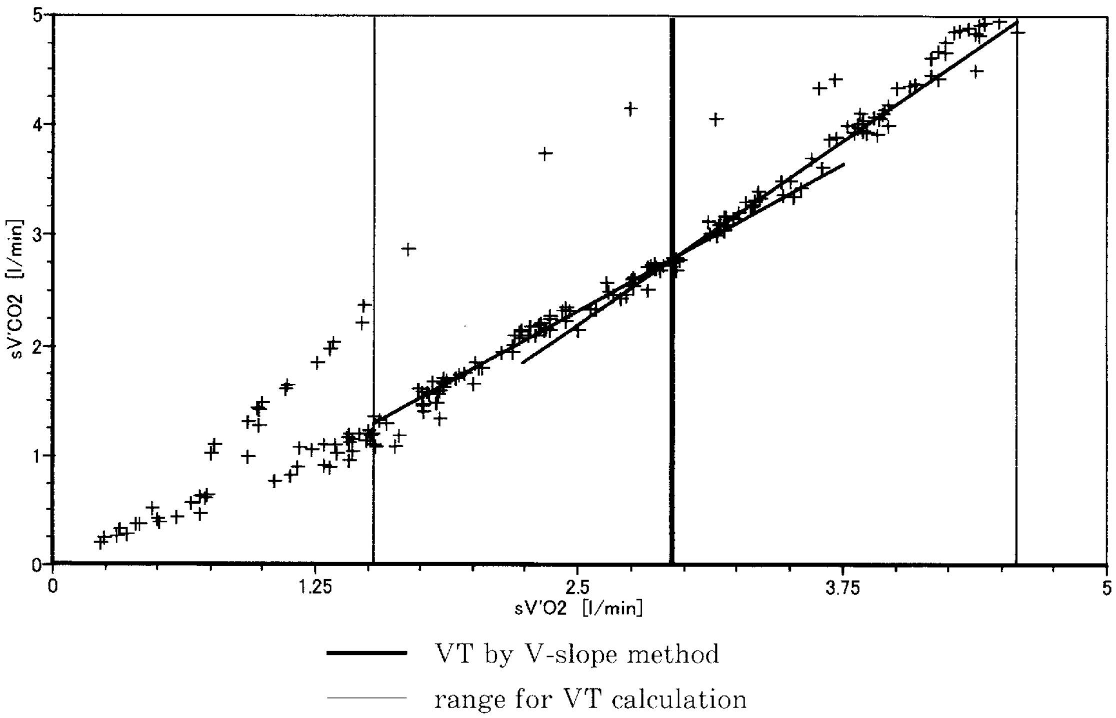

Figure 1. Diagramatic representation for determination of ventilatory threshold (VT) from the relationship between CO_2 production (VCO_2) and oxygen uptake (VO_2) by means of two-part discontinuous linear model.

Heck et al.[10]. The ventilatory threshold (VT) was assessed by means of two compartments linear model from the relation to pulmonary ventilation to VO_2 or VCO_2. This was done automatically with a computer algorithm to establish a two-line regression intersection point. Calculation of the VT employed the V-slope method. This principle is illustrated in Figure 1.

The training program

Subjects attended three sessions per week for a period of 9 weeks (27 training sessions). The training program for the IR group consisted of a 600-m fast run with a 3-min very easy jogging between each 600-m interval. Six (6) sets of the training were completed during the first 3 weeks, 8 sets during the second 3 weeks, and 10 sets for the final 3 weeks. Subjects were always asked to cover the distance at running pace of "hard" evaluated by their rating of perceived exertion (RPE). The "hard" of RPE was equivalent to 16～18 of Borg's scale[11].

On the other hand, the training program for ER was their regular endurance running. The running distance for training was 5 km during the first 3 weeks, 7 km during the second 3 weeks, and 9 km for the final 3 weeks. Subjects asked to cover the distances at running pace perceiving a "somewhat hard" to "hard" (RPE = 13-15). When the program was completed, subjects were tested using the identical protocol to that used before the test.

Training heart rate

Heart rates during respective training run were monitored using either a Mac heart rate memory (Vine Ltd, Tokyo), or a Polar heart rate monitor (Polar Electro, Kempere, Finland) once every week in order to check if the runners had appropriate running intensities. For the ER group an average value of HR monitored during the last 5 min was recorded while an average value of HR monitored during the last 30 seconds of every fast run was recorded for the IR group.

Statistical analysis

The dependent measures, VO_2max, LT and VT were analyzed using a 2 (groups) X 2 (test) repeated measures analysis of variance (ANOVA). When significant difference was revealed, Turkey's post hoc test was used to specify where the difference were occurred. The

Pearson's product moment correlation test was used to determine the relationship between LT and VT values before and after testing. Differences for all dependent measures were considered significant at the $P<0.05$ levels. The test analyses were carried out employing the SPSS

Table 1. Anthropometric characteristics, maximal heart rate (HRmax) and maximal oxygyen uptake (VO_2max) of the subjects

Group	Age (yr)	Mass (kg)	Height (cm)	Body fat (%)	BMI	VO_2max (ml/kg/min)	HR max (bpm)	Years of training
IR (N=10)	40	60.1	168.1	16.7	21.3	52.3	187.2	10.8
(SD)	4.6	2.9	3.6	1.6	1.5	5.1	4.6	5.2
ER(N=10)	41.7	58.7	167.2	17.6	21	52.5	185.6	12.6
(SD)	4	3.2	3.6	1.9	1.7	5.3	7	6.5

Values are mean(SD)

Table 2. Heart rate values measured during respective training run. The HR values are the average of all values collected during the run and are expressed either in absolute term (bpm) or as a percentage of maximal heart rate (% HR max)

Group		Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Mean
IR	HR	168(6)	170(5)	173(4)	175(6)	172(4)	176(5)	169(7)	170(6)	173(7)	172
	%HRmax	90	91	93	94	92	94	90	91	93	92
ER	HR	148(6)	159(7)	153(11)	156(7)	152(7)	145(4)	151(6)	148(8)	159(9)	152
	%HRmax	80	86	82	84	82	78	81	80	86	82

Values are mean (SD)

Table 3. VO_2max in the IR and ER groups before and after training

Group	Before	After	Improvement	ANOVA
IR	52.3 (5.1)	57.4 (5.1)	5.1	P<0.01
ER	52.5 (5.3)	54.1 (5.5)	1.6	P<0.05
Condition, P	0.9186	0.1262		

VO_2max; ml/kg/min
Values are mean (SD)

Table4. Ten (10) km run finish time of the IR and ER groups before and after training

Group	Before	After	Diff.	ANOVA
IR	2282(130)	2190(110)	92	P<0.05
ER	2249(140)	2207(130)	42	P<0.05
Condition, P	0.5984	0.7569		

Time is in second
Values are mean(SD)

software package (base 10.0J).

Results

The descriptive data of the physical characteristics of the subjects before training in both groups are presented in Table 1. There were no significant differences in any variables between groups before training. The training HR in both IR and ER groups are reported in Table 2. The

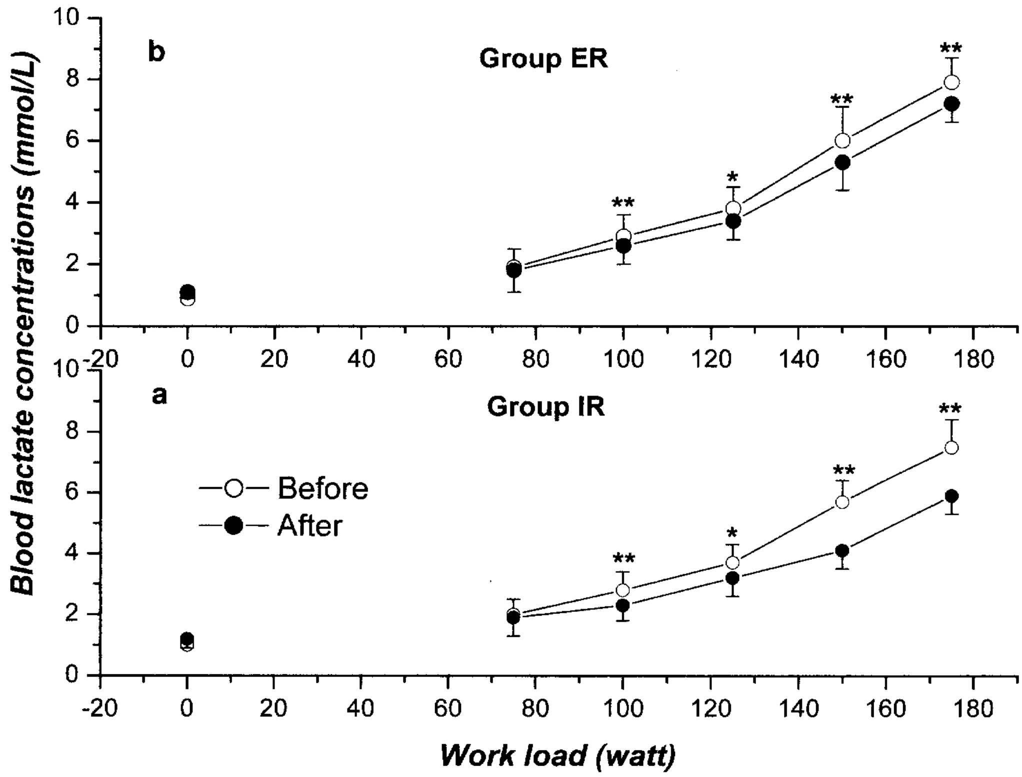

Figure 2. Blood lactate concentrations (mean ± SD) during graded exercise in the IR (a) and ER (b) groups.
*P<0.05, and **P<0.01, before versus after.

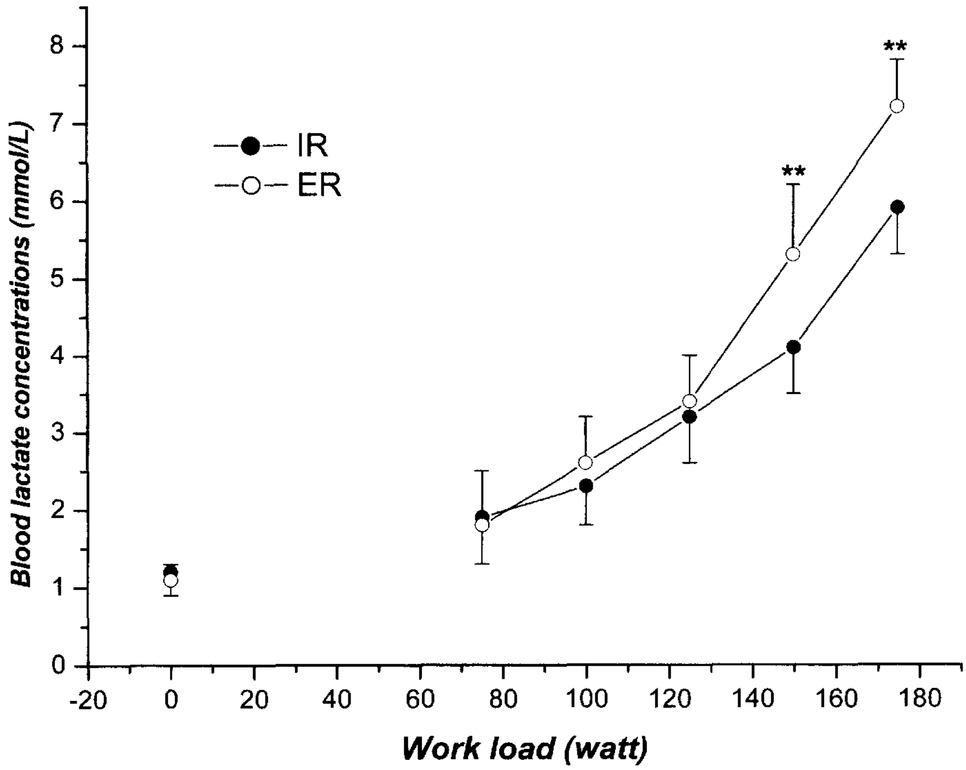

Figure 3. Blood lactate concentrations during graded exercise after resective training in the IR and ER groups.
**P<0.01, IR versus ER.

average training HR was 152 (145-159) bpm in ER representing 82 (78-86) % of their maximal HR while the corresponding value in IR was 172 (168-176) bpm representing 92 (90-94) % of their maximal HR.

Both groups improved significantly in VO_2max after respective 9-week training program. However, no significant differences were noted between the groups over time (Table 3). Also, both groups demonstrated a significant improvement in running time of 10 km. A magnitude of the improvement, however, was higher in the IR group than the ER group demonstrating an improvement in 92 and 46 seconds, respectively (Table 4).

Blood lactate concentrations at the identical submaximal workloads were lowed in the IR and ER groups after their respective training. The statistical significances were observed at higher work loads in both groups (Figure 2). However, a magnitude of the differences was greater in the IR than the ER groups. It could be seen in the figure that in the IR group the 4 mmol/L lactate concentration occurred about 2 minutes

Table5. Lactate (LT) and ventiratory (VT) thresholds expresssed as %VO2max before and after training in the IR and ER groups

LT	Before	After	Improvement	ANOVA
IR	68.8 (4.2)	79.4 (4.6)	10.6	P<0.01
ER	67.4 (4.4)	70.6 (3.9)	3.2	P<0.05
Condition, P		0.00002		
VT				
IR	69.5 (5.2)	81.3 (4.0)	11.8	P<0.01
ER	70.2 (3.5)	75.6 (3.3)	5.4	P<0.01
Condition, P		0.021		

Values are mean(SD)
Valuesare percentage

later from the pre-training levels. When looking at the lactate concentrations during the post-training test, the values in the IR were significantly lower at 150 W ($P<0.01$) and 175 W ($P<0.0001$) than the values in contrast to the ER group (Figure 3). In addition, the difference between the workloads corresponding to a lactate concentration of 4 mmol/L in both groups was significant ($P<0.001$). When the LT was expressed as percentages of the post-training VO_2max, the LT was significantly increased both in the IR ($P<0.001$), and ER ($P<0.01$) groups (Table 5). However, at the post-training test the LT level (%VO_2max) was significantly ($P<0.05$) higher in the IR than ER groups. Table 5 also shows the VT level expressed as percentage of VO_2max in the IR and ER groups. The VT increased significantly ($P<0.001$) in both IR and ER groups after training. The difference in post training VT between the IR and ER groups was significant ($P<0.01$).

The Pearson's product moment correlation test was used to determine the relationship between LT and VT values before and after training. The correlation coefficient was 0.78 and 0.82 in IR before and after training, respectively. Corresponding value in ER was 0.81 and 0.85, respectively. All values were significant at $P<0.05$.

Discussion

After the 9-week training program, both groups improved significantly in VO_2max . However, no significant differences between groups were noted over time (Table 2). The interval-run group (IR) in this study showed a large magnitude of improvements in maximal aerobic capacity as well as running performance than the endurance-run group (ER). The increase in VO_2max demonstrated by IR in the present study is in accordance with other interval training studies which employed training intensities of 80～95% VO_2 max [1,2,12] although training intensities in our study were about 90～94% of HRmax. Several conclusions regarding the optimum length of the work interval have been reported by previous investigators. Daniel and Scardina[3] suggested that exercise bouts lasting approximately 3～5 min are considered optimal for training the aerobic energy system. While Astrand et al.[13] suggested that a 2-min work and 2-min rest interval was considered more appropriate. MacDougall and Sale[14] also stated that 2～3 min exercise periods are ideal. In addition, Burk et al.[2] found no significant differences in aerobic capacity between the 30 seconds and 2 min interval-training groups. In the present investigation, a 600-m distance was used as a work period. The length of faster run seemed to be adequate because significant improvement in VO_2max was achieved.

In the present study, both VO_2max and 10km running performance were improved significantly ($P<0.001$) in both IR and ER groups. The magnitude of the improvements, however, was higher in IR than ER, that is, the increase in VO_2max in IR and ER was 9.7 and 2.4%, respectively while the improvement of running time in 10 km was 92 and 42 seconds, respectively. It may be speculated that peripheral adaptations, such as a concurrent up-regulation of aerobic and anaerobic respiration, appear to be responsible for the improvement in endurance performance and VO_2max following interval training.

The interval-run training appeared to modify significantly the submaximal work blood lactate response. After the 9 weeks a fall in blood lactate concentration was observed as a given submaximal work load (Figure 2). Onset of blood lactate threshold (OBLA) in IR shifted to a higher work load. An estimated OBLA in IR before and after the training was approximately at 131 and 146 watts, respectively. In contrast to the IR group, a marginal shift to higher work rate in OBLA was seen in the ER group. However, the endurance-run training was also effective to lower significantly the submaximal work blood lactate concentrations although a magnitude was smaller than that in the IR group, as shown in Figure 2. The findings in the present study are in good agreement to those by Poole and Gaesser[15] in which the authors concluded that both continuous and interval training were equally effective in augmenting LT, but interval training was more effective in elevating LT and VT. Intensity of training is important in submaximal exercise lactate response. Training at 70% VO_2max is effective in lowering the plasma lactate response[16]. On the basis of the overload principle it has been suggested that high intensity exercise at 70% VO_2max or more is necessary to stress the lactate production and thus result in adaptation[17]. Laursen et al[18]. used high-intensity interval-training in highly trained cyclists, and reported that a small, yet significant improvement in peak oxygen uptake (+4.3%), as well as a more marked increase in ventilatory threshold (15%～22%). In the present study training intensity in IR averaged in 92% HRmax which is equivalent to approximately 80～85% of VO_2max. Therefore, we can say that the training intensity in IR was high enough to adapt to the anaerobic energy metabolism. Previous studies have shown that the greater intensity of exercise associated with aerobic interval training yields more pronounced peripheral than central adaptations. Increases in mitochondrial volume[19] and increased capillarization of muscle[20] provide the mechanism for a delay in lactate production after the high intensity interval training.

While the physiological adaptations that occur following endurance training in previously sedentary and recreationally active individuals are relatively well understood, the adaptations to training in already highly trained endurance athletes remain unclear. While significant improvements in endurance performance and corresponding physiological markers are evident following submaximal endurance training in sedentary and recreationally active groups, an additional increase in submaximal training (i.e. volume) in highly trained individuals does not appear to further enhance either endurance performance or associated physiological variables such as VO_2 max, oxidative enzyme activity. It seems that, for athletes who are already trained, improvements in endurance performance can be achieved only through high-intensity interval training. The subjects in this study are recreational but serious runners who have already served in running field for average 10 years or more. This study also showed that further increases in performance and physiological markers could be achieved through high-intensity interval training.

In the present study, VT was determined using V-slope method. However, Gaskill et al.[21]. recommended using of a combination of the following three methods in order to determine VT, i.e., ventilatory equivalencies, 2) excess CO_2 production, and 3) a modified V-slope method. The VT and VO_2max both increased significantly through the 9-week training in both IR and ER groups. However, the average value of the VT after the training in IR was significantly higher ($P<0.01$) than that in ER. This result would suggest that as compared to the training in IR, the training program employed in the ER group did not provide the necessary training stimulus to promote a large change in the ventilatory threshold in the conditioned runners. A previously reported study[22] in which interval training (90-95% HRmax) was employed found significant VT increases as well as VO_2max increases after 9 weeks of running training. Hill et al.[23] also found increases in VT after 18 interval-training sessions (five X 5 min cycling at 90-100% VO_2max) and 8 continuous training sessions (40 min running) in 6 weeks. The authors pointed out that exercise at the ventilatory threshold was perceived as "somewhat hard" to "hard" (RPE = 13-15). The intensity in their study was the same as the training intensity for ER in this study. Therefore, even continuous running, the training intensity for ER might be adequate to elevate not only aerobic capacity but also anaerobic threshold. Using the ventilatory threshold as the index of exercise training intensity is often seen in training for elderly people. Ahmaidi et al.[24] have reported increase in VO_2max and VT in elderly humans by 20% and 26%, respectively after the 3-month interval training program at VT. The metabolic adaptation to exercise can be evaluated according to the percentage of maximal aerobic power at ventilatory threshold. The higher the level of metabolic adaptation to certain physical work may be assumed, the higher the values of percentage of VO_2max may be found. Many studies on the long-term physiological effect of supramaximal intermittent exercise have demonstrated an improvement in VO_2max or running economy. At the modern marathon era, such running economy, that is, athletes can run with higher percentage of their high VO_2max, may be considered as one of the most important physiological parameters. Although our values of $\%VO_2max$ at VT are lower than the ones presented in highly trained athletes in literature[25,26], the effects of interval training on VT are in good agreement with those.

Significant correlations between LT and VT were shown in the present study. The strong correlation has been explained on the basis of the increased carbon dioxide produced as a result of lactate buffering by the bicarbonate system[27].

In summary, the present study has shown that both continuous and interval training were equally effective in augmenting maximal aerobic power (VO_2max), lactate threshold (LT) and ventilatory threshold (VT), but interval training was more effective in elevating VO_2max, LT and VT for those who have already aerobic training for certain years.

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インターバル走及び持続走トレーニングに対する血中乳酸と肺換気性応答

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要約

研究目的。健康マラソンと称する市民ランナーの間に広く用いられているトレーニング方法は長い距離を続けて走る持続走である。近年，各種レースでの高いランニングパフォーマンスを狙う市民ランナーが増えている。長距離ランニングの成績は速いペースで走るスピード要素と長距離を著しい疲労を伴わないで走る持久性要素の両面に依存している。マラソンのスピード化が著しい今日，トップランナーはこの高い有酸素性能力に加えて無酸素性能力をも兼ね備えねばならない。すなわち，筋疲労を起こすような乳酸値濃度を伴わないで高い有酸素性レベルで走り通す能力が求められる。本研究の目的は，ある程度真剣にランニングに取り組んでいる市民ランナーを対象にランニングスピードを高めるためのインターバル走トレーニングと持久力を高めるために習慣的に行っている持続走トレーニングを実施し，ランニングパフォーマンス，乳酸性閾値及び肺換気性閾値からトレーニング方法を検討することである。

研究方法。ランニングクラブに所属し，ある程度真剣にランニングに取り組んでいる平均年齢41歳の男子市民ランナー20名が被験者として参加した。被験者の有酸素性能力（最大酸素摂取量＝VO_2max）が均等になるようにしてそれぞれ10名がインターバル走トレーニング群（IR）と持続走トレーニング群（ER）に分類された。トレーニング期間は9週間で被験者は毎週3回，9週間にわたってトレーニングを行った。IR群のトレーニングは600mの距離をボルグスケール（REP）の“きつい”（16〜18）

という感覚で走り，その後3分間のごく緩やかなジョギングを挟むトレーニングを6～10セットとしたものである。これに対してER群はボルグスケールの“ややきつい”(13～15)という感覚で6～10kmを持続的に走った。各ランナーの運動時負荷を確かめるために，毎週1回すべてのランナーが心拍メモリー計ないしポラール心拍モニター計を用いて心拍数(HR)を記録した。

鍛錬効果を検討するために10kmのタイムトライアルに加えてVO_2max，同一作業負荷に対する乳酸濃度，及びVスロープ法による肺換気性作業閾値(VT)が測定された。生理的パラメターの測定に対して，2分毎に25W上昇するランプ負荷による自転車エルゴメターを用い，被験者は所定のペダリングリズムで運動が不可能な時点までサイクル運動を継続した。

結果とまとめ。それぞれのトレーニング時の平均HRはIR群で172(168～176)，ER群で152(145～159)拍／分で，最大HRのそれぞれ92%，82%に相当した。10kmのタイムトライアルでは両群に有意な記録の向上が認められ，短縮時間はIR群で92秒，ER群で46秒であった。

いずれのトレーニング方法においてもVO_2maxは有意に増加したが，その度合いはIR群に大きかった(ただし有意差は見られななかった)。トレーニング後の同一作業時の血中乳酸濃度は両群に有意な低下が観察された。この場合でも，その低下の度合いはIR群において大きかった($P<0.001$)。暫増負荷に対する乳酸濃度の回帰線から得られた推定乳酸4mmol/L値をLTとし，それを%VO_2max値で表すと，両群ともLTは有意に高められた。しかし，トレーニング後値の比較ではIR群はER群より有意に高く($P<0.001$)，トレーニング後のVTにおいても両群に有意な増加が認められたが，LTと同様にIR群値は有意に高かった($P<0.01$)。

本研究は市民ランナーのランニング記録の向上においても，ランナーに求められる生理的パラメターにおいても，インターバル走トレーニングと持続走トレーニングの両方法は有効であることを示した。しかし，トレーニング効果はインターバル走トレーニングにおいて大きかった。インター

バル走トレーニングは持続走トレーニングよりLT，VTレベルのいずれをも高めることができ，そのことがVO_2maxの高いレベルで走ることを可能にさせるものと考えられる。以上の諸結果からある程度のトレーニングを積み相当の持久性能力を持つ者に対する効果的なトレーニングとして，トレーニングの量的な強度より質的な強度つまり，VO_2maxの90%を超えるような高強度のスピードによるインターバル走トレーニングを持つことが望ましいと言える。

（受理日　平成14年10月9日）