Pilot Study on VO_{2max} Assessment and Oxygen Uptake on Normal and Hypoxic Environments

Patrícia Alexandra Mota Esteves
(patricia.a.esteves@gmail.com)
Dissertação de Tese de Mestrado em Engenharia Biomédica –Prof. Miguel Tavares da Silva

Resume
VO_{2max} is a key physiological determinant of an athlete´s running performance. Howley et al. 1995 defined VO_{2max} as the highest rate at which oxygen can be taken up and utilized by the body during severe exercise and therefore it is also used to indicate the cardiorespiratory fitness of an individual.
With this work, we want to test a control group of less conditioned individuals and groups of runners and athletes well trained to determine their maximal oxygen uptake (VO_{2max}), during a treadmill protocol developed at sea level and in hypoxia conditions, simulating training in altitude. With the personal data collected, we want to investigate if there is a correlation between Age, Height, Weight, BMI and physical activity with the calculated VO_{2max}.
The participants will follow a treadmill protocol of three to five minutes, with constant speed and varying grade. The grade of the treadmill would increase 2,5% each thirty seconds running.
The average maximal oxygen uptake value (VO_{2max}) for all the participants in this study was 51,67 ± 13,85 $ml.kg^{-1}.min^{-1}$.
The study also showed that there is no correlation between Age, BMI, and VO_{2max}.
Regarding exercise, VO_{2max} appears to increase with the frequency of exercise.
The altitude results showed that there is a low correlation (negative) between the two variables with R^2 of 0,33.
This may indicate that with higher VO_{2max} the reaction and possible adaptation to hypoxia will be better. However the results were a bit inconclusive on whether training has an important influence over hypoxic environments.

Key-Words: oxygen uptake, VO_{2max}, altitude, hypoxia, running.

Introduction

Bassett and Howley 2000 defined maximum oxygen uptake (VO_{2max}) as the highest rate at which oxygen can be taken up and utilized by the body during severe exercise.
The oxygen uptake increases with the exercise intensity up to a maximum value, called VO_{2max}, a plateau that even if the intensity of the exercise raises the oxygen uptake will not increase anymore.
One way to possibly change this plateau value is through an elevation in the blood hemoglobin concentration and therefore the oxygen content and this has been shown in the studies with hypoxic environments Stray-Gundersen et al. 2001, Levine and Stray-Gundersen 1997 and Burtscher et al. 1996.
The motivation for this work is to analyze and calculate this variable, VO_{2max}, which is very beneficial for an athlete in terms of their performance or just an individual starting to exercise. The extent by which VO_{2max} can change with training also depends on the starting point. The fitter an individual is to begin with, the less potential there is for an increase.
This way, it can become a motivation not only for sedentary individuals starting to train but also for athletes chasing better results accordingly to their VO_{2max}. The evolution in

training may be measured through VO_{2max} calculation and investigate the efficiency of gas exchange during training.
We will also investigate if there are characteristics more advantageous than others to have a better VO_{2max} and also investigate what are the factors that can improve this variable.
The aim of this study is with the help of several volunteers from the age of 18 until 61 years old, with different sports backgrounds and level of current physical condition, to measure the VO_{2max} value of each participant and correlate these values with the level and intensity of exercise preformed every week.
Among the thirty participants that took part in this study, there is a control group of less conditioned individuals and a group of better trained individuals.
The group of less conditioned individuals is characterized for a lack of training habits and a sedentary lifestyle in contrast to the better conditioned individuals with very active daily life, and some of them working out every day.
Between the group of better trained individuals, we have two types of training, some are runners and some do intensity interval training in the gymnasium.
Having this in mind, we will test every participant in a treadmill running protocol that took into account the work developed by Taylor et al. 1955, Howley et al. 1995 and Kennard and Martin 1984.
This protocol will allow us to establish a VO_{2max} for each participant and then compare the values obtained. With this, we can assess the influence of training methodologies on the VO_{2max}, if there is a VO_{2max} trainability and the influence of genetics on the oxygen uptake, since there are some sedentary individuals among the participants in the test.
Later on we want also to compare the values obtained with the better-conditioned athletes in a hypoxic environment simulating training in altitude and assess the influence of these conditions in oxygen uptake values. Having this done, we want to evaluate the adaptability of these participants in a hypoxic environment.
The VO_{2max} was successfully calculated for all the participants and distributed normally among the sample.

Methodology

Thirty healthy subjects took part of the study and were fully informed about the associated risks and the procedures, before giving written informed consent to participate in the treadmill running protocol approved by an institutional ethics committee.
Only half of the participants was familiar with treadmill running, consequently, laboratory exercise testing procedures were all explained and there was always a person near the treadmill giving support and motivation to the participant running. The studies were conducted in an air-conditioned laboratory maintained at approximately 22°C. Subjects were asked to walk on a motor-driven treadmill at 4 km/h up for warm up during 2 to 3 minutes. After this, the participants rested for about 1 min, and then ran for 3 minutes with increasing grades. The subjects ran at a constant speed of 8km/h starting on 0,0% grade for the first 30 seconds. For each 30 seconds the treadmill would rise 2,5% until the end of 3 minutes, with a final grade of 12,5%.
The participants in this study consisted of fifteen men and women. 30% had ages from 18 to 25, 13% had ages from 26 -35, 13% had ages from 36-45, 37% had ages from 46-55 and 7% were over 55.
Relatively to the physical condition 73% affirmed that they exercised regularly and 27% are more sedentary and are less active daily. From the 73% of active subjects, 43% run and the other 30 % go to the gym and/or train HIIT.
Regarding the frequency of training about 26,66% % train 4 times to everyday, 46,66% train 1 to 3 times a week and 26,66%% do not train.

BMI from the participants was also calculated, 73,33% have normal weight, 23,33% are overweight and 3,33% are underweight.

Results Discussion

VO_{2max} at Sea Level

The results were attained by the gas analyzer for each subject and were analyzed for the determination of the VO_2 plateau.
Below, we have an example of the oxygen consumption during time when following the running treadmill protocol.
The criteria chosen for the determination of a plateau was an existence of at least three sequential points separated by less than 300 ml.min^{-1}. In Table 1 we can see the validation of this criteria.

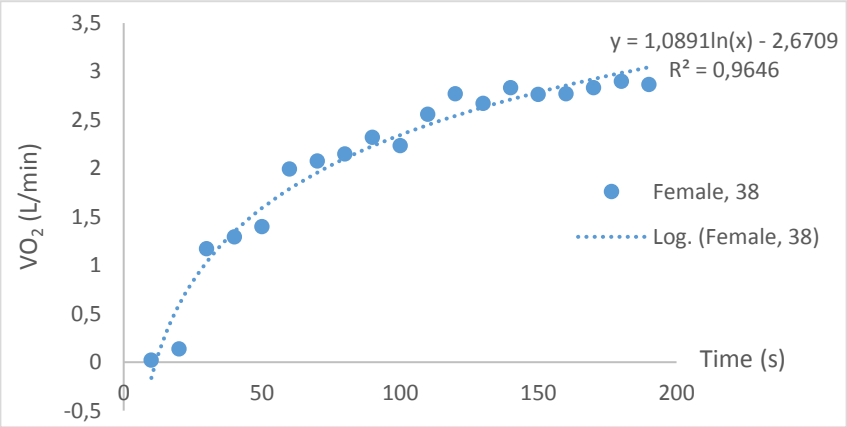

Figure 1 - Results for the oxygen volume uptake of an active female during a treadmill protocol.

Table 1 - Plateau definition for the VO_2 results of an active female

Time (s)	Grade (%)	VO_2 (l.min^{-1})	|diference| (l.min^{-1})
120	7,5	2,77	0,10
130	10	2,67	0,16
140	10	2,83	0,07
150	10	2,76	0,01
160	12,5	2,77	0,06
170	12,5	2,83	0,06
180	12,5	2,90	0,03
190	12,5	2,86	0,10

The oxygen consumption increases with the intensity of the exercise, which means for this test, with the increasing grade of the treadmill. As a first analysis we can see that the curve behavior translating the VO_2 with time can be described through a logarithmic relationship, once the variable R^2, regarding the adjustment of the variables is close to 1, which proves a strong relationship.

The average maximal oxygen uptake value (VO_{2max}) for all the participants in this study was 51,67 ± 13,85 ml.kg^{-1}.min^{-1}.
For the female individuals the average maximal oxygen uptake value (VO_{2max}) was 54,28 ml.kg^{-1}.min^{-1} and for the male individuals the average maximal oxygen uptake value (VO_{2max}) was 49,05 ml.kg^{-1}.min^{-1}.
The highest value, 89,19 ml.kg^{-1}.min^{-1} was attained by an experienced female runner with 48 years old who plateaued with a max VO_2 value of 4,48 L.min^{-1}.

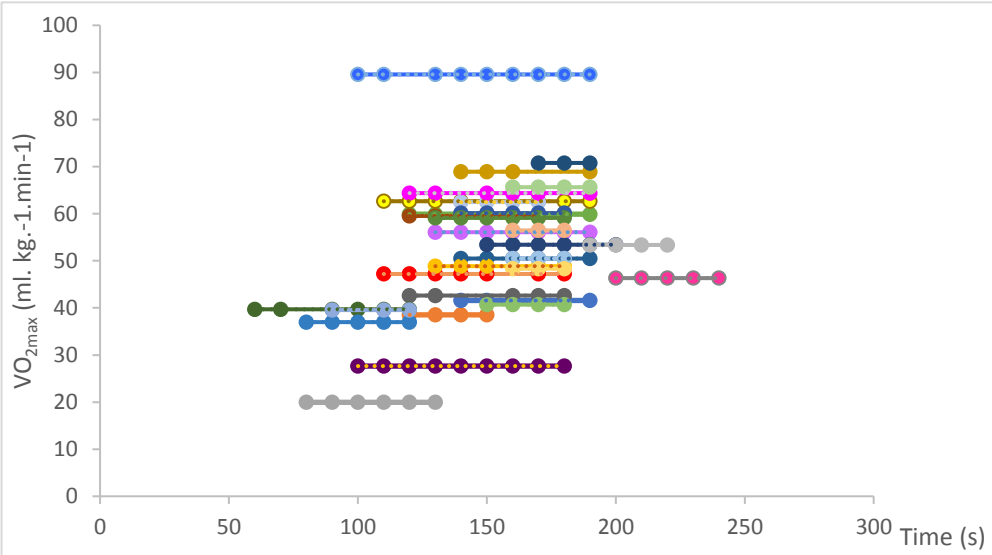

Figure 2 – Results for the VO_{2max}

Intravariability
To assure if the protocol and acquisitions were performed correctly and the VO_{2max} was well calculated, the same subject was tested four times, to check if there is any intravariability of the data.

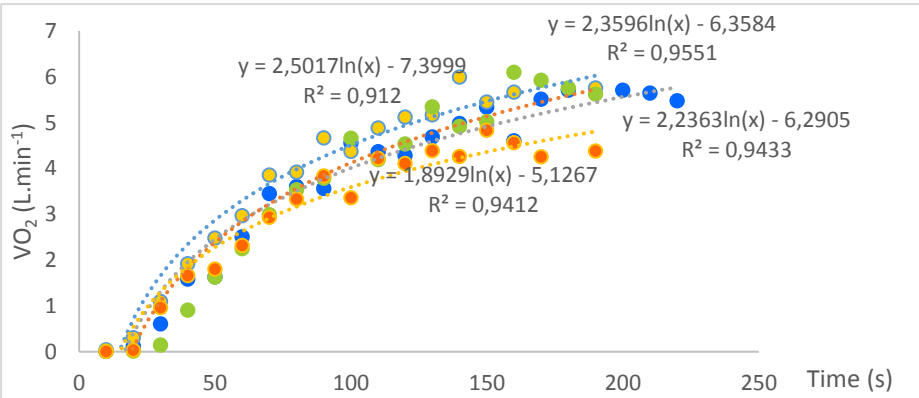

Figure 1 - Intravariability of a male with 31 years old with four acquisitions

As we can see from the chart above (Figure 3), the data collected from the four acquisitions is very similar.
The results show little difference between the acquisitions except the 4th acquisition where the results vary more when compared to the other acquisitions. The value calculated for the VO_{2max} is significantly lower which may have various reasons.
In first place, all three acquisitions where done very close to each other about two or three days apart. However, the 4th acquisition was done about one week after the last

acquisition, which may indicate that the individual got used to the protocol and may not have put enough effort on the last test.
It can also translate some evolution in training and higher preparation for the test.
Because of this, the athlete may have plateaued on a lower VO_2, leading to a wrong calculation of the VO_{2max}.
One possible way to recalculate the VO_{2max} would be to change the speed of the protocol.

VO_{2max} with gender

According to some studies, there are no significant sex differences in VO_{2max} or between groups with different performance levels in marathon running. Results in Helgerud, J. 1994 show that the female runners have about 10% higher utilization of VO_{2max} then men, in spite of a higher VO_{2max}, in the men than in the women ($P<0.05$).
The explanation for this was that a more extensive endurance training of the women probably resulted in an increased "aerobic fitness", indicating that they are able to exercise at a higher proportion of their VO_{2max}. Because of this, Helgerud, J. 1994 discuss that women match men performances due to a superior running economy and ability to exercise at a higher proportion of VO_{2max} during the marathon race.
The results in this study showed, however, that the mean VO_{2max} for the female group was higher (54,28 ± 15,50 $ml.kg^{-1}.min^{-1}$) than the men (49,05 ± 11,93 $ml.kg^{-1}.min^{-1}$).

	Gender	N	Mean	Std. Deviation	Std. Error Mean
VO_{2max}	Male	15	49,05	11,93	3,08
	Female	15	54,28	15,50	4,00

Table 2 - VO_{2max} with gender group statistics

The mean VO_{2max} of the men tested regarding the men indicates a good maximal aerobic power, and the female mean VO_{2max} indicates an excellent maximal aerobic power, when compared with the tables provided by the American College of Sports Medicine (ACSM). Given the data available in the literature these results in spite of being contradictory may be justified by our sample. The women who volunteered to participate in this study are fitter then the men, exercise more regularly and because of that may have led to a wrong conclusion. The sample is very heterogeneous regarding all parameters evaluated and because of that the conclusions may not agree with studies performed with more homogeneous and competitive athletes.
Nevertheless, to access if there is a statistical significant difference between the mean VO_{2max} of female and male individuals it was performed an independent t test using the software SPSS. It was concluded that there isn't any difference between the average VO_{2max} between groups (female and male), since our p-value (Sig. 2-tailed) for the t-test for equality of means is higher than the alpha value (0,309 > 0,05).

VO_{2max} with age

When the participants signed the consent to participate in this study, they had to fill one form with their data, regarding age, weight, height and physical activity. The data collected and the results are resumed in Table 3.

Age (years)	N	Minim VO_{2max} (ml. $kg^{-1}.min^{-1}$)	Maxim VO_{2max} (ml. $kg^{-1}.min^{-1}$)	Mean VO_{2max} (ml. $kg^{-1}.min^{-1}$)	Standard Deviation (ml. $kg^{-1}.min^{-1}$)
All	30	19,96	89,57	51,67	13,85
x < 25	9	27,65	65,01	52,58	12,26
26 < x < 35	4	48,26	65,25	55,07	7,20
36 < x < 45	4	38,53	65,63	48,93	12,14
46 < x < 55	11	19,96	89,57	50,99	18,62
x > 56	2	39,99	59,90	49,95	14,08

Table 3 - SPSS descriptive statistics for all of the age groups

From looking at the table it does not seem to be a correlation between VO_{2max} and age. The higher value for VO_{2max} in each age group varies between 60 and 70 ml.kg^{-1}.min^{-1}. On the age group from 46 to 55 years old the higher value of VO_{2max} is registered, with 89, 57 ml.kg^{-1}.min^{-1} from an experienced female runner. Contrarily to what was expected, a higher age group had the higher VO_{2max} value, even though studies have shown that VO_{2max} decreases with age. Betik, A. C. 2008 report in their study that age is associated with a progressive decline in the capacity for physical activity, corroborating a reduction in the maximal rate of oxygen utilization, or VO_{2max}.
The first step in studying the relationship between two continuous variables (VO_{2max} and age) is to draw a scatter plot of the variables to check for linearity. The results showed a very weak (positive) linear relationship since the R^2 value is of 0,01.
To investigate if there is any statistically significant differences between the means of the age groups we can perform a one-way analysis of variance (ANOVA).
We can assume that there are no statistically significant differences between group means as determined by one-way ANOVA (F (2,27) = 1.88, p = 0.830).

VO_{2max} with BMI

Another factor also collected in the data provided by the participants was the weight and height that together make possible the calculation of the BMI. BMI was calculated based on the weight and height given, through the following expression:

$$\text{BMI} = \frac{weight\ (kg)}{height^2\ (m)}$$

BMI	N	Max VO_2 (ml.kg^{-1}.min^{-1})	BMI (Max VO_2)
(20 - 25) Normal	22	89,57	21
(< 20) Underweight	1	59,11	19
(> 25) Overweight	7	68,92	26

Table 4 - VO_{2max} distribution among the BMI groups

From these results presented on table 4, we can see that the group of BMI with the higher VO_{2max} is the group of participants with normal BMI from 20 to 25. Nonetheless, the person having the higher VO_{2max} of 89, 57 ml.kg^{-1}.min^{-1} has a BMI of 21, which is in the inferior limit of normal BMI, almost considered Underweight. Only one person represents the group of participants underweight, or low BMI, from the sample, which means that

the results are not statistically significant to extrapolate a correlation between people with low BMI and VO_{2max} based on this study.
Regarding the group of overweight, or high BMI there are seven subjects tested.
The result for the higher VO_{2max} is from a subject very well conditioned with high training habits. This subject has a high BMI because the formula for its calculation only takes in consideration height and weight. This subject, in spite of being considered overweight based on this calculation, has little body fat and high lean and muscle mass. Due to this, the subject´s weight is higher, and not due to fat. That is where this formula fails to report reality, since it doesn't translate body composition. An individual with big weight is not necessary overweight. The correlation studied should be between body fat and VO_{2max} and studies showed that the lower the weight, the higher the VO_{2max}.
To investigate this, it should have been performed a waist circumference measurement or skinfold measurement in this study. However this last one is very dependent on the expertise of the technician and anatomical knowledge to obtain accurate measurements.
Nevertheless, the study of Shete et al. 2014 showed a negative correlation between VO_{2max} and body fat percentage but was not statistically significant.
To access if there is a correlation between this variable, BMI, and $VO_{2max,}$ it was considered the statistical method of linear regression. The results showed a very weak (positive) linear relationship once the R^2 value is of 0, 02. So, accordingly to these results, there appears to be no linear relationship between BMI and VO_{2max}.
There are no statistically significant differences between the BMI group means as determined by one-way ANOVA ($F(2,27) = 1.88$, $p = 0.830$).

VO_{2max} with exercise

The last factor to be analyzed and that was also collected in the data provided by the participants was exercise.
Subjects were asked to indicate if they did exercise, and in the case they did, what was the type of exercise, distinguishing between running and gymnasium, and also how frequently they exercised. The results are represented on the figure 4.

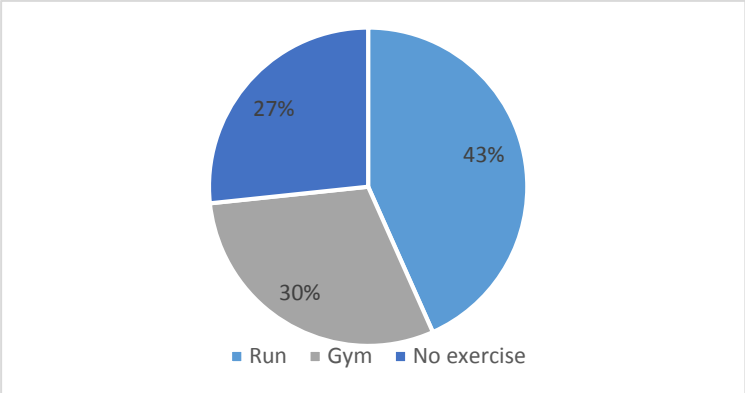

Figure 2 - Type of training

From looking at the figure above we can see that almost one third of the sample does not exercise (27%). From the other 73% of the sample, 43% runs and 30% goes to gym and does interval training.
We wanted to see if there is a relationship between frequency of exercise and VO_{2max} so the sample was divided in three groups regarding the frequency of training about 26,66% % train 4 times to everyday (group 3), 46,66% train 1 to 3 times a week (group 2) and 26,66%% do not train (group 1).

Exercise group	Mean ($ml.kg^{-1}.min^{-1}$)	St. Deviation ($ml.kg^{-1}.min^{-1}$)	Maximum ($ml.kg^{-1}.min^{-1}$)	Minimum ($ml.kg^{-1}.min^{-1}$)
1	47,07	16,70	65,01	19,96
2	48,67	8,90	65,63	36,98
3	61,51	14,68	89,57	39,99

Table 5 - Descriptive statistics for the variable frequency of exercise with VO_{2max}

We can see from the results in table 5 that the mean VO_{2max} increases with the frequency of exercise. The group of subjects with no exercise habits have the poorer VO_{2max} value of 19,96 $ml.kg^{-1}.min^{-1}$. The group of subjects with higher frequency of exercise, higher than 5 times a week have the higher mean VO_{2max} and also the higher VO_{2max} value registered, 89, 57 $ml.kg^{-1}.min^{-1}$.
Looking from the tables available by American College of Sports Medicine (ACSM) the values obtained are slightly high, namely the female runner with a 89, 57 $ml.kg^{-1}.min^{-1}$ VO_{2max}. For her age group the value considered as a superior fitness category is values of VO_{2max} over 46,1 $ml.kg^{-1}.min^{-1}$.Probably this women has an excellent VO_{2max}, however the calibration of the system may have misled the results with an overestimated value.
The women high the lowest VO_{2max}, 19,96 $ml.kg^{-1}.min^{-1}$ for her age group has a very poor maximal aerobic power which is consistent with the lack of regular exercise reported.
There are no statistically significant differences between group means as determined by one-way ANOVA ($F(2,27) = 3,218$, $p = .056$). However, because the p value is very similar to the alpha value, Dorey, F. 2010 refer that the sample size might not be enough evidence to reject, H0 (H0): $\rho = 0$, that all group means are the same.

VO_{2max} at altitude

To investigate if the VO_2 changes with the atmosphere content, this is, hypoxia or sea level conditions, thirteen volunteers agreed to return to the lab and repeat the running protocol in this conditions. The figure below represents the results for the VO_2 evolution through time when the protocol followed is in hypoxia conditions. The values of oxygen uptake attained at hypoxia increased significantly when compared to sea level values, but there are some irregularities when it comes to defining a plateau at altitude, contrarily to sea level conditions. The growth of the oxygen consumption is not as smooth and logarithmic as the consumption at sea level (Figure 5).
In spite of the irregularities, we can still interpret the VO_2 evolution at hypoxia conditions through a logarithmic behavior since the adjustment coefficient (R^2) given is 0,72, which is still a strong adjustment. Still, not as strong as the sea level correlation (R^2) of 0,96.

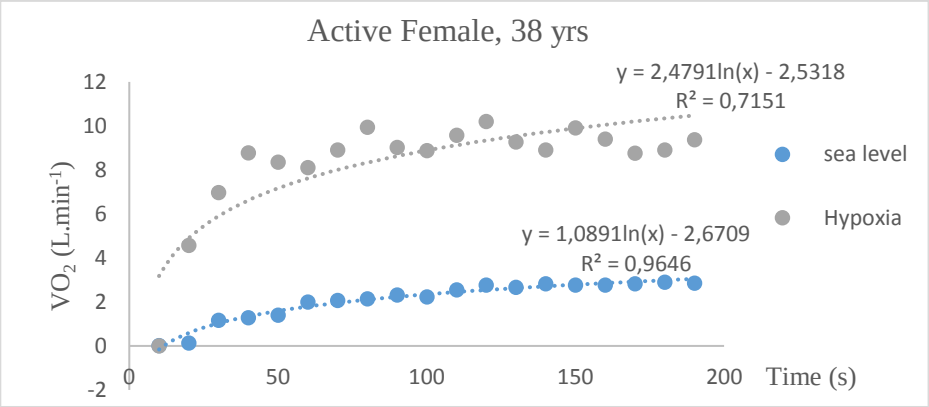

Figure 3 - Differences between VO_2 at sea level and hypoxia

Because the plateau in hypoxia is not well defined, and does not meet the criteria defined previously for the achievement of a plateau it was decided to analyze VO_2 peaks, instead of VO_2 plateaus.
Table 6 has the results of the comparison between the maximum value of VO_2 at sea level and at simulated altitude, which was calculated by the following expression:

$$\text{Difference between } VO_{2peaks} = |max(VO_{2peak})_{hypoxia} - max(VO_{2peak})_{sealevel}|$$

Table 6 - Results VO_{2peaks} at altitude

Subject	Difference between VO_2 peaks ($l.min^{-1}$)	VO_{2max}	Physical Condition	Age
Female	2,30	70,78	Run (3/4x week)	52
Female	3,31	89,57	Run (3/4x week)	48
Male	6,41	48,26	Gym (3x week)	35
Male	6,73	63,33	Run (4 x week)	43
Female	7,31	50,48	Gym (3x week)	38
Female	7,48	60,13	Gym (4x week)	23
Female	7,48	49,49	Run (3/4x week)	52
Male	8,02	67,53	Gym (4x week)	31
Female	8,53	56,45	Gym (4x week)	19
Female	9,98	59,90	Gym + Run (4 x week)	59
Male	10,57	56,07	Run (3/4x week)	51
Female	10,60	40,04	Run (1x week)	48
Female	11,32	62,65	NA	21

Some athletes had greater differences in VO_2 then others, but all of them had higher VO_2 peaks at simulated altitude instead of sea level. The least change in VO_2 peaks occurs with the athletes with higher values of VO_{2max} from the sample of athletes.
This may be indicative that a reaction to hypoxia may be better.

Final Considerations

The primary aim of the present investigation was to better clarify the VO_2 response to exercise and determinate a VO_{2max} plateau through a running treadmill protocol. As a first analysis the results showed that the curve behavior translating the VO_2 with time can be described through a logarithmic relationship, once the variable R^2, regarding the adjustment of the variables is close to 1 which proves a strong relationship.
For all the subjects tested it was possible to establish a plateau and determine their VO_{2max}. The values obtained were distributed normally among the sample. The average maximal oxygen uptake value (VO_{2max}) for all the subjects was 51,67 ± 13,85 $ml.kg^{-1}.min^{-1}$.
Regarding gender, the results showed a normal distribution of VO_{2max} between genders. The VO_{2max} for the female group was higher (54,28 ± 15,50 $ml.kg^{-1}.min^{-1}$) than the men group (49,05 ± 11,93 $ml.kg^{-1}.min^{-1}$), nonetheless, after performing a p-value test it was concluded that the difference is not any statistically significant between the mean VO_{2max} of the female and male group, with a confidence interval of 95%.
Regarding age, this study showed that there is no correlation between this variable and VO_{2max} contrarily to the literature available. However size sample should be higher to

confirm this. There were no statistically significant differences between age groups VO_{2max} means as determined by one-way ANOVA (F (4,25) = 0.108, p = 0,978).
Regarding BMI, this studied showed that there is no correlation between this variable and VO_{2max}. There are no statistically significant differences between group means as determined by one-way ANOVA (F (2,27) = 1.88, p = 0.830). Even so, the highest VO_{2max} came from a subject with one of the lowest BMI which indicates that BMI may influence VO_{2max} more than what here assessed.
Regarding exercise, VO_{2max} appears to increase with the frequency of exercise. By dividing the sample in groups of frequency of exercise from none, to 1-3 times a week and higher than 5 times a week we can see that the mean VO_{2max} value increased from 47,07 $ml.kg^{-1}.min^{-1}$, to 48,67 $ml.kg^{-1}.min^{-1}$, to 61,51 $ml.kg^{-1}.min^{-1}$, respectively.
The highest VO_{2max} registered, 89, 57 $ml.kg^{-1}.min^{-1}$, belongs to a subject on the group of higher frequency of exercise. The lowest VO_{2max} value of 19, 96 $ml.kg^{-1}.min^{-1}$belongs to a subject on the group of the no exercising. There was a statistically significant difference between groups as determined by one-way ANOVA (F(2,27) = 3,218, p = .056).
Finally, regarding altitude the observations were a bit contradictory indicating that for some people training has an important influence over the adaptation to different conditions while running, for fewer people, the frequency of train did not seem to improve their hypoxia reaction. This may indicate that there are some other factors influencing the process of acclimatization that were not taken into account here in this study. The results from the scatter plot show that there is a low correlation (negative) between the two variables with R^2 of 0,33. This may indicate that with higher VO_{2max} the reaction and possible adaptation to hypoxia will be better.
Given the results and the conclusions of this study there are some suggestions concerning future work that would not also complement this study but also explore some other fields less investigated. From an athlete and performance point of view, it would be interesting to test the evolution of VO_{2max} after following a protocol of high intensity or even endurance program during a few weeks. Not only athletes with active lifestyles but also sedentary people and quantify how much the levels of VO_{2max} can actually change.

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