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Cardiovascular Alterations in Workers Performing at High Altitude on the Etna Volcano

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Abstract: Background: high-altitude work exposes individuals to reduced oxygen levels, imposing physiological adaptations. These conditions can induce alterations in the cardiovascular system, potentially exacerbating pre-existing health issues and impacting overall well-being of workers in such environments. This study has investigated the cardiovascular challenges for the high-altitude worker on Etna volcano. Methods: Through an observational study, ten healthy, non-smoking male participants underwent cardiovascular and pulmonary function tests at altitudes below 500m and above 3000m, simulating work conditions on the volcano. Results: significant findings include elevated systemic blood pressure and heart rate, indicating an increased cardiovascular workload necessary for adaptation to hypoxia. Conclusions: the study highlights the importance of acclimatization to high altitude for minimizing cardiovascular risks among workers. It calls for the development of safety protocols, underlining the critical role of preventative measures and specific safety protocols for high-altitude workers.

Keywords: High altitude workplace; occupational medicine; cardiovascular alterations; CVDs; Etna

1. Introduction

Mountainous regions, representing a significant portion of the Earth's surface, are an ideal setting to study the effects of high altitude on human physiology, particularly the cardiovascular system. The physiological adaptation to high altitude imposes an increased workload on the cardiovascular system, with physiological responses that can represent stress for the human organism [1].

Previous study, have identify high altitude, as an altitude > 2500 meters slm. This high level, imposes a particular strain on the cardiovascular system due to hypobaric hypoxia, necessitating physiological acclimatization to maintain tissue oxygenation [2].

Workers at high altitudes face important challenges, including reduced oxygen levels that can impact health and performance. Adaptation involves physiological changes to cope with hypoxia [3].

Many studies have, indeed, highlighted the importance of acclimatization, which includes an increase in ventilation, blood volume and oxygen transport capacity, as well as metabolic changes at the microvascular and cellular level to maintain adequate levels of tissue oxygen [4].

However, exposure to high altitude is also associated with increases in systemic blood pressure, heart rate at rest and during exercise, and minute ventilation, as well as vasoconstriction of the pulmonary circulation leading to increased resistance pulmonary vascular and pulmonary arterial pressure [1].

These conditions could represent a health risk, in particular, for those with pre-existing cardiovascular pathological conditions [1]. In Sicily (Italy), there is the highest active volcano in Europe: the Etna [5]. It represents an important resource for the region. However, the neighboring population is not free from problems related to its activity [6]. Its monitoring conducted from many workers who periodically work at high altitudes also [5].

The aim of the study is to investigate the interactions between high altitude and the cardiovascular health of subjects working at high altitude on Etna Volcano.

2. Materials and Methods

2.1. Study Design

An observational study was conducted in the spring/summer of 2023-2024 to investigate the physiological changes induced by exposure to high altitude on the cardiovascular system of subjects working at high altitude. The tests were conducted on the Etna volcano, taking advantage of its altitude to reproduce working conditions at high altitude. Each participant performed specific physical activities that included a 200-meter climb at an 18% gradient and a two-hour walk carrying a backpack weighing 3 kg. For each subject, two tests (test A and B) were carried out on two different days: test A) test carried out at an altitude <500 m above sea level; test B) test carried out at an altitude >3000 m above sea level. The tests took place in similar weather conditions, at the same altitude at start (T0) and at the end (T4) less the 100 m above sea level with temperatures between 20-24°C, to ensure consistency of test conditions. This was possible by carrying out measurements in the spring period for test A and in the middle of summer for test B.

2.2. Sample Characteristics

The study sample consisted of 10 healthy, non-smoking males, the participants were selected from workers, residing on the slopes of Etna, at an altitude lower than 500 meters above sea level, who work occasionally (less than 20 days/year) at high altitude. Before participation, a medical evaluation was carried out to exclude the presence of cardiovascular or respiratory diseases. All workers invited to take part in the project were informed about the objectives and procedures of the study and provided written informed consent. It was not necessary to receive confirmation from the ethical committee as the activity is governed by the Law Decree (DL) 81/08 article 25 within the health promotion actions.

2.3. Tests Conducted

All subjects underwent a medical examination, including a history of family history of cardiovascular disease, measurement of systolic (SBP) and diastolic (DBP), basic electrocardiographic (ECG) examination, blood pressure, and measurement of heart rate (HR) with an electrocardiograph (ESAOTE P8000, Genoa, Italy).

Venous blood (10 ml) was collected to carry out routine tests, also taking into account the lipid profile of each subject.

Each subject was provided with a cardiac Holter (HoC) device (Spiderview & Synescope v3.10, MICROPORT®, Clamart, France) and a blood pressure Holter (Hop) (Agilis MiniTM, MICROPORT®, Clamart, France).

The HoC and Hop measurements were carried out continuously for about 10 h: 2 h before (T0), upon arrival at altitude (T1), after the ascent phase (T2) after 2 hours of staying at altitude (T3) and at end (T4).

Before starting the recording, each subject was asked not to carry out physical activity and to drink coffee in the previous 2 hours; only a light meal and drinking water were allowed.

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Oxygen saturation was conducted using a GIMA Mindray PM-60 Pulse Oximeter.

Pulmonary function tests were conducted using a spirometer (SpiroLab, MIR, Padua, Italy) (Rapisarda et al. 2015). Equipment, calibration and maneuvers met ATS guidelines [7]. Forced vital capacity, forced expiratory volume in 1 s, peak expiratory flow, maximal expiratory flow at 25–75% of vital capacity, and total lung capacity were measured and expressed as a percentage of European Community reference values of Coal and Steel adjusted for individuals. characteristics (age, weight and height) recorded at the time of testing (Hansell et al. 2008).

2.4. Statistical Analysis

Statistical analysis was performed with SPSS software (IBM Corp., SPSS Statistics for Windows, version 23.0, Armonk, NY, USA). The collected data were entered into an ad hoc database. Descriptive statistics were used to characterize the groups of subjects in the study and the association between the different variables was analyzed with a chi-square test (X2) or Fisher's exact test and Student's t test. Furthermore, one-way ANOVA was applied to compare the variables for all three time points (T0-T4). Statistical significance was set at $p<0.05$.

3. Results

The sample consisted of 10 (100%) males, healthy volunteers, mean age 39.4 ±7.3 years, BMI 24.93 ±4.8. 70% (n=7) of participants practiced at least 1 hour of sport per week. Only 20% (n=2) consumed at least one unit of alcohol per day. None had a positive family history of cardiovascular pathologies (see Table 1).

Table 1. Main characteristics of the sample.

Variables	*n=10 (100%)*
Age (years)	
Male	39.4 ±7.31
100% (n=10)	
BMI (kg/m2)	24.93 ±4.8
Alchool Consume (>2 AU/week)	20% (n=20)
Playing sport (≥ 1h/week)	70% (n=7)
Family history of CVD	No (100%)

AU=Alcohol units, 12g of ethanol.

The analysis of the pulmonary function indices did not show significant variations between the measurements at T1 compared to T0 in both test A and test B measurements; furthermore, no significant changes were observed at T0 and T1 between tests A and B.

However, a statistically significant reduction in respiratory parameters measured at T2 was observed in both test A and test B compared to the measurements conducted at T0, T1 and T4. This reduction also persisted at T3, but only in test B. Furthermore, there was a statistically significant reduction in the FVC and FEV_1 parameters at T2 of test B and compared to test A.

The O_2 saturation detected at T1 and T0 in both test A and B did not show statistically significant variations; also, between tests A and B (at T0 and T1). However, a statistically significant reduction in O_2 parameters measured at T2 and T3 was observed, but only in test B compared to the measurements conducted at T0, T1 and T4. This reduction was statistically significant both at T2 and T3 also compared to test A (see Table 2).

Table 2. Lung function indices and O_2 saturation measured from T0 to T4, in the A and B tests.

	T0	**T1**	**T2**	**T3**	**T4**
FVC (%)-A	101,2 ±3,9	100,2 ±3,4	93,3 ±5,9^	97,8 ±4,8	99,2 ±3,2
FVC (%)-B	103,1 ±4,1	99,1 ±6,9	90,1 ±2,3^"	92,1 ±2,3°*	99,4 ±5,1

FEV1 (%)-A	99,2 ±2,3	99,4 ±2,2	95,3 ±5,9^	97,3 ±5,9	99,8 ±3,7
FEV1 (%)-B	99,3 ±3,1	97,9 ±3,3	91,1 ±2,3^”	94,1 ±2,3°*	98,1 ±4,6
PEF (%)-A	97,3 ±3,4	97,4 ±2,3	94,1 ±4,1^	95,5 ±3,5	98,3 ±3,6
PEF (%)-B	98,2 ±2,5	97,9 ±2,9	93,5 ±3,7^	95,4 ±3,4°	97,8 ±3,5
SO_2 (%)-A	98,6 ±1,2	98,3 ±1,3	96,2 ±4,8	97,3 ±3,8	98,5 ±1,6
SO_2 (%)-B	98,2 ±0,9	97,6 ±1,9	93,5 ±3,7^”	93,3 ±5,6°*	98,3 ±1,6

^p<0,05, T2 vs. T0, T1 and T4; ”p<0,05, T2B vs. T2A; °p<0,05, T3 vs. T0, T1 and T4; *p<0,05, T3B vs. T3A.

The results of the measurements of the cardiovascular parameters blood pressure (SBP and DBP) and cardiac function (HoC) did not show statistically significant variations between the measurements at T1 compared to T0 in both test A and test B measurements, furthermore no significant variations were observed between the findings of test A and test B (see Table 3).

Table 3. Results of cardiovascular parameters measured from T0 to T4 in the A and B tests.

	T0	**T1**	**T2**	**T3**	**T4**
HoP (mmHg)-A SBP	123,1±8,7	135±8.2	175±18,4^	148±23,5°	123,1±8,7
HoP (mmHg)-B SBP	124,2±9,2	138±10.7	196±21,6^”	167±25,3°*	124,2±9,2
HoP (mmHg)-A DBP	82.6±12,5	84.9±12,8	94,3±8,4^	93,3±8,4°	83.7±15,8
HoP (mmHg)-B DBP	81,9±14,2	84,6±13,3	105,7±10,3^”	102,5±11,9°*	84,2±17,3
HR (bpm)-A	77,4±5,7	79,6±6,3	120,8±10,7^	100,5±10,7°	80,4±9,2
HR (bpm)-B	78,9±6,1	83,3±7,2	144,5±20,6^”§	124,5±23,5°*	82,6±10,1

^p<0,05, T2 vs. T0, T1 and T4; ”p<0,05, T2B vs. T2A; °p<0,05, T3 vs. T0, T1 and T4; *p<0,05, T3B vs. T3A; §p<0,05, T2B vs. T3B.

A significant increase in mean blood pressure (SBP and DBP) and mean heart rate were observed at T2 compared to measurements at T0, T1 and T4, in both test A and B (see Table 3).

A significant increase in SBP, DBP and HR parameters was observed at T2 in test B compared to test A.

The HR value on test B at T2 was also significantly higher than at T3. Furthermore, an increase in SBP, DBP and heart rate values was detected at time T3 when conducting test B compared to test A.

No electrocardiographic abnormalities were detected in all measurements.

4. Discussion

The study on the cardiovascular health of high-altitude workers, particularly on Mount Etna, investigates into a significant area of research, highlighting the physiological challenges of the operators. For the chronical exposition, the acclimatization throughout enhanced ventilation, increased cardiac out-put, augmented red cell mass and blood oxygen-carrying capacity, and metabolic adaptations at microvascular and cellular levels, ensure an adequate oxygen supply despite the reduced atmospheric pressure. While acute ascent to high altitudes may adversely affect cardiovascular health in the people, particularly in those with pre-existing diseases (2,8).

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The results of the study regarding the cardiovascular health of high-altitude workers on Etna volcano offer a profound insight into the adaptive and non-adaptive physiological changes induced by high altitude, emphasizing the importance of acclimatization processes and the potential risks for individuals with pre-existing cardiovascular conditions.

The study has shown that the physiological responses to high altitude, such as increased systemic blood pressure and heart rate, confirm with the concept of hypoxic pulmonary vasoconstriction and systemic vascular resistance. These responses are critical adaptations to maintain oxygen delivery in the face of reduced atmospheric oxygen. However, the elevation in HR and blood pressure, particularly noted at high altitudes, indicates an increased cardiovascular workload, which could potentially exacerbate pre-existing cardiovascular conditions, highlighting the necessity for careful cardiovascular health management in such environments [9]. The acute response is dominated by increased sympathetic tone, which results from hypoxic stimulus of the peripheral chemoreceptors. This activation of the autonomic nervous system increases in proportion to the level of hypoxia and is sustained or increases throughout the duration of altitude exposure [10].

In the present study, analysis were conducted at 4 different times: 2 hours before departure (T0); T1 arrival at altitude with off-road vehicle; T2 ascent to altitude; T3 stay at altitude with a 2-hour walk; T4 descent. The average data obtained from the analysis of blood pressure monitoring (HoP) show that at times T0 and T1, no significant variation is observed either in test A or in test B. On the contrary, at time T2 there is a notable increase in both of systolic blood pressure than diastolic blood pressure, with a significantly greater increase in test B. This increase in physical effort can be attributed to the ascent of 200 meters on foot on rough and steep terrain, with an 18% gradient. The difference in blood pressure detected at T2 between tests A and B can be attributed to the altitude at which the two tests are carried out, which in fact present a similar degree of difficulty (ascent 200 m and slope 18%). This data is supported by the SpO2 which is markedly reduced in test B compared to A. A confounding factor present in test B compared to test A derives from the presence at altitude (>3000 m) of constant fumaroles which expose the worker to aqueous vapours, carbon dioxide, sulfur dioxide (SO_2), etc. which is emitted into the atmosphere at temperatures between 250-1000 °C [11].

Moving from T2 to T3, in the case of test A there is a reduction (return towards normal values) in both SBP and DBP, while in the case of test B a slight suggested SBP is observed, which therefore always remains significantly high. This discrepancy is due to the fact that in time T3, compared to T2, the subjects were engaged in physical activity of lower intensity, which included a walk at high altitude. However, while in test A a return to blood pressure values close to normal was observed, in test B the average arterial pressure remained high, especially the SBP which maintained values above 160 mmHg on average.

This data can be correlated to what has already been said previously, i.e.,: high altitude hypoxia, but exposure to airborne particles present in the summit area of the volcano cannot be ruled out. In the literature, there are no studies on volcanic fumes of this type and the effects on the cardiovascular system; while there are numerous studies on environmental pollution and its effects on humans (12,13). In particular, on the impact of SO_2 and the increased risk of cardiovascular diseases, which affects the number of emergency hospitalizations in cardiology departments and increases mortality from cardiovascular diseases, especially in the age group over 65 years old [13–15].

Furthermore, a study conducted on animals showed that an increase in SO_2 as an environmental pollutant and particles in the previous days leads to a significant increase in SBP, but not in DBP [16].

The results of a retrospective study based on people exposed to SO_2 for a long period demonstrated a correlation between the level of exposure and blood pressure [17]. Finally, a prospective study conducted on subjects exposed to SO_2 confirmed that systemic blood pressure increases as the concentration of the gas in the atmosphere increases [18].

But none of these studies reported a reduction in SpO_2. This would strengthen the hypothesis that the predominant factor in metabolic changes is staying at high altitude after intense physical effort, in subjects not accustomed to staying at high altitude.

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However, at T4 (corresponding to the return to altitudes lower than 500 m above sea level) in both test A and test B, a return of blood pressure values to normal was detected.

From the data collected, it seems possible to deduce that working at high altitude leads to an increase in blood pressure, especially during sub-maximal efforts. Furthermore, it seems that remaining high, despite moderate intensity activity, does not allow a return to optimal blood pressure values, in particular with regard to SBP. However, at time T4, when one is below 500 m above sea level, in both test A and test B, a rapid return of blood pressure values to normal is observed. This indicates that altitude itself can influence blood pressure regulation and lead to increased values, especially during intense exertion and can reduce the system's ability to regulate or reduce blood pressure.

Previous studies show that the effect of altitude on blood pressure shows considerable individual variability. Typically, changes in blood pressure below 2500-3000 slm may not be clinically relevant. However, some people react abnormally to high altitude, experiencing a significant increase in blood pressure. Unfortunately, there is currently no method to identify these people in advance before climbing to high altitudes [19].

Taking into account the increases in blood pressure, which can exceed normal limits, it is plausible to hypothesize that frequent exposure to high altitude in the absence of adaptation, especially in hypertensive subjects, could determine the onset of pathologies, including hypertensive heart disease, coronary artery disease and myocardial infarction, stroke (particularly haemorrhagic type), renal failure and therefore an increased risk of mortality [20].

In summary, severe or prolonged high blood pressure can have a significant impact on cardiovascular health and cause serious damage to target organs. This highlights the importance of considering the long-term effects of high-altitude hypoxia on the cardiovascular health of workers exposed to such conditions.

Study limitation: it is important to underline that our study was conducted on ten, healthy subjects, who did not have pre-existing arterial hypertension or other cardiovascular pathologies and who were not used to staying at high altitudes frequently.

5. Conclusions

In conclusion, this study highlighted how exposure to high altitude significantly influences cardiovascular parameters, such as blood pressure and HR, confirming the need to adopt preventive measures and specific safety protocols for workers exposed to these conditions. The observed change in cardiovascular parameters reflects the body's adaptation to hypoxia and highlights the importance of carefully monitoring the health of workers at high altitude.

The prevention and management of risks related to chronic hypertension become fundamental aspects in protecting the health of workers who carry out their work in high-altitude environments [21].

The need for adequate safety protocols and specific training for workers on identifying and managing symptoms related to high altitude is highlighted by our analysis and existing literature. These protocols should include cardiovascular medical evaluations before assigning the worker to work at high altitude, and strategies for progressive acclimatization to the hypoxic environment, in order to minimize risks to cardiovascular health [21–23].

Further research is needed to more fully explore individual responses to high altitude and to develop more effective strategies for prevention and management of cardiovascular risks. These studies will need to overcome current limitations, including small sample size and short duration of observation, to provide more definitive and applicable data to the high-altitude working population.

In this context, the role of the occupational physician becomes central in identifying and managing the risks associated with exposure to high altitude, ensuring the safety and health of workers, considering any pre-existing conditions that could increase the risk of complications [24].

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Ermanno Vitale; Supervision, Ermanno Vitale, Nektaria Zagorianakou, Marco Barbanti and Venerando Rapisarda; Validation, Giulia Laterra, George Dounias and Andrea Marconi; Visualization, Giulia Laterra, Serena Matera and Ginevra Malta; Writing – original draft, Ermanno Vitale, Giulia Laterra, Veronica Filetti and Andrea Marconi; Writing – review & editing, Venerando Rapisarda.

All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study complied with the ethical principles of the Declaration of Helsinki. All participants provided written informed consent. This study was carried out by a cohort of workers within the framework of occupational health surveillance in accordance with the Italian Law (no. 81/2008).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflicts of interest.

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