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Increased Sports Performance Determined by the Altitude Factor among Senior Mountain Runners

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Abstract: ***Background****: Although quality is one of the oldest ways to increase sports performance, a precise protocol of acclimatization and participation in competitions is not yet established, studies in the field not being able to specify exactly a methodologist is ideal. The purpose of this research is to study whether the sports performance of mountain runners increases after performing an altitude training program and whether a VO_2max higher conditions the obtaining of superior results in mountain running races.* ***Methods****: The paper is based on a case study performed on a selected 7 male subjects, mountain performance runners from the National Team of Romania, subjected to three tests: initial in plain conditions, intermediate in altitude conditions and final in plain conditions. The tests involved performing the Bruce protocol to identify the VO_2max value and to go through a route specific to the short-distance mountain running test in maximum effort conditions.* ***Results****: Hypoxic effects of altitude determine the obtaining of one hour VO_2max inferior comparative with wave times obtained in conditions of flat. SpO_2 decreases during effort regardless of altitude or flat, but at altitude the values fall below the physiological limit of 95% and return to physiological limits 15 minutes after effort regardless of flat or altitude. It was also found that following an altitude training camp, the sports performances of the mountain runners increased: the place in the general classification at the National Championship was better and the VO_2max had higher values in FT compared to IT. However, an excellent VO_2max does not condition a higher place in the ranking of specialized competitions.* ***Conclusions****: The training camps at altitude are an efficient method of maximizing the sports performances in mountain running, provided that they are performed according to a specific duration of at least 4-6 weeks and an optimal acclimatization.*

Keywords: *altitude; VO_2max; Bruce Protocol; mountain running; sports performance increase.*

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Introduction

The undoubted development of the mountain running test leads to the need to conduct studies on the practitioners of this discipline, in order to maximize the sports performances of the athletes in the field (López-García et al., 2022).

The main objective of this paper is to research and reconfirm the important role of altitude as a favorable prognostic factor of sports performance through all the physiological and biochemical changes it produces at the level of the athletes' organism. The secondary objective of the research is to highlight if there is a correlation between VO_2max and the performances obtained in the specialized competitions in which the athletes participated. Also, a third objective of the research is represented by comparing the attitude of the athletes' organism in altitude vs. flat conditions and how this fact influences the sports performance.

Respiratory ability is crucial in resistance efforts, with scientific evidence in this area claiming that runners have a relatively high cost of energy consumption for effort maintenance, considered to be twice as high as in mammals of similar size. However, it has been found that there is also an advantageous trait of the human species compared to that of other species, namely, the ability to self-regulate their running speed in order to reduce or increase energy costs consciously (Selinger et al., 2022). The normal consumption of O_2 at rest is about 250 mL / min. Under conditions of maximum stress, there is a linear relationship between the consumption of O_2 and the pulmonary ventilation, because both values increase directly proportional to the degree of stress (Radak et al., 2013) . Both parameters can increase about 20 times in conditions of effort at maximum intensity in trained athletes. However, there is a discrepancy between pulmonary ventilation and respiratory capacity during maximum intensity effort. This discrepancy offers from a practical point of view to the body a surplus of ventilation that can be used in conditions of effort in an unfavorable environment, such as the effort made at altitude or at very high temperatures, due to the possibility of the maximum respiratory capacity to reach values 50% higher than the pulmonary ventilation (Hall et al., 2018).

VO_2max is the maximum amount of oxygen inspired, transported and used to produce ATP during exercise every minute (Grzebisz-Zatońska et al., 2022). Vo_2max value is most often related to the body weight of an individual in kilograms. This allows comparisons between individuals with varying body weights. VO_2max is the most common parameter determined in the study of sports performance by direct measurement of respiratory

gases through a laboratory system and is considered the superior method of evaluating cardiorespiratory capacity according to the American College of Sports Medicine (Thompson et al., 2013). Although VO_2max represents the maximum rate of consumption of O_2 in aerobic exercise conditions and its value can increase through training, it can also be genetically conditioned. Subjects who have strong respiratory muscles and an upper chest size compared to body size are susceptible to a superior VO_2max in specific training condition (Pardo Albiach et al., 2021). During the sports trials for the quantification of VO_2max, the duration and intensity of the effort are directly proportional to the stress exerted on the body and the energy consumption in relation to the individual possibilities of the human body. Thus, cellular physiological and metabolic processes are the answer to these new difficult conditions, but they are also the actual method by which the adaptation to effort takes place (de Oliveira-Nunes et al., 2021).

The diffusion capacity of O2 measures the rate of diffusion O2 from the alveoli into the lung blood (Ferretti et al., 2022). During the effort this increases because the blood flow through the pulmonary capillaries increases in turn, causing the maximum infusion of the capillaries, thus increasing the total area through which O2 can diffuse (Pilotto et al., 2022). During sustained effort, the consumption of O2 of the muscles increases, but the pO2 of the arterial blood and of the pCO2 of the venous blood remain quasi-normal (Li et al., 2022). This is possible due to the mainly neurogenic stimulation of physical activity by activating the respiratory center. Thus, the pulmonary ventilation increases at the level necessary to maintain the respiratory gases at values close to the physiological ones (4). For the increased maintenance of the pulmonary ventilation, the cardiac output increases directly proportionally with the needles to stand, thus achieving the humoral control of the circulation through the vasoconstrictive and vasodilatory agents (Sullivan & Gorlin, 1967). Physical effort stimulates the sympathetic nervous system, the response being the release of norepinephrine from the nerve endings to stimulate the heart and contract arterioles and venules (Hall et al., 2018). Epinephrine dilates the coronary arteries during physical activity in response to increased cardiac activity (Darwish et al., 2022). Due to increased pulmonary ventilation, 40% of performance runners may experience effort dyspnea as a result of insufficient physiological changes occurring to maintain the effort. Although slow and deep breathing techniques have proven to have benefits in resting conditions, they are inaccessible and totally ineffective in conditions of effort, having no benefit on respiratory effort or sports performance (Harbour et al., 2022).

A normal breathing mechanics correctly shapes the posture and stabilizes the spine, while dysfunctional breathing is responsible for pain and poor motor control of respiratory movements. Clinically, dysfunctional breathing is a condition often underdiagnosed for the simple reason that the faulty sports breathing technique is difficult to assess and specialists in the field do not have a clearly established procedure to diagnose it and provide recommendations. Studies have shown that non-pharmacological treatments and psychological factors play a particularly important role that can provide amateur and professional runners with superior therapeutic options to improve the respiratory condition and increase sports performance (Thompson et al., 2013). Because physical effort is correlated with an increased consumption of O_2 at the muscular level, the increase in arterial pressure is achieved by stimulating the sympathetic nervous system with a direct effect on the general circulation and local vasodilation of muscle vessels, which in turn increase the metabolism of muscle cells (Mongin et al., 2022). Arterial pressure increases by about 40% during maximum physical effort, being the equivalent of increasing blood flow twice more (Radak et al., 2013). In the case of performance athletes, it can often be considered that it is not the inspiring muscle effort itself that is very high, but the subjective perception of the subject on the inspiratory load and the effort actually alters the capacity of sports performance. Minimizing the sensation of respiratory effort is independent of the mechanics of the respiratory muscles and may prove useful for increasing sports performance (Pardo Albiach et al., 2021). As for mountain running, it has two demanding portions: the climb, in which the subjects have to raise their own muscle mass against gravity in the fastest and most efficient way possible, and the descent, its level of difficulty being directly proportional to the skill, suppleness and subjective vision of each runner (de Oliveira-Nunes et al., 2021). Due to studies in the field, it has been proven that VO_2max is a faithful parameter of the climbing process from mountain running, its utility being relatively low for the descent process (Patel & Zwibel, 2022). Performing physical effort undoubtedly produces specific effects depending on the altitude at which it is practiced, being the fundamental cause of hypoxia problems (Fernández-Lázaro et al., 2022). As the altitude increases, the atmospheric pressure decreases, and the partial pressure of atmospheric oxygen decreases proportionally, remaining 21% lower than the total atmospheric pressure (Harbour et al., 2022). At high altitudes, the concentration of oxygen in the alveoli is reduced because the water on the respiratory surface evaporates into the inspired air, carbon dioxide is continuously excreted from the lung blood in the alveoli and thus, the two

gases dilute the oxygen in the alveoli (Dempsey et al., 2014). Under these conditions, hypoxia is likely to set in as a hallmark of the increase in altitude with important physiological effects on the human body. The main effects are felt by the cardiovascular system and the respiratory apparatus, their purpose being to maintain the balance between supply and demand of oxygen (Greiwe et al., 2022)

Acclimatization is a process that ensures the adaptation of the body to low conditions of atmospheric pressure and concentration of O_2. During the acclimatization process, the human body goes through a series of physiological changes in order to maintain the body's homeostasis (Hall et al., 2018). The main factors that influence the acclimatization process are the altitude level, the speed of progress, there being also an extremely variable individual component (Albertus-Cámara et al., 2022). These changes are represented by the increase in pulmonary ventilation, the increase in the pulmonary diffusion capacity, the increase in the number of erythrocytes, peripheral angiogenesis and the tissue capacity to use O_2 in conditions of partial low oxygen pressure (Kelley et al., 2022). Low pO_2 exposure stimulates arterial chemoreceptors, which increase alveolar ventilation by about 1.65 times compared to normal conditions. During acclimatization, the stimulation of these chemoreceptors additionally increases the pulmonary ventilation reaching a level by about 5 times compared to the normal level, allowing the human body to adapt to the altitude conditions (Hall et al., 2018). The diffusion capacity following the acclimatization process increases 3 times, in conditions similar to performing physical effort at normal altitude. This increase in the diffusion capacity is due to the dilation of capillaries and the increase of the diffusion surface, the increase in the volume of pulmonary air that increases the alveolar exchange surface and the increase in arterial pressure that causes the penetration of blood into a greater number of pulmonary capillaries than normal. In response to hypoxia, the human body stimulates the production of the erythrocyte series, resulting in the increase of hematocrit and the concentration of Hb (Dempsey et al., 2014). Following a complete acclimatization process, Hb gets to grow about 50 times or even more, because not only the erythrocytic parameters increase, but also the blood volume expands by about 20-30%. As Ht increases during the acclimatization process at altitude, the initial cardiac output increased by approximately 30%, returns to normal values (Björklund et al., 2019).

The phenomenon of neoformation of tissue capillaries is due to hypoxia and is especially evident in the right ventricle following pulmonary hypertension caused by high altitudes (Toyomura et al., 2018). Capillary

angiogenesis is dependent on endothelial growth factors, which occur in response to inducible hypoxia factor (HIF—1) (Lemieux & Birot, 2021). Thus, the researchers launched presumptive hypotheses targeting prolonged exposure to high altitude as being responsible for increasing blood levels of endothelial growth factors. However, through specialized studies, it was found that this phenomenon of angiogenesis was not detected even after prolonged exposures to higher altitude conditions. Even after eight weeks of exposure to an altitude of 4100m, such changes were not detected. Thus, it was concluded that the dependence of the increase in hemoglobin concentration is sufficient to maintain an adequate level of oxygen intake in the muscle and that angiogenesis is not necessary to preserve the delivery of oxygen in optimal parameters to the skeletal muscle (Sinex & Chapman, 2015). The partial low oxygen pressure and the sudden variations in temperature and density of inhaled air are directly responsible for the changes affecting the respiratory system and in particular, the oxygenation process(Lemieux & Birot, 2021). The effect of these changes can compromise individual altitude tolerance, aggravate the already initiated respiratory dysfunction and cause difficulty to exercise (Sinex & Chapman, 2015). For these reasons, the aerobic capacity of an individual, namely VO_2max, is reduced by about 12-16%, and the performance decreases by 6-8%. This is possible because the costs of oxygenation at altitude are much lower than the sea level (Radak et al., 2013). Under favorable conditions, any athlete will get used to the conditions of low atmospheric pressure in about 7—10 days, the acclimatization process being considered complete after 15—20 days. The increased level of erythrocytes offers continuous benefits up to 3 months after the athlete returns to flat conditions (Storz & Scott, 2019). Regarding the optimal moment of return to the flat and participation in the objective competition, the studies offer various piece of information. For these reasons, further studies are necessary, this being one of the main limits of the topic addressed. What is clear, however, is that altitude training has visible beneficial effects on sports performance, which is why it can be assumed that African runners identify themselves as the best runners over long distances because the climate and geographical area naturally offer them these conditions (Płoszczyca et al., 2018).

Materials and methods

Participants

This study included a number of seven subjects, mountain runners of the national mountain running team with remarkable results at national

and international level. The selection of the group of subjects was made by means of very well established criteria: to be male persons; to have at least two years of experience in the field of mountain running; the last VO_2max level recorded maximum one year ago to be superior; sports performances to be important at least at national level; to continue to work as professional athletes throughout the research; to be coached by the same coach and to be registered at the same sports club. The last two criteria were selected in order to facilitate the communication process between the researchers, the coach and the subjects and to ensure the specific physical training in conditions of maximum rigor through a single coach so that the present research is not perched. Because the VO value$_2$max and the percentage of fat mass is correlated with superior performance (Doutreleau, 2021), the body mass indices and ages of all subjects were recorded, the values being found in the following table:

Table 1. The athletes' anthropometric data

Athlete	Age (2022) (years)	BMI (kg/m^2)
A1	23	16.7
a2	38	18.4
a3	26	20.8
a4	35	19.4
a5	30	21.1
a6th	24	22.4
a7th	33	21.4

Legend: cm—centimeters, kg—kilograms, m^2—squared meters.

Procedures

The application of the control samples was carried out according to a rigorous protocol. In order to bring the group of subjects to the same standards, they followed during the research a protocol of general physical training specific to the mountain running test conducted by their coach, in order to maintain all the subjects within the research at an increased level of physical training and to maximize the sports performances of the entire group.

In the research, the tests took place according to the following table:

Table 2. Research framework

Test	Period (year 2022)	Content	Location
IT	April	VO_2max Dairy	Bucharest, INCS
		Race	Campulung Moldovenesc
IntT	Young	VO_2max Dairy Race	Piatra Arsa, Bucegi Mountains
FT	September	VO_2max Dairy	Bucharest, INCS
		Race	Campulung Moldovenesc

Legend: IT—Initial testing, IntT—Mid-term testing, FT—Final testing, INCS—National Sports Research Institute.

IT took place within the first stage of the National Mountain Running Championship, Tint was made on the plateau of the Bucegi Mountains at an altitude of about 2000m in June 2022 after the batch of subjects performed four weeks of training in these conditions, and the final test was carried out at the National Institute of Research for Sport in Bucharest (INCS) and in the final stage of the National Mountain Running Championship (EFCNAM) in Câmpulung Moldovenesc in September 2022.

During the initial tests, the initial VO_2max values was determined according to Bruce's protocol on the treadmill and the performances of the athletes measured as the duration for the specialized competition in which they participated. IntT aimed to highlight the changes occurred within that same set of samples in hypoxia conditions after performing a prior acclimatization of four weeks at altitude of 2000 meters in the national training center Piatra Arsa. The specific sports test within IntT took place only between the subjects of the research simulating a similar route at the same time as the national specialized competitions. FT has reassessed the VO_2max values and the performances obtained at the objective competition within the annual training plan in order to identify the role on the which the altitude had in the process of preparation and in the possible maximization of performances.

Through the values obtained in the three tests, a comparative analysis could be performed between the metabolic behavior of the subjects, of their general reaction and of the organism during the perform intense maximum effort in conditions of low vs. high atmospheric pressure and determine the effect of altitude training camps in mountain runners.

Materials and testing

VO_2max test

For the determination of VO_2max, the subjects were subjected to a test in laboratory conditions, according to a rigorous protocol, because the type of test protocol used to determine VO_2max is especially important for obtaining a real result. In this study, it was opted for the use of Bruce protocol, widely considered superior for the determination of precise VO_2max (Storz & Scott, 2019). Due to the use of this protocol, an overload of the work rate was obtained by means of increasing the speed, inclination or both at a certain time interval. Bruce Protocol consists din practical terms in increasing speed and inclination over seven stages as follows: Level 1—Speed(S) of 2.7 km/h and 10% inclination (E), Level 2—S 4km/h and 12% E; Level 3—S 5.4 km/h and 14% E; Level 4—S 6.7 km/h and 16% E; Level 5—S 8km/h and 18% E; Level 6—S 8.8 km/h and 20% E; Level 7—S 9.6 km/h and 22% E (Vilcant & Zeltser, 2023). Before the actual testing, the subjects performed 15 minutes of static and dynamic gymnastics, 30 minutes of indoor cycling at heart rate less than 120 beats per minute and 8 minutes of light running on the treadmill for getting used to the contact surface. In this test, the parameters recorded were heart rate (HR), O_2 saturation (SPO_2) and lactate concentration (LC). In all their tests, the parameters were measured in three situations: in basal conditions—immediately after the athletes woke up that morning; at the end of the VO_2max test and after 15 minutes of active recovery, respectively walking combined with breathing exercises.

Mountain Race

The sports test involved the completion of a mountain route specific to the short-distance mountain running race, held a week after the VO_2max testing in the framework of the tests. The purpose of the sports test was to achieve an internal ranking of the subjects starting from the premise that there may be a correlation between the results obtained in the VO_2max test and the sports performances that they can achieve. Also, in order to study the group's performance, there were recorded and studied including the positions that the subjects obtained in the general classification of the competitions, except for Tint who it was simulated and participated strictly only by the subjects of the research.

The data regarding the characteristics of the three race routes can be found in the following table:

Table 3. Technical data about the three tests

Test	The Distance Miles	Elevation m	Surface
IT	10,40	+990	<1km paved road off-road
IntT	10,20	+200	off-road
FT	10	+450	<1km paved road off-road

Legend: IT—Initial testing, IntT—Intermediate testing, FT—Final testing, km—kilometers, m—meters, + — plus, <—less than.

The differences in level addressed in both races were similar, but faithfully copying the profile of a route is very difficult because the mountain profile depends on each mountain massif and the geographical region. Thus, two hiking trails in different regions may be similar, but it is impossible to be identical. Also, IT and FT are races that are part of the competition calendar of subjects being objective competitions in which they must participate in order to maintain them in the national team. The characteristics of these routes are stable by the organizer of the competition, namely, the Romanian Athletics Federation (FRA, n.d.) according to WMRA rules (WMRA, n.d).

Statistical Analysis

Using the statistical analysis, it was possible to compare the results obtained in the tests. The tests were compared as follows: IT with IntT; IntT with FT and IT with FT because IntT was deployed at altitude and so the test conditions are different. It was opted for this reason for the application of paired T-Test for the selected test groups and one-way ANOVA test for comparing the values between the VO_2max levels and the places occupied in the internal ranking of the competition in order to analyze whether a VO_2max higher is correlated with a higher position in the ranking of the competitions to specialized ones, using SPSS software (IBM, Romania). Also, media Artimetica (Av), Median (M) were calculated to express the central tendency of the group and Amplitude (A), Standard Deviation (st-dev), Coefficient of Variability (CV) to study the variability and homogeneity of the group. The statistical results could confirm if VO_2max is correlated with obtaining a superior sports performance, if the altitude really improves the sports performance and if after such a training camp the results obtained at the specialized competitions can be superior.

Results

VO_2max results

The results obtained when determining VO_2max within IT, IntT and FT can be found in the following table:

Table 4. VO_2max results

	Basal conditions			At the end of the effort				After effort 15 min		
IT	**H.R. 1**	**SpO_{21}**	**LC_1**	**VO_2max_1**	**H.R. 2**	**SpO_{22}**	**LC_2**	**H.R. 3**	**SpO_{23}**	**LC_3**
A1	48	98	1.1	65.1	197	95	15	95	98	11.6
a2	46	98	1.1	65.3	185	94	13.5	88	97	7.9
a3	49	98	1.5	69.5	184	94	11.7	80	97	8.6.6
a4	48	98	1.7	70.7	190	95	14.4	89	96	8.2
a5	50	98	2	65.2	190	95	12.7	89	96	10
a6th	55	98	1.9	64.1	187	93	13.1	90	96	8.8
a7th	54	98	1.8	70.9	188	92	14.7	100	95	8.3
IntT	**H.R. 1**	**SpO_{24}**	**LC_1**	**VO_2max_2**	**H.R. 2**	**SpO_{25}**	**LC_2**	**H.R. 3**	**SpO_{26}**	**LC_3**
A1	64	97	0.7	64	193	95	16.9	97	97	5.1
a2	62	97	2.7	64	186	93	13.2	77	97	6.8
a3	62	97	2	67.5	179	92	12.6	70	97	9.8
a4	78	97	2.7	73	187	94	13.1	105	92	5.6
a5	78	98	2.9	63.5	185	94	11.9	71	94	9.0
a6th	55	98	2	62.7	192	92	11.6	92	93	7,4
a7th	74	97	1.8	65.2	188	94	12.8	103	97	6.8
FT	**H.R. 1**	**SpO_{27}**	**LC_1**	**VO_2max_3**	**H.R. 2**	**SpO_{28}**	**LC_2**	**H.R. 3**	**SpO_{29}**	**LC_3**
A1	64	98	0.8	67.5	198	96	14.7	90	98	10.8
a2	62	98	0.9	66.3	187	95	13.1	86	98	7.2
a3	62	97	1.4	70.2	187	94	10.5	75	97	7.4
a4	63	98	1.6	75.2	194	96	12.3	85	98	6.7
a5	65	98	1.9	68.4	190	96	13.8	79	98	8.5
a6th	58	97	1.8	66.2	188	94	12	83	97	5
a7th	74	98	1.5	72.6	190	96	15.8	97	98	7.5

Legend: IT—initial test, IntT—intermediate test; FT—final test, HR_1—basal conditions heart rate, SpO_{21}—basal conditions oxygen saturation during IT, LC_1—basal conditions lactate level, VO_2max_1—VO_2max at the initial test, HR_2—effort conditions heart rate, SpO_{22}— effort conditions oxygen saturation during IT, LC_2—effort conditions dairy level, HR_3 —rest conditions heart rate, SpO_{23}—rest conditions oxygen saturation during IT, LC_3—rest conditions lactate level, SpO_{24}—basal conditions oxygen saturation during IntT , SpO_{25}—effort conditions oxygen saturation during IntT, SpO_{26}—rest

conditions oxygen saturation during IntT, SpO_{27}—basal conditions oxygen saturation during FT, SpO_{28}—effort conditions oxygen saturation during FT, SpO_{29}—rest conditions oxygen saturation saturation during FT.

According to table 3, it can be seen that the VO_2max values recorded within FT are superior compared to IT and IntT, which is a sign being an improvement in the maximum consumption rate of O_2 in aerobic conditions after performing the training camp at altitude. Also, most likely, the values lower than VO_2max obtained in all subjects within IntT comparative with IT and FT most likely reveal the hypoxic effects of low atmospheric pressure on the human body and implicitly on sports performance.

Regarding SpO_2, it can be seen that the values obtained within IntT are inferior to those in IT and FT in all three situations measured: basal, effort and rest. This situation denotes the effects that hypoxia imprints on performance capacity and on the transport of O_2 at the cellular level, both under conditions of effort, as well as in basal conditions, which is why coaches must pay extra attention to these values before some intensity workouts, for example, because it could accentuate hypoxia and cause a respiratory acidosis that will in turn decrease sports performance.

The lactate recovery rates were calculated using the following mathematical formula and can be found in Table 4:

$$LRC = 100 - \frac{LC_3 \text{ x } 100}{LC_2}$$

Legend: LRC—dairy recovery rate concentration, LC_3—rest dairy concentration, LC_2—effort lactate concentration.

Table 5. Lactate recovery rates

Athlete	LRC_{IT} mmol/L	LRC_{IntT} mmol/L	LRC_{FT} mmol/L
A1	22,67	69,82	26,53
a2	41,48	48,48	45,04
a3	26,50	22,22	29,52
a4	43,06	57,25	45,53
a5	21,26	24,37	38,41
a6th	32,82	36,21	58,33
a7th	43,54	46,88	52,53

Legend: LRC_{IT}—initial test dairy recovery rate, LRC_{IntT}—intermediate test lactate recovery, LRC_{FT}—final test dairy recovery rate.

Mountain Race results

During the three tests, the duration of the competition trials and the position occupied in the internal ranking were recorded. Within IT and FT, because the competitions were nationwide and not simulated like IntT, the positions occupied in the overall ranking were also recorded.

Table 6. Results at the three competitions

Athlete	**D_{IT} (s)**	**IT** IC	**GC_{IT}**	**D_{IntT} (s)**	**IC_{IntT}**	**D_{FT}(s)**	**THE FT** IC	**PHC** GC
A1	3765	3	3	2388	1	2484	1	2
a2	3642	1	1	2390	2	2559	3	6
a3	3807	4	5	2515	5	2692	5	9
a4	3693	2	2	2414	4	2492	2	4
a5	3904	5	8	2397	3	2561	4	7
a6th	4058	7	10	2550	6	2697	6	10
a7th	3964	6	9	2565	7	2713	7	11

Legend: D_{IT}—duration measured in seconds in initial testing, IC_{IT}—internal classification during initial test, GC_{IT}—general classification at initial test, D_{IntT}—duration measured in seconds in intermediate testing, IC_{IntT}—internal ranking subjects intermediate testing, D_{FT}—duration measured in seconds at final testing, IC_{FT}—internal classification during final testing test, GC_{FT}—general classification at final test, s—seconds.

Statistical analysis

In the following table, are represented the main statistical parameters used for the comparative analysis of HR, SpO_2 and LC within the three tests in the different situations used: basal conditions, of effort and rest post effort.

Table 7. Comparative statistical analysis between the three tests

	H.R. 1 bpm	SpO_{21} %	LC_1 mmol/L	H.R. 2 Bpm	SpO_{22} %	LC_2 mmol/L	H.R. 3 bpm	SpO_{23} %	LC_3 mmol/L
AV_{IT}	50,00	98,00	1,59	188,71	94,00	13,59	90,14	96,43	9,06
Av_{IntT}	67,57	97,29	2,11	187,14	93,43	13,16	87,86	95,29	7,21
AV_{FT}	64,00	97,71	1,41	190,57	95,29	13,17	85,00	97,71	7,59
M_{IT}	49,00	98,00	1,70	188,00	94,00	13,50	89,00	96,00	8,60
M_{IntT}	64,00	97,00	2,00	187,00	94,00	12,80	92,00	97,00	6,80
M_{FT}	63,00	98,00	1,50	190,00	96,00	13,10	85,00	98,00	7,40
A_{IT}	9,00	0,00	0,90	13,00	3,00	3,30	20,00	3,00	3,70
A_{IntT}	23,00	1,00	2,20	14,00	3,00	5,30	35,00	5,00	4,70
A_{FT}	16,00	1,00	1,10	11,00	2,00	5,30	22,00	1,00	5,80
st-dev_{it}	3,32	0,00	0,37	4,31	1,15	1,19	6,20	0,98	1,31
st-dev_{intt}	9,05	0,49	0,76	4,67	1,13	1,75	14,97	2,21	1,70
st-dev_{ft}	4,93	0,49	0,42	4,08	0,95	1,78	7,19	0,49	1,77
CV_{IT}	6,63	0,00	23,15	2,28	1,23	8,76	6,88	1,01	14,45
CV_{IntT}	13,40	0,50	35,75	2,50	1,21	13,33	17,04	2,32	23,56
CV_{FT}	7,71	0,50	29,84	2,14	1,00	13,48	8,46	0,50	23,35

Legend: Av_{IT}—initial test average, Av_{IntT} intermediate test average, Av_{FT}—final test average, M_{IT} — initial median test, M_{IntT}—intermediate median test, M_{FT}—final median test, A_{IT}—initial amplitude test, A_{IntT}—intermediate amplitude test, A_{FT}—final amplitude test, st-dev_{IT} —initial test standard deviation, st-dev_{IntT}—intermediate test standard deviation, st-dev_{FT}—final test standard deviation, CV_{IT}—initial test variability coefficient; CV_{IntT}—intermediate test variability coefficient, CV_{FT}—final test variability coefficient, HR_1—basal conditions heart rate, SpO_{21}—basal conditions Oxygen saturation, LC_1—basal conditions lactate concentration, HR_2—effort conditions heart rate, SpO_{22}—effort conditions Oxygen saturation, LC_2 —effort conditions dairy concentration, HR_3—rest conditions heart rate, SpO_{23} — rest conditions Oxygen saturation, LC_3—rest conditions lactate concentration, bpm—heart beats per minute, %—percent.

Comparing the values in Table 6, it is inferred that in terms of HR in basal conditions, the greatest variability is found within IntT, which emphasizes the effects of hypoxia on the myocardium even in conditions of total rest. In conditions of effort, the highest variability is also found within IntT, but the difference in variability between the three tests is much reduced. Under exercise conditions, the average HRmax recorded was 190 bpm within ft, which denotes the effects of increasing the exercise capacity that altitude training produced on the body of mountain runners.

Regarding SpO_2, lower values were recorded in all three hypostases tested within IntT compared to IT and FT. Although in basal conditions and after effort, Av and M for SpO_2 fall within the physiological limits of more than 95% in the three tests, at the end of the effort, the average values decreased below the physiological limit within IT and IntT. The lowest average spo_2 *values* were recorded at altitude, and although the variability of the group in terms of SpO_2 is a small one, the maximum modified value is found within IntT, thus defining the variability from individual to individual in terms of the adaptation mechanism of the O_2 *transport* in altitude conditions.

Analyzing the concentrations of lactate, it is noticed that although the average concentrations are within the physiological limit, the highest value is found within IntT, which signifies the role of low atmospheric pressure even in basal conditions and the variability of the group is a small one for all tested hypostases and all tests. However, in the three tests, the homogeneity of the group is a medium to high one in the testing in basal conditions and of rest after effort, while in the actual *effort*, the homogeneity is small, which indicates that the altitude affects all individuals in similar conditions.

The results obtained at the Paired T—*Test statistical testing* can be found in the following table:

Table 8. Paired T—Test results

Pair of Variables	95% CID	t—Value	*p*—Value	Result
VO_2max_1—VO_2max_2	(—0.59;3.71)	1,76	0,047	H_0
VO_2max_2—VO_2max_3	(—5,48;-2,08)	—5,43	0,013	H_0
VO_2max_1—VO_2max_3	(—3,43;-1,01)	—4,5	0,003	H_0
LRC_1—LRC_2	(6,44; —26,32)	—1,69	0,15	H_A
LRC_2—LRC_3	(—18,58;21,25)	0,16	0,87	H_A
LRC_1—LRC_3	(—17,43; —1,01)	—2,74	0,03	H_0
SpO_{21}—SpO_{22}	(0,43;2,93)	9,17	0,01	H_0
SpO_{22}—SpO_{23}	(0,36; —3,33)	—6,58	0,01	H_0
SpO_{21}—SpO_{23}	(0,36;0,67)	4,26	0,01	H_0
SpO_{24}—SpO_{25}	(0,5;2,61)	7,59	0,01	H_0
SpO_{25}—SpO_{26}	(0,92; —3,68)	—1,55	0,17	H_0
SpO_{24}—SpO_{26}	(0,89;0,24)	2,71	0,04	H_0
SpO_{27}—SpO_{28}	(0,2;1,93)	12,02	0,01	H_0
SpO_{28}—SpO_{29}	(0,2; —2,92)	—12,02	0,01	H_0
SpO_{21}—SpO_{24}	(0,18;0,26)	3,87	0,01	H_0
SpO_{24}—SpO_{27}	(0,29; —1,16)	—1,44	0,20	H_A
SpO_{21}—SpO_{27}	(0,18; —0,17)	1,55	0,17	H_A
SpO_{22}—SpO_{25}	(0,48; —0,61)	1,19	0,28	H_A
SpO_{25}—SpO_{28}	(1,42; —2,21)	—13	0,01	H_0
SpO_{22}—SpO_{28}	(0,47;-2,45)	—2,71	0,03	H_0
SpO_{23}—SpO_{26}	(0,57;0,17)	2,75	0,03	H_0
SpO_{26}—SpO_{29}	(0,82; —4,89)	—3,45	0,01	H_0
SpO_{23}—SpO_{29}	(0,42; —2,31)	—3,06	0,02	H_0
D_{IT}—D_{IntT}	(1295,85;1479,57)	36,9	0.03	H_0
D_{IntT}—D_{FT}	(—175,03; —104,68)	—9,72	0.02	H_0
D_{IT}—D_{FT}	(1160,59;1335,11)	34,99	0.03	H_0
CG_{IT}—CG_{FT}	(—3,76,0,62)	—1,74	0,04	H_0

Legend: CID— confidence interval of the differences, VO_2max_1—VO_2max_2 —Pair of VO_2max values between IT and IntT, VO_2max_2—VO_2max_3 — Pair of VO_2max values between IntT and FT, VO_2max_1—VO_2max_3 — Pair of VO_2max values between IT and IntT, LRC_1—LRC_2—Pair of dairy recovery rate between IT and IntT, LRC_2—LRC_3 —Pair of dairy recovery rate between IntT and FT, LRC_1—LRC_3 —Pair of dairy recovery rate between IT and FT, SpO_{21}—SpO_{22}—Pair of SpO_2 values between basal and effort conditions in IT, SpO_{22}—SpO_{23} —Pair of SpO_2 values between effort and rest conditions in IT, SpO_{21}—SpO_{23}—Pair of SpO_2 values between basal and rest conditions in IT, SpO_{24}—SpO_{25}—Pair of SpO_2 values between basal and effort conditions in IntT, SpO_{25}—SpO_{26} —Pair of SpO_2 values between effort and rest conditions in IntT, SpO_{24}—SpO_{26}—Pair of SpO_2 values between basal and rest conditions in IntT, SpO_{27}—SpO_{28}—Pair of SpO_2 values between basal and effort conditions in FT, SpO_{28}—SpO_{29}—Pair of SpO_2 values between effort and rest conditions in FT,, SpO_{21}—SpO_{24}—Pair of SpO_2 in basal conditions between IT and IntT, SpO_{24}—SpO_{27}—Pair of SpO_2 in basal conditions

between IT and IntT, SpO_{21}—SpO_{27} —Pair of SpO_2 in basal conditions between IT and FT, SpO_{22}—SpO_{25}—Pair of SpO_2 in effort conditions between IT and IntT, SpO_{25}—SpO_{28}—Pair of SpO_2 in effort conditions between IntT and FT, SpO_{22}—SpO_{28}—Pair of SpO_2 in effort conditions between IT and FT, SpO_{23}—SpO_{26}—Pair of SpO_2 in rest conditions between IT and IntT, SpO_{26}—SpO_{29}—Pair of SpO_2 in rest conditions between IntT and FT, SpO_{23}—SpO_{29}—Pair of SpO_2 in rest conditions between IT and FT, D_{I1}—D_{IntI}—Pair of duration between IT and IntT, D_{IntI}—D_{FT} —Pair of duration between IntT and FT, D_{I1}—D_{FI}—Pair of duration between IT and FT,CG_{I1}—CG_{FI}—Pair of general rank between IT and FT.

In VO_2max testing, it is found that the null hypothesis is rejected within the following three pairs: VO_2max_1—VO_2max_2, VO_2max_2—VO_2max_3, VO_2max_1—VO_2max_3. This means that within the group, for the imposed conditions and factors involved depending on each test, for example the altitude within IntT, *the* VO_2 *max* values were successively improved from one test to another.

Regarding the milk values measured within the three determined hypostases, namely basal, effort and rest, the pairs LRC_1—LRC_2, LRC_2—LRC_3, LRC_1—LRC_3 *were analyzed*. It can be seen that the alternative hypothesis for LRC_1—LRC_2 and LRC_2—LRC_3 *pairs is accepted*, which means that lactate recovery rates were lower in IT compared to IntT and higher within IntT compared to FT. This is explained by the hypoxic effect of altitude on the human body and the variety of options by which the human body can respond to these effects. This supports the idea that each organism is individual and the response to hypoxia is also individual. Thus, no correlations were found between the production of lactate in altitude conditions compared to plain conditions, and the low atmospheric pressure conditions do not determine a lower rate of restoration of the lactate concentration within the maximum aerobic effort. However, it is noted that the null hypothesis is accepted within the LRC 1-LRC_3 *pair*, which means that the lactate recovery rate was higher within the TF compared to IT, which can contribute to increasing the results in the specialized competitions of mountain runners.

In all pairs analyzing SpO_2, the null hypothesis is rejected except for the pairs: SpO_{24}—SpO_{27}, SpO_{21}—SpO_{27}, SpO_{22}—SpO_{25}. This explains why SpO_2 recorded in basal conditions was higher in IT and FT compared to IntT, which again denotes the effect of hypoxia on the concentration of O_2 at the tissue level in altitude conditions. The alternative hypothesis is accepted for the pair SpO_{21}—SpO_{27} because there were no changes between the Values of SpO_2 measured under base conditions within IT compared to FT. Also, analyzing the pair SpO_{22}—SpO_{25}, the alternative hypothesis is accepted because the values recorded within IntT under stress conditions compared to those in FT under stress conditions are lower, this means that

hypoxia reduces the concentration of O_2 in tissues at the completion of maximum aerobic effort in altitude conditions. In the rest of the SpO_2 *pairs*, the null hypothesis is rejected, which underlies the fact that in all three tests: IT, IntT and FT, in basal conditions, the highest values of the O_2 *concentration* in the tissues were recorded, that at the end of the effort this concentration was decreased compared to the basal level, but after 15 minutes of active rest, the concentration returned to physiological values for all subjects. This fact concludes that SpO_2 decreases in conditions of effort regardless of the conditions of flat or altitude, that the decrease is more accentuated in conditions of effort at altitude compared to the conditions of plain and that the recovery after 15 minutes of break brings the saturations *closer to* those in basal conditions both in the plain and at the altitude, but the restoration is individual and not all subjects necessarily reach the initial values. However, the recovery in all the tests brought SpO_2 back to the physiological limits regardless of the altitude at which the effort test takes place.

In the mountain running test, analyzing the pair of variables D_1—D_2, D_2—D_3, D_1—D_3, the null hypothesis is rejected, which means that there have been improvements in the sequence of tests addressed for the distance and elevation traveled by athletes within each mountain running route approached. As regards the pair CG_1—CG_3, it is also found *that* the null hypothesis is rejected and that the positions occupied in the general classification within FT are superior compared to those obtained in the IT framework, which is why it can be stated that the athletes have registered superior sports performances within FT, most likely due to the implementation of the training camp at altitude in the annual training plan.

The results obtained within the ANOVA territory can be found in the following table:

Table 9. VO_2max and the position occupied in the ranking (Anova results)

Rank	No.	Av mmol/L	*st-dev*	Min mmol/L	Max mmol/L
1	3	65,6	1,76	64,00	67,50
2	3	69,9	5,63	64,00	75,20
3	3	64,9	1,4	63,50	66,30
4	3	70,3	2,4	68,40	73,00
5	3	67,6	2,5	65,20	70,20
6	3	66,6	4,11	62,70	70,90
7	3	67,3	4,62	64,10	72,60

Legend: No.—number, AV—average, st—dev — standard deviation, Min — minimal value, Max —maximum value.

Using the one-way ANOVA test to compare the values between VO_2max levels and the places occupied in the internal ranking of the competition, it was found that the value p=0.465 accepts the alternative hypothesis, namely that it is not a significant difference in obtaining a higher place in the ranking of the specialized competition if the value of VO_2max is higher. It can also be seen that the vo_2 **max minimum value** was recorded for both first and second **place**, while the maximum value VO_2max was recorded in second place and the positions in the rankings, respectively 4, 5, 6 and 7. This means that a superior VO_2max does not condition the achievement of a superior performance in the ranking of a mountain running competition and that obtaining such a result is conditioned by a multitude of other factors for the physical, tactical, technical or mental component.

In the second stage of the research, we designed a SEM PLS model to test the validity of 2 hypotheses:

H1: Favorable basal conditions positively influence the results and

H2: Intense effort negatively influences the results

A first step in testing hypotheses is to verify the correlation between variables.

Table 10. Correlation between variables

	Basal	*Effort*	*Results*
Basal	1		
Effort	-0.420	1	
Result	0.782	-0.882	1

Table 10 demonstrates a very strong positive correlation between Basal and results variables (0.782) and a very strong negative one between Effort and Results (-0.882). These very strong correlations allow us to realize the model in Fig.1.

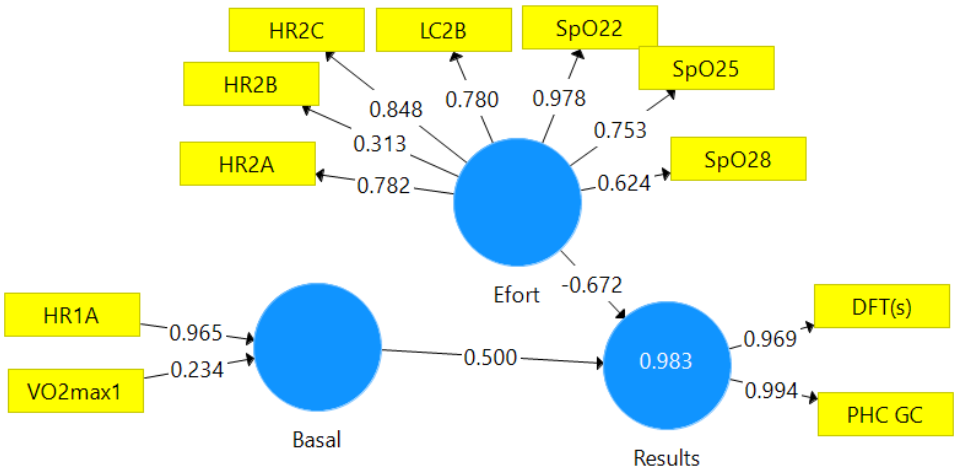


Figure 1. R Square coefficient, Track-side coefficients and Weighting of variables (LF=loading factors)

The Path Analysis coefficients BasalResults (PA=0.500) and EffortResults (PA= -0.672) confirm the assumptions H1 and H2 (Fig 1). The model consists of 2 reflective variables (Effort and Results) and a formative one (Basal).→→

The Basal formative variable consists of 2 HR1A sub-variables, which represent the Heart Rate value at the initial moment...., having a very high loading factor (LF=0.965), so a very strong influence and VO_2max1 at the initial moment.... with a LF=0.234, so a small influence.

The Reflective Effort variable consists of several sub-variables including:

- HR2A (LF=0.782), HR2B (LF=0.313), HR2C (LF=0.848) – note that HR is very high at times A and C (why?)
- LC2B with a high loading factor (LF=0.780), so with a large weight in the value of the Variable Effort
- SpO22 (LF=0.978), SpO25(LF=0.753) and SpO28 (LF=0624) – to explain why they have these values and to refer to the above texts

The Results reflective variable consists of several sub-variables including:

- DFT(s) (LF=0.969), PHC GC (LF=0.994) with very large LF, (why?)

The F and R Square tests presented in Table 2 demonstrate the power of our model. The calculated Square F has higher values than the tabular ones for the Basel and Effort variables, which denotes that the factors from which these variables are composed are representative of the model. The very high value of R Square demonstrates the very strong correlation (0.930) between the variables. The vainness of the independent variables Basel and Effort explains 98% of the variance of the dependent variable, since the Adjusted R square has a wave of 0.980.

Table 11. Tests F and R Square

	F Square	*R Square*	*R Square Adjusted*
Basel	12.305		
Effort	22.219		
Result		0.983	0.980

Further on, using the SmartPls software, the consistency of the presented model was validated based on the parameters set in Table 11 (Hair et al., 2017; Sarstedt et al., 2022), relying on rho_A value which is greater than 0.7, the minimum acceptable threshold, for all the model variables. It was noticed that Cronbach's Alpha and Composite Reliability values have very high values, greater than the minimum threshold accepted 0.7 and AVE also have very high values greater than the minimum threshold accepted 0.5 (Table 11). Cronbach's Alpha coefficient proves that all sub-items that form the our 3 variable are very relevant for the model.

The Heterotrait- Monotrait criterion proves the discriminant validity of the model, meaning that each variable measure a different element.

Table 12. Model validation steps (Source: the authors)

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)	Heterotraite-Monotraite
Basal		1			
Effort	0.902	0.923	0.894	0.564	
Results	0.981	0.982	0.982	0.964	0.843

Furthermore, in order to verify the validity of the model, a bootstrap analysis to confirm the hypothesis has been performed (Table 12), using the PLS-SEM analysis, which is a renowned bootstrap procedure that allows testing the significance of the subsequent applied tests: path coefficients,

Cronbach's alpha, and R^2 values. From the analysis, the Path coefficient Basal → Results is 0.500 (Tstat= 3.14 and p value=0.002) demonstrates and confirms the H1 and Effort→ Results is - 0.672 (Tstat= 4.7 and p value=0.000) demonstrates and confirms the H2. T Statistics for these regressions have high values that T critical and P values have lower values than the maximum accepted threshold = 0.05 (Hair et al., 2017; Sarstedt et al., 2022).

Table 13. T Statistics and P Values of Bootstrapping analysis (Source: the author)

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
Basal → Results	0.500	0.477	0.159	3.14	**0.002**
Sustainability → Waste	-0.672	-0.665	0.143	4.7	**0.000**

Discussion

The aim of the present study was to determine if a VO_2max superior conditions reaching a higher position in the general ranking of mountain running races within high performance athletes specialized in the mountain running, because similar studies have shown that for other athletics samples, such as 5,000m, 10,000m, hammer throwing, triple jumping or rowing the effects are beneficial (Dunn, 2018; Hamlin et al., 2018; Cerda-Kohler et al., 2022) .

The main purpose of this study was to assess whether altitude is indeed an important factor in increasing sports performance for mountain runners as other articles in the field suggest (Dragos et al., 2022; Lukanova-Jakubowska et al., 2022; Alanis et al., 2022; Furian et al., 2022) and whether the implementation of an altitude training camp in the annual training plan may determine the increase of sports performances.

The second important purpose was to analyze the effects that low atmospheric pressure causes on the human body, both under basal and effort conditions , and to compare the response the body in the two different hypostases: altitude vs. flat. It has been observed in several studies that low atmospheric pressure causes hypoxia (Girard, 2022; Billaut et al., 2022) and reaching a lower max VO_2 (Pühringer et al., 2022), but performing a cantonment of preparation at altitude with a duration of at least 4-6 weeks (Mujika et al., 2019; Deldicque, 2022). leads to the increase of biochemical parameters such as: 2.3—BPG, Hb, RBC, EPO (Ploszczyca et al., 2018; Baranauskas et al., 2022; Beidleman et al., 2017) and implicitly of the

performance sports (Girard et al., 2020) and VO_2max (Lukanova-Jakubowska et al., 2022; Mancera-Soto et al., 2022))

Also, it has been observed that if the tendency of SpO_2 is to decrease in altitude conditions, the rate of lactate recovery is not influenced, which is why an individual response to hypoxia is obtained from each athlete.

As it has been identified in other studies, the hypoxic effects of the altitude determine the obtaining of a vo_2max lower value compared to the results obtained in flat (41), which is translates into lowering the upper aerobic threshold. However, this does not mean that the results obtained in a mountain running race are conditioned in a similar way.

Conclusions

The highlights of this study were firstly that a VO_2max superior does not automatically result in obtaining a higher position in the general ranking of a mountain running competition, which is why it can be stated that a number of other factors are the determinants of obtaining such a result, such as physical training, indemnity, suppleness or mental attitude in relation to the competition. Also, at altitude, the maximum aerobic threshold of the athletes is reduced, which is why the determination of the VO_2max values will be lower compared to the values obtained at flat.

Secondly, it has been observed that SpO_2 decreases in conditions of effort regardless of the area where the testing is applied: flat or altitude. The effects of hypoxia on SpO_2 cause the decrease of the O_2 concentration from the tissue level to altitude either in basal and effort conditions or after active recovery. After 15 minutes of active rest, the SpO_2 values return to physiological values regardless of the atmospheric pressure. However, each organism is unique, which is why the response to hypoxia differs from one individual to another.

Thirdly, no correlations could be found between the production of lactate at altitude compared to the flat and it was also observed that the altitude does not determine in the maximum aerobic effort a lower rate of recovery of the lactate concentration. Also, the lactate recovery rate is just another parameter that contributes to the increase of sports performances, because in this research, it has been observed that a better lactate recovery rate conditions the achievement of a superior performance in specialized competition.

Last but not least, it was noticed that a series of values were superior within the FT, which is why it can be concluded that in order to record superior sports performances, performing a well-thought-out altitude

training camp leads to obtaining the main objective within the mountain runners.

Patents

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to the fact the respondents gave their consent to use the research results.
Informed Consent Statement: Ethics approval and consent to participate was granted. After receiving information on the objectives and procedures of the study, the participants signed an informed consent form, which complied with the ethical standards of the World Medical Association's Declaration of Helsinki (2013). The study was approved by the ethics committee of San Jorge University with registration number: 009-18/19.
Data Availability Statement: The datasets generated and analyzed for this study can be requested via correspondence with the author at iulia.gainariu@student.unitbv.ro.
Conflicts of Interest: The authors declare no conflict of interest.
List of Abbreviations: VO_2max—maximum aerobic capacity; SpO_2—oxygen saturation; O_2 — oxygen; ATP—adenosine triphosphate; pCO_2—partial pressure of carbon dioxide; pO_2—partial pressure of oxygen; Hb—hemoglobin; HT—the hematocrit; HIF—1— hypoxia inducible factor; m-meters; cm—centimeters, kg—kilograms, m^2—squared meters; IT—Initial testing, IntT—Intermediate testing, FT—Final testing, INCS—National Sports Research Institute; S—speed; E—elevation; km/h— kilometers per hour; HR— heart rate; LC—dairy concentration; WMRA—World Mountain Running Association; Av—average; M—median; A—amplitude; st—dev—standard deviation; CV—variability coefficient; LRC—dairy recovery rate concentration; D_{IT}—duration measured in seconds at initial testing; IC_{IT}—internal classification during initial test; GC_{Ti}—general classification at initial test; D_{IntT}—duration measured in seconds at intermediate testing; IC_{InT}—internal ranking subjects intermediate testing; D_{FT}—the duration measured in seconds at the final test; IC_{FT}—internal classification during final test; GC_{FT}—general classification at final test, CID—confidence interval of the differences, D—duration; No. —number; 2,3—BPG—bisphosphoglyceric acid; RBC—red blood count; EPO—erythropoietin.

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