

Physiological and jump performance alterations induced by a dramatic increase in running volume. A case study

Alteraciones fisiológicas y de capacidad de salto inducidas por un dramático aumento de volumen de carrera. Un estudio de caso

José Augusto Rodrigues dos Santos

University of Porto

CORRESPONDENCIA:

José Augusto Rodrigues dos Santos

University of Porto

Faculty of Sport

Rua Plácido Costa, 91

4200-4450 Porto, Portugal

jaugusto@fade.up.pt

Recepción: junio 2011 • Aceptación: septiembre 2011

Abstract

This study aimed to verify how a severe increase in running volume induced new alterations in several physiological and performance indicators, in previously well-trained subjects in endurance running. Three subjects running 10-12 km·day⁻¹, increased running volume to 35.8 ± 6.2 km · day⁻¹. The following parameters were assessed: VO₂max, Running Economy, Ventilatory Threshold (VT), Squat Jump (SJ), Counter Movement Jump (CMJ), 15" Repeated Jump (15" RJ), and Body mass. Absolute VO₂max didn't change (4.6 ± 0.17 to 4.6 ± 0.2 L · min⁻¹). Relative VO₂max improved clearly (61.7 ± 2.5 to 66.7 ± 2.4 ml · kg⁻¹ · min⁻¹). Oxygen consumption at 16 km · h⁻¹ showed a slight decrease (42.8 ± 3.3 to 41.5 ± 2.5 ml · kg⁻¹ · min⁻¹) decreasing markedly when related to VO₂max (69.4 ± 4.6 to 62.2 ± 3.1%). Energetic cost at VT increased differently among subjects (53.5 ± 4.6 to 56.5 ± 3.8 ml · kg⁻¹ · min⁻¹); when related to VO₂max VT decrease in two subjects. The velocity attained at VT remained the same (18 km·h⁻¹). Body mass was sharply reduced (72.6 ± 6.4 kg to 69.2 ± 5.5 kg). Jump performance decreased 7.7% for SJ (33.8 ± 2.8 to 31.3 ± 2.9 cm), 10.4% for CMJ (35.6 ± 2.4 to 31.9 ± 0.9 cm), and 17.7% for 15" RJ (25.6 ± 1.4 to 21.1 ± 2.5 W · kg⁻¹). The dramatic increasing in running volume induced new physiological and motor alterations in well trained subjects.

Key words: endurance training, VO₂max, running economy, ventilatory threshold, SJ, CMJ.

Resumen

Estudio de las alteraciones fisiológicas y de rendimiento en sujetos aeróbicamente entrenados después de un dramático aumento en el volumen de carrera. Tres sujetos entrenando 10-12 km · día⁻¹, aumentaron el volumen de carrera para 35,8 ± 6,2 km · día⁻¹. Fueron evaluados los siguientes parámetros: VO₂max, economía de carrera, umbral ventilatorio (VT), peso corporal, salto sin contra-movimiento (SJ), salto en contra-movimiento (CMJ) y teste de 15" de saltos repetidos (15"RJ). VO₂max absoluto no cambió (4,6 ± 0,17 a 4,6 ± 0,2 L · min⁻¹). VO₂max relativo mejoró (61,7 ± 2,5 a 66,7 ± 2,4 ml · kg⁻¹ · min⁻¹) así como la economía de carrera relacionada al VO₂max (69,4 ± 4,6 a 62,2 ± 3,1%). El coste energético en el VT aumentó de forma diferente entre los sujetos (53,5 ± 4,6 a 56,5 ± 3,8 ml · kg⁻¹ · min⁻¹); cuando se relativizó con el VO₂max, el VT disminuyó en dos sujetos. La velocidad conseguida al umbral ventilatorio no cambió (18 km · h⁻¹). El peso corporal se redujo acentuadamente (72,6 ± 6,4 kg a 69,2 ± 5,5 kg). El rendimiento de salto disminuyó 7,7% en el SJ (33,8 ± 2,8 a 31,3 ± 2,9 cm), 10,4% en el CMJ (35,6 ± 2,4 a 31,9 ± 0,9 cm), y 17,7% en el 15" RJ (25,6 ± 1,4 a 21,1 ± 2,5 W · kg⁻¹). El dramático aumento del volumen de carrera indujo nuevas alteraciones fisiológicas y motoras en sujetos bien entrenados.

Palabras clave: entrenamiento aeróbico, VO₂max, economía de carrera, umbral ventilatorio, SJ, CMJ.

Introduction

Long-distance running is a powerful stressor with multiple implications. Volume, intensity, and frequency are the main parameters to be considered for training adaptations (Rodrigues dos Santos, 2005).

While for middle- and long-distance runners training intensity assumes paramount importance corresponding to 20% of the training sessions (Seiler, 2010), for ultramarathon runners, the main focus for training is the adaptation to sustain large volumes of running and not training intensity. Lower energy cost of running plus running regularity (i.e. the adequate rate for each individual to accomplish ultra-long-distance events) are the main characteristics to be developed by ultramarathon runners. Hoffman (2010), has stated that the average times of the fastest runners over a 161-km ultramarathon didn't change over the past two decades for any age group or either sex. While maximum oxygen consumption ($VO_2\text{max}$) improvement usually demands high-intensity stimuli (Esfarjani and Laursen, 2007), it seems that high-volume low-intensity training better improves sub-maximal physiological indicators (e.g. running economy) (Seiler, 2010).

This is corroborated by Billat et al. (2002) who showed that short periods of high-intensity endurance workouts can improve $VO_2\text{max}$ without changing running economy in well-trained athletes. $VO_2\text{max}$ improvement is difficult to achieve in very well-trained endurance subjects.

While for elite endurance runners, performance improvement can be achieved after hard training without changes in $VO_2\text{max}$ (Legaz-Arrese et al., 2005), in less-skilled or less-trained runners, higher running performance is usually accompanied by $VO_2\text{max}$ improvement. Enoksen et al. (2011) verified that $VO_2\text{max}$ didn't change after both high-volume low-intensity and low-volume high-intensity interventions in well-trained middle distance runners; however, low-volume high-intensity workouts were more effective for performance improvement ($VO_2\text{max}$ velocity and lactic threshold velocity).

It seems that in well-trained subjects, ventilatory threshold is not very sensitive to endurance training (Hoogeveen, 2000) and is not affected by age (Lenti et al., 2011); however, mechanical fatigue can impair the ventilatory response to exercise (Millet, 2009). Strength deterioration induced by continuous training can negatively affect the ventilatory threshold (Koutedakis et al., 1992). Thus, alterations in jumping capability can function as an index for strength deterioration induced by long-lasting running.

High running intensities are necessary to improve running performance in events up to 10 km (Iaia & Bangsbo, 2010); however, performance improvement in ultra-endurance events can be achieved by low-intensity long-lasting workouts, which have a positive effect on running economy (Scrimgeour et al., 1986). It seems that mean weekly running hours is one of the best predictors of 100-km running race time (Knechtle et al., 2010).

Small increments in training volume are not capable of inducing measurable changes in both performance and physiological indicators (Gjovaag and Dahl, 2008); therefore, by stabilizing training intensity, it is assumed that only large increments of training volume are able to induce significant changes in several physiological and performance indicators. However, this type of study is scarce in the literature.

While $VO_2\text{max}$, anaerobic threshold, economy of motion, and fractional utilization of oxygen uptake correlate highly with endurance performance (Laursen and Rhodes, 2001), for ultra-endurance events, these indicators are not very reliable.

Therefore, this study sought to verify the physiological and performance changes after 17 weeks of a drastic increase in training volume in active subjects preparing to participate in a 100-km running race.

Methods

Participants

With institutional ethics approval (Scientific Council of the Faculty of Sport at the University of Porto), three soldiers from the Portuguese Army Elite Corps (Special Forces), provided written informed consent and voluntarily participated in this study. Participants' age and height were as follows: P.L. (26 years; 169.5 cm), H.P. (27 years; 167.9 cm), and M.C. (27 years; 180.7 cm). These subjects were not typical athletes but very active elite soldiers that have running as a fundamental part of their physical military preparation and have more than 5 years of running training. They regularly participated in military orienteering races with sporadic participations in civil road races. They had periodically medical screenings which showed no health constraints. During the last year prior to the study they usually ran 10-12 km daily.

The participants can be considered non-elite runners (average rate of 4 min/km for the half-marathon) very far from middle- and long-distance elite runners' performance (average rate \leq 3 min/km at half-marathon).

Training protocol

With the objective to compete in a military ultra-marathon (100-km), the subjects executed 10-12 training sessions per week, totalizing 200-260 km. Average daily running volume was 35.8 ± 6.2 km. The intensity of the efforts was controlled by thoracic frequency counter. Low to moderate running pace was selected (130-160 beats per minute corresponding to 70-85% of the maximum heart rate) for continuous uniform running with 2 fartlek sessions per week (10 accelerations of 300 m) inducing heart rates close to the maximum. They practiced twice a day on Tuesdays, Wednesdays, Thursdays, Fridays and Saturdays; they had only one workout on Sundays (the longest one); and they also had one workout on Mondays (the shortest one). Every four weeks a performance test (30 km) was conducted which improved over time (week 4: 2h00; week 8: 1h57; week 12: 1h55). The performance test was preceded by a resting day. In the last week before testing, volume training was reduced in half while maintaining the usual intensity.

It should be noted that with the exception of fartlek training sessions, the continuous uniform running sessions were conducted at intensities below that which the subjects were previously accustomed. The fundamental training goal was the completion of an ultra-marathon (100-km) at an adequate pace to avoid over-exertion while achieving the best performance possible.

Nutrition

Throughout the duration of the study, participants were requested to maintain their usual dietary diversity, increasing energy and carbohydrate intake *ad libitum*.

Evaluated parameters

The following parameters were evaluated at the beginning and the end of the study after a compulsory 48h rest.

Physiological: A treadmill test was conducted with a 2% slope, a continuous running protocol, an initial speed of $8 \text{ km}\cdot\text{h}^{-1}$ with $2 \text{ km}\cdot\text{h}^{-1}$ increments every two minutes until exhaustion. Respiratory parameters were measured with an EOS-Sprint System (Erich Jaeger GmbH & Co, XT/AT JK model) and analyzed by a JVC GD-H 3214VCW computer model.

The following parameters were selected:

VO_2max ($\text{L}\cdot\text{min}^{-1}$); relative VO_2max ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$); ventilatory threshold (VT) obtained by ventilatory equivalent (Davis, 1985); running economy expressed by oxygen consumption at $16 \text{ km}\cdot\text{h}^{-1}$

(VO_{2-16}) and as percentage of VO_2max at that speed ($\text{VO}_{2-16}\cdot\%\text{VO}_2\text{max}$); and velocity attained at VO_2max ($v\text{VO}_2\text{max}$). Heart rate was measured with a heart-rate monitor (Servomed, SMS 182, Hellige). Body mass (SECA Robusta 813 High Capacity Digital Floor Scale) and height (CHARDER HM 200 P Portstad Portable Stadiometer) were also measured.

Motor Testing: Lower limb explosive power was assessed with the Ergojump Digitime 1000 developed by Bosco et al. (1983). Each subject was assessed with the squat jump (SJ), counter movement jump (CMJ), and 15" repeated jump (15" RJ) following the procedures established by Bosco et al. (1983).

Results

Body mass and jumping performance data are shown in Table 1. Mean body mass reduction (72.5 ± 6.6 kg for 69.1 ± 5.5 kg) is related to the explosive power deterioration expressed by a 7.7% decrease in the SJ (33.8 ± 2.8 to 31.3 ± 2.9 cm), a 10.4% in the CMJ (35.6 ± 2.4 to 31.9 ± 0.9 cm), and a 17.7% in the 15" RJ (25.6 ± 1.4 for $21.1 \pm 2.5 \text{ W}\cdot\text{kg}^{-1}$).

Table 1. Body mass and jumping performance changes induced by training.

Variables	P.L.		H.P.		M.C.	
	Start	End	Start	End	Start	End
Body mass (kg)	68.5	66.5	69.3	65.5	80.0	75.5
Squat Jump (cm)	36.6	34.6	31.0	30.1	33.9	29.1
Counter Movement Jump (cm)	37.9	32.7	33.2	31.2	35.8	31.9
15" Repeated Jump ($\text{W}\cdot\text{kg}^{-1}$)	27.2	18.2	25.3	22.2	24.4	22.9

Table 2. Physiological changes induced by training

Variables	P.L.		H.P.		M.C.	
	Start	End	Start	End	Start	End
VO_2max ($\text{L}\cdot\text{min}^{-1}$)	4.5	4.6	4.5	4.4	4.8	4.8
VO_2max ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	64.4	69.0	61.1	66.8	59.5	64.2
$v\text{VO}_2\text{max}$ ($\text{km}\cdot\text{h}^{-1}$)	22	22	20	20	22	22
Maximum Heart Rate (bpm)	187	189	182	184	191	190
VO_{2-16} ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	43.6	41.5	45.6	44.0	39.2	39.0
VO_{2-16} ($\%\text{VO}_2\text{max}$)	67.7	60.1	74.6	65.8	65.8	60.7
$\text{VO}_2\text{-VT}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	58.8	58.9	51.6	58.4	50.2	52.1
$\text{VO}_2\text{-VT}$ ($\%\text{VO}_2\text{max}$)	91.3	85.4	84.5	87.4	84.4	81.2
$v\text{VO}_2\text{-VT}$ ($\text{km}\cdot\text{h}^{-1}$)	18	18	18	18	18	18
RERmax	1.17	1.18	1.20	1.19	1.24	1.23

Physiological and performance variables are shown in Table 2. While absolute VO_2max and $v\text{VO}_2\text{max}$ remained quite stable, relative VO_2max demonstrated marked improvements. Maximum heart rate was characterized by slight variability. The energy cost of running (VO_{2-16}) decreased slightly; however, when related to VO_2max , the decrease was accentuated. Oxygen consumption at ventilatory threshold had different individual behaviours while the velocity at VT remained unchanged.

Discussion

The main result of this study is the marked reduction in body mass and the explosive power deterioration provoked by the long-lasting running workouts. Explosive power deterioration is probably related to the reduction in maximal strength which is eventually related to the loss of muscle mass. These chronic adaptations are in accordance with the acute power reduction verified after a 10-km running race (Gómez et al., 2002). The decrease in lower-limbs explosive power that was found in our study despite the negative effect on jumping performance wasn't reflected in running performance perhaps due to the increased mechanical efficiency provoked by alterations in gait pattern (Eriksson et al., 2011) or higher metabolic efficiency (Millet et al., 2011) induced by long-lasting workouts.

Endurance training imposes an overall stress with reflection in the cardiac phenotype plasticity probably involving, in addition to genetic determinants, factors like length, duration, type, intensity, and age of initiation of the training stimulus (Levine, 2008). Endurance training promotes rapid cardiovascular changes (cardiac output and systolic volume) that are measurable after 10 days of training (Mier et al., 1997); however, in well-trained subjects, further physiological increments seem to be difficult to achieve. Our results (Table 2) show that VO_2max ($\text{L}\cdot\text{min}^{-1}$), $v\text{VO}_2\text{max}$ (velocity at VO_2max), and maximum heart rate [HRmax] were not sensitive to training and suffered minor changes without physiological significance. These results are in accordance with Legaz-Arrese et al. (2005) who stated that hard training in young subjects improves performance without changes in VO_2max .

Relative VO_2max ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) experimented substantial increases (PL: 7.1%; HP: 9.3%, and MC: 7.8%) which were directly related to the marked reduction in body weight. Absolute VO_2max ($\text{L}\cdot\text{min}^{-1}$) improvement in well-trained individuals demands training

stimuli higher than 95% of VO_2max (Midgley and McNaughton, 2006). The two fartlek sessions per week with intensities close to VO_2max included in the microcycle seem to not be sufficient to induce significant improvements in absolute VO_2max or maximum aerobic power expressed as the velocity attained at VO_2max ($v\text{VO}_2\text{max}$). Partially conflicting with these data, Saunders et al. (2010) found a 1.4% increase in VO_2max ($\text{L}\cdot\text{min}^{-1}$) after 17 weeks of endurance training in well-trained distance runners. The differences may be related to the reduced number of high-intensity training stimuli carried out in our study. To improve absolute VO_2max and $v\text{VO}_2\text{max}$, high-intensity low-volume loads are preferable to low-intensity high-volume loads (Enoksen et al., 2011). As the training protocol in this study put the emphasis on low-intensity workouts, the lack of improvements are justified.

The slight changes in HRmax have no physiological significance. In well-trained subjects, endurance training doesn't change HR at different exercise intensities (Hoogeveen, 2000).

Running economy depends on metabolic and biomechanical adaptations. In this study, the metabolic cost of running at $16\text{ km}\cdot\text{h}^{-1}$ decreased slightly but when related to VO_2max , it improved markedly (-10.3%), which can be linked to physiological adaptations and/or greater mechanical efficiency of running (Fletcher et al., 2010). It seems that heavy strength training improves running economy (Guglielmo et al., 2009); however, Dumke et al. (2010) stated that increasing the volume of training decreases muscle power, increases tendon stiffness, and improves running economy. This is in accordance with our data which demonstrated running economy improvement with a significant reduction in muscle power. Besides higher mitochondrial oxidative capacity, performance in ultra-endurance events is mainly related to running economy (Millet et al., 2011), which corroborates the most significant physiological adaptations verified in this study. It seems that running economy improves independently of running intensity when running volume is significant (Enoksen et al., 2011), which was the main characteristic of the training protocol in this study. Long-distance running training promotes alterations of the movement pattern in order to reduce the mechanical cost of running (Millet et al., 2000; Eriksson et al., 2011), delaying fatigue. It seems that, until a certain level, improvement in running economy is related to running volume more than intensity (Billat et al., 2002).

Oxygen consumption at ventilatory threshold (VT) increased differently among subjects corroborating data from Hoogeveen (2000). When related to

VO₂max, VT increased in one subject and decreased in the other two, which can be attributed to the individual changes in VO₂max or to different individual sensibility to alterations in anaerobic contribution to exercise (Hoogeveen, 2000). These alterations can also be attributed to the emphasis put on the low-intensity running. Contrary to untrained subjects, in trained athletes, VT doesn't differ much following endurance training (Hoogeveen, 2000).

Additionally, in endurance runners, significant differences in training volume are expressed by similar ventilatory thresholds (Kilding et al., 2006). Both studies are completely uncorroborated by our data. Combining strength and endurance training, VT was improved (García-Pallarés et al., 2009); strength deterioration verified in this study may be the reason for the absence of VT improvement in two subjects. Ultra-endurance training seems to deteriorate anaerobic ventilatory threshold when the training pace is lower than usual.

Conclusion

This study concluded that subjects with a high level of endurance training adapt to a dramatic increase in running volume by improving their relative VO₂max and running economy, which are directly related to the marked decrease in body mass with a corresponding deterioration of lower limb explosive power. These adaptations were reflected in slight but continuous improvements on running performance. Training experienced by the subjects spurred their adaptive capacity taking them to a new level of conditioning with improvement of some capabilities and impairment of others. The laboratory protocol chosen seems to not be the most accurate to demonstrate small physiological changes eventually attained in this study.

Subjects enlisted in long-lasting workouts must introduce complementary strength training to attenuate muscle mass reduction and the deterioration of strength levels.

We thank the General Commandant of the Northern Region of the Portuguese Army (Porto) and the Commandant of the Special Forces - C.I.O.E. (Lamego).

BIBLIOGRAFÍA

- Billat, V.; Demarle, A.; Paiva, M.; Koralsztein, J.P. (2002). Effect of training on the physiological factors of performance in elite marathon runners (males and females). *Int J Sports Med.* 23:336-341.
- Bosco, C.; Luhtanen, P.; Komi, P.V. (1983). A simple method for measurement of mechanical power in jumping. *Eur J Appl Physiol Occup Physiol.* 50:273-282.
- Davis, J.A. (1985). Anaerobic threshold: review of the concept and directions for future research. *Med Sci Sports Exerc.* 17:6-21.
- Dumke, C.L.; Pfaffenroth, C.M.; McBride, J.M.; McCauley, G.O. (2010). Relationship between muscle strength, power, and stiffness and running economy in trained male runners. *Int J Sports Physiol Perform.* 5:249-261.
- Enoksen, E.; Shalfawi, S.A.; Tonnessen, E. (2011). The effect of high- vs. low-intensity training on aerobic capacity in well-trained male middle-distance runners. *J Strength Cond Res.* 25:812-818.
- Eriksson, M.; Halvorsen, K.A.; Gullstrand, L. (2011). Immediate effect of visual and auditory feedback to control the running mechanics of well-trained athletes. *J Sports Sci.* 29:253-262.
- Esfarjani, F.; Laursen, P.B. (2007). Manipulating high-intensity interval training: effects on VO₂max, the lactate threshold and 3000 m running performance in moderately trained males. *J Sci Med Sport.* 10:27-35.
- Fletcher, J.R.; Esau, S.P.; MacIntosh, B.R. (2010). Changes in tendon stiffness and running economy in highly trained distance runners. *Eur J Appl Physiol.* 110:1037-1046.
- García-Pallarés, J.; Sánchez-Medina, L.; Carrasco, L.; Díaz, A.; Izquierdo, M. (2009). Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle. *Eur J Appl Physiol.* 106:629-638.
- Gjovaag, T.F.; Dahl, H.A. (2008). Effects of training with different intensities and volumes on muscle fibre enzyme activity and cross sectional area in the m. triceps brachii. *Eur J Appl Physiol.* 103:399-409.
- Gómez, A.L.; Radzwich, R.J.; Denegar, C.R.; Volek, J.S.; Rubin, M.R.; Bush, J.A.; Doan, B.K.; Wickham, R.B.; Mazzetti, S.A.; Newton, R.U.; French, D.N.; Hakkinen, K.; Ratamess, N.A.; Kraemer, W.J. (2002). The effects of a 10-km run on muscle strength and power. *J Strength Cond Res.* 16:184-191.
- Guglielmo, L.G.; Greco, C.C.; Denadai, B.S. (2009). Effects of strength training on running economy. *Int J Sports Med.* 30:27-32.
- Hoffman, M.D. (2010). Performance trends in 161-km ultramarathons. *Int J Sports Med.* 31:31-37.
- Hoogeveen, A.R. (2000). The effect of endurance training on the ventilatory response to exercise in elite cyclists. *Eur J Appl Physiol.* 82:45-51.
- Iaia, F.M.; Bangsbo, J. (2010). Speed endurance training is a powerful stimulus for physiological adaptations and performance improvements of athletes. *Scand J Med Sci Sports.* 20:11-23.
- Kilding, A.E.; Winter, E.M.; Fysh, M. (2006). A comparison of pulmonary oxygen uptake kinetics in middle- and long-distance runners. *Int J Sports Med.* 27:419-426.
- Knechtle, B.; Knechtle, P.; Rosemann, T.; Lepers, R. (2010). Predictor variables for a 100-km race time in male ultra-marathoners. *Percept Mot Skills.* 111:681-693.
- Koutedakis, Y.; Boreham, C.; Kabitsis, C.; Sharp, N.C. (1992). Seasonal deterioration of selected physiological variables in elite male skiers. *Int J Sports Med.* 13:548-551.
- Laursen, P.B.; Rhodes, E.C. (2001). Factors affecting performance in an ultraendurance triathlon. *Sports Med.* 31:195-209.
- Legaz Arrese, A.; Serrano Ostáriz, E.; Jcasajús Mallén, J.A.; Munguía Izquierdo, D. (2005). The changes in running performance and maximal oxygen uptake after long-term training in elite athletes. *J Sports Med Phys Fitness.* 45:435-440.
- Lenti, M.; De Vito, G.; di Palumbo, A.S.; Sbriccoli, P.; Quattrini, F.M.; Sacchetti, M. (2011). Effects of aging and training status on ventilatory response during incremental cycling exercise. *J Strength Cond Res.* 25:1326-1332.
- Levine, B.D. (2008). VO₂max: what do we know, and what do we still need to know? *J Physiol.* 586:25-34.
- Middley, A.W.; McNaughton, L.R. (2006). Time at or near VO₂max during continuous and intermittent running. A review with special reference to considerations for the optimization of training protocols to elicit the longest time at or near VO₂max. *J Sports Med Phys Fitness.* 46:1-14.
- Mier, C.M.; Turner, M.J.; Ehsani, A.A.; Spina, R.J. (1997). Cardiovascular adaptations to 10 days of cycle exercise. *J Appl Physiol.* 83:1900-1906.
- Millet, G. (2009). Physiological differences between cycling and running. *Rev Med Suisse.* 5:1564-1567.
- Millet, G.Y.; Banfi, J.C.; Kerhervé, H.; Morin, J.B.; Vincent, L.; Estrade, C.; Geyssant, A.; Feasson, L. (2011). Physiological and biological factors associated with a 24 h treadmill ultra-marathon performance. *Scand J Med Sci Sports.* 21:54-61.
- Rodrigues dos Santos JA (2005). Estudo comparativo, fisiológico, antropométrico e motor entre meio-fundistas e fundistas Portugueses de atletismo. *Rev Port Med Desp.* 23:67-78.
- Saunders, P.U.; Cox, A.J.; Hopkins, W.G.; Pyne, D.B. (2010). Physiological measures tracking seasonal changes in peak running speed. *Int J Sports Physiol Perform.* 5:230-238.
- Scrimgeour, A.G.; Noakes, T.D.; Adams, B.; Myburgh, K. (1986). The influence of weekly training distance on fractional utilization of maximum aerobic capacity in marathon and ultramarathon runners. *Eur J Appl Physiol Occup Physiol.* 55:202-209.
- Seiler, S. (2010). What is best practice for training intensity and duration distribution in endurance athletes? *Int J Sports Physiol Perform.* 5:276-291.