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CARDIORESPIRATORY HEALTH EFFECTS ASSOCIATED WITH ACUTE EXPOSURE TO HYDROTHERMAL GAS EMISSIONS FROM FURNAS VOLCANO

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RESUMO

O vulcão das Furnas localiza-se na parte oriental da ilha de São Miguel (Açores, Portugal), onde a atividade vulcânica é marcada por várias manifestações hidrotermais que emitem continuamente gases vulcânicos, inalados pela população residente (exposição crónica) ou visitantes dessa localidade (exposição aguda). Tendo em conta a atmosfera característica das Furnas e a falta de estudos sobre os efeitos da exposição aguda aos gases vulcânicos, este trabalho foi desenvolvido com o objetivo de responder a duas questões: (1ª) Quais são os efeitos decorrentes de uma exposição aguda a gases vulcânicos num grupo de voluntários, em relação à frequência cardíaca e tensão arterial, saturação periférica de oxigénio e parâmetros da função pulmonar? (2ª) Qual a constituição química do condensado dos gases vulcânicos de uma das fumarolas das Furnas?

Os resultados da oximetria, espirometria, pressão arterial e frequência cardíaca obtidos da exposição aguda de um grupo de voluntários às fumarolas mostram que apenas a frequência cardíaca foi afetada significativamente. A diminuição do valor da frequência cardíaca desde a pré-exposição até à pós-exposição indica que a exposição à elevada concentração de CO_2 da atmosfera das fumarolas teve um efeito calmante e relaxante nos voluntários.

De forma a ter-se uma noção dos elementos químicos presentes nas emissões a que os voluntários estariam expostos, foi efectuada uma recolha de amostras do condensado dos gases, sendo as mesmas analisadas em termos de elementos químicos. Os resultados mostram que o condensado das fumarolas das Furnas é maioritariamente constituído por Ca, Na, Si e K.

ABSTRACT

Furnas volcano is located on the eastern part of the island of São Miguel (Azores, Portugal), where volcanic activity is marked by several hydrothermal manifestations that continuously emit volcanic gases, inhaled by the resident population (chronic exposure) or visitors to that locality (acute exposure). Taking into account the characteristic atmosphere of Furnas and the lack of studies on the effects caused by acute exposure to volcanic gases, this study was developed with the aim to answer two questions: (1st) What are the cardiorespiratory effects resulting from an acute exposure to volcanic gases on a group of volunteers, namely regarding heart rate and blood pressure, peripheral oxygen saturation and lung function parameters? (2nd) What is the chemical constitution of Furnas volcanic gases condensate?

The oximetry, spirometry, blood pressure and heart rate measurement results obtained from the acute exposure of a group of volunteers to the fumaroles showed that only the heart rate was significantly affected. The decrease in the heart rate value from the pre-exposure to the post-exposure period indicates that exposure to the high CO_2 atmosphere of the fumarole had a calm and relaxing effect on the volunteers.

The elemental composition of Furnas volcanic gases condensate was determined in order to better evaluate the environment that volunteers would be exposed to when visiting Furnas. The results show that the chemical composition of the Furnas fumarole condensate is mainly Ca, Na, Si and K

INTRODUCTION

All around the globe, it is possible to find examples of geographic coexistence of human populations with volcanoes, as it happens, for example, in the subduction complexes of Greece and Italy, in the Southeast Asian arc systems, in the East African Rift system, in the "Ring of Fire" of the Pacific Ocean and in the oceanic islands of "hotspot" volcanism (*e.g.* Azores, Iceland and Hawaii) (Blong, 1984; Small & Naumann, 2001). Volcanoes are well known for their capability of originating soils rich in nutrients, which result from rapid erosion of structures (made up by lava and ash) but also by their massive potential of destruction associated with eruptive episodes, which many times occur without warning (Simkin & Siebert, 2000). In addition to these stunning events, more discrete events occur although also potentially lethal at long term, such as the release of toxic gases and fine particulates by active volcanoes (during or after eruptions), not only through the main crater but also through fumarolic fields and soil diffuse degassing. Thus, on one hand, populations living in close proximity to active volcanoes may obtain benefits from volcanic activity, but on another hand, their lives and health may well be under threat on a daily basis (Amaral & Rodrigues, 2011).

Every day several tons of different compounds are produced and ejected by active volcanoes. Depending on their chemical composition, the way they are expelled, their physicochemical characteristics, and the proximity of humans to the volcano, these compounds may pose a hazard to humans (Blong, 1984).

The main volcanic gases and aerosols produced by an active or dormant volcano are carbon dioxide (CO_2) and water vapour (H_2O), which together constitute more than 70% of the emissions. Volcanoes also release others gases in smaller amounts, such as hydrogen (H_2), hydrogen chloride (HCl), hydrogen fluoride (HF), hydrogen sulphide (H_2S), carbon monoxide (CO), methane (CH_4), sulphur dioxide (SO_2), sulphuric acid (H_2SO_4) and radon (Rn) (Delmelle & Stix, 2000; Amaral *et al.*, 2006; Amaral & Rodrigues, 2011).

Depending on the type of gas emitted, the degree of hazard from volcanic gases varies. Some gases are poisonous while others are dangerous only if present in such high concentrations that they block oxygen respiration. From a health perspective, the most important volcanic gases and aerosols are CO_2, SO_2, Rn, H_2S, HCl, HF, and H_2SO_4. Exposure to these has been the cause of the majority of volcanic gas-related pathologies and fatalities (Williams-Jones & Rymer, 2000). Volcanic emissions are also responsible for releasing to the environment several essential and nonessential metals and metalloids, the following elements being produced in higher amounts: aluminium (Al), arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), magnesium (Mg), mercury (Hg) and rubidium (Rb) (Delmelle & Stix, 2000; Amaral *et al.*, 2006; Amaral & Rodrigues, 2011). This volcanic environment is a reason for concern since it contaminates the resident population and visitors via the polluted atmosphere, water and food (Abiye *et al.*, 2011; Dahal *et al.*, 2008; Queirolo *et al.*, 2000). The main threats from heavy metals to human health are associated with exposure to arsenic, cadmium, mercury and lead (Järup, 2003).

Compounds present in volcanic emissions can be transported to great distances by water and wind, although the surrounding environment is always the most polluted area (Vigneri *et al.*, 2017). So, for people living near active volcanoes and for scientists and tourists visiting them, toxic gases, aerosols and metals are a potentially serious health hazard (Durand *et al.*, 2004).

Exposure to volcanic emissions, even at low but constant concentrations, can cause health pathologies such as the development of chronic respiratory diseases like acute bronchitis (Amaral & Rodrigues, 2007; Iwasawa *et al.*, 2009; Longo & Yang, 2008), and it has been associated has a risk factor for the development of cancers, such as thyroid cancer (Russo *et al.*, 2015; Vigneri *et al.*, 2017), breast cancer (Amaral *et al.*, 2006; Kristbjornsdottir & Rafnsson, 2013; Russo 2015), lip, oral cavity and pharynx cancers (Amaral *et al.*, 2006) and prostate, stomach, kidney, lymphatic and haematopoietic tissue cancers (Kristbjornsdottir & Rafnsson, 2013; Russo *et al.*, 2015). These studies have demonstrated that populations that are chronically exposed to volcanically active environments have a higher risk for cytotoxicity and genotoxicity on the upper respiratory tract tissues, as well as for developing other respiratory pathologies and several types of cancer. Studies regarding the human health effects of acute exposure to volcanic gases are scarce, being to this date the work of Durand *et al.* (2004) the most notable in that area. Their study showed that the excretion rate and concentration of Al and Rb in urine were increased following exposure of only 20 minutes to volcanic gas emissions.

The Furnas Volcano case

The Azores archipelago is composed of nine islands situated in the centre of the North Atlantic Ocean, about 1,500 km west of continental Portugal, where the African, Eurasian and American lithosphere plates meet (between 36°45′-39°43′N and 24°45′-31°17′W) (Searle, 1980). Seismic and volcanic activity is frequent in the archipelago (Ferreira *et al*., 2005). São Miguel, the largest island, is formed by three major active central volcanoes (Furnas, Fogo and Sete Cidades), linked by rift zones (Guest *et al*., 1999). Furnas volcano is located on the eastern half of the island, where volcanic activity is marked by several hydrothermal manifestations consisting of active fumarolic fields, thermal and cold CO_2-rich springs, and soil diffuse degassing areas (Ferreira *et al*., 2005; Viveiros *et al*., 2009). Gases released in these diffuse degassing areas are essentially carbon dioxide (CO_2) and radon (^{222}Rn), the latter a radioactive gas (Linhares *et al*., 2015). The work of Rodrigues and colleagues (2012) shows a higher risk of DNA damage in human buccal epithelial cells of Furnas inhabitants. Furthermore, in some other studies (Amaral *et al*., 2006; Amaral & Rodrigues, 2007), evidence has been found that Furnas inhabitants have a high incidence of chronic bronchitis and of some cancer types (*e.g*. breast, lip, oral cavity and pharynx). Moreover, a study by Camarinho *et al*. (2013) showed that chronic exposure to volcanogenic air pollutants from Furnas volcano causes lung injury in wild mice and a more recent study from Linhares *et al*. (2016) showed that individuals chronically exposed to indoor radon (^{222}Rn) in a hydrothermal area have a higher level of DNA damage in their oral epithelial cells.

Objective

Taking into account the studies mentioned above, the characteristic atmosphere of Furnas and the lack of studies on the effects from acute exposure to volcanic gases in hydrothermal areas, this study was developed with the aim to answer two questions: (1st) What are the cardiorespiratory effects resulting from an acute exposure to volcanic gases on a group of volunteers, namely regarding heart rate and blood pressure, peripheral oxygen saturation and lung function parameters? (2nd) What is the chemical composition of Furnas volcanic gases condensate? This second question was made in order to have a notion of what the volunteers would be exposed to when visiting Furnas. This work aims to contribute to the assessment of the cardiorespiratory health risks from acute exposure to environments with intense secondary volcanic activity (*i.e.* diffuse soil degassing and fumaroles), particularly in a hydrothermal area highly visited by tourists.

MATERIAL, SUBJECTS & METHODS

The methodology involved in this study was divided into three main steps: evaluation of the cardiorespiratory effects from the acute exposure to a volcanic atmosphere in a group of volunteers, sample collection and chemical characterization of the samples.

Evaluation of the cardiorespiratory effects from the acute exposure to a volcanic atmosphere in a group of volunteers

For this work, 18 volunteers underwent 30 minutes of direct acute volcanic gas exposure within a range of 10 meters to the fumaroles of Furnas volcano. Pre-exposure and post-exposure spirometry, oximetry, blood pressure and heart rate measurements were made. The time of exposure was determined taking into account the short time spent by visitors of Furnas near the fumaroles.

Study group

Only male individuals that did not have history of smoking habits and respiratory diseases were accepted to participate in this study, to ensure uniformity and convey strength to the results.

A standard questionnaire was applied to each participant. Medical history data for respiratory symptoms were taken using a standard questionnaire modified from a standardized respiratory symptom questionnaire from the American Thoracic Society (ATS) (Ferris, 1978) and British Medical Research Council's Committee (BMRCC, 1960). Each person was interviewed about age, height, weight, education, occupation, smoking habits, fatigue, and general respiratory health status. In compliance with the Helsinki Declaration (WHO, 2001) and Oviedo Convention (CE, 1997), to participate in this study, all individuals signed a written informed consent. Table 1 summarizes the general characteristics of the studied group.

Spirometry

The forced vital capacity (FVC) and the forced expiratory volume in one second (FEV_1) values were obtained by spirometry in all participants before and after exposure to the gases emitted from the fumarole. Spirometry measurements were conducted as described by Linhares *et al.* (2015). Briefly, spirometry tests were conducted with the participants in a standing position wearing a nose clip and a disposable mouth piece using the EasyOne automated portable spirometer

TABLE 1. Description of the study group. BM,: Body Mass Index.

General Characteristics	
Study Group	*n* = 18
Age (years)	20.8 ± 0.4
Weight (kg)	72.4 ± 3.7
Height (m)	1.75 ± 0.02
BMI (kg/m^2)	23.8 ± 1.5
Gender	Male
Smoking Status	Non-smokers

(NDD, Zürich, Switzerland); this equipment meets ATS/ERS spirometry standards (Miller *et al.*, 2005), is equipped with software that checks for unacceptable manoeuvres and compares the measured values with reference tables. Participants performed three to five attempts to provide at least three technically acceptable manoeuvres, following the criteria recommended by the ATS (ATS, 1995) and the guidelines of the European Respiratory Society (Miller *et al.*, 2005). Standardized operating procedures were implemented and controlled. Post bronchodilator tests were not applied.

Oximetry

Oximetry tests were conducted according to Hanning & Alexander-Williams (1995) guidelines using an Onyx® II 9550 fingertip pulse oximeter (Nonin Medical, Plymouth, United States of America) to measure functional oxygen saturation of arterial haemoglobin (*i.e.* %SpO$_2$) on the index finger of each volunteer, before and after exposure to the gases emitted from the fumarole.

Heart Rate and Blood Pressure

The values of heart rate and blood pressure measurements were obtained for each volunteer, before and after exposure to the gases emitted from the fumarole using an Acofarma BD8700 Full Automatic Arm Type Blood Pressure Monitor (Bremed Limited, Kowloon, Hong Kong) and according to Frese *et al.* (2011) guidelines.

Statistical Analysis

t-Tests were used to compare means between the different results obtained in each assay regarding the evaluation of the respiratory effects of pre- and post-acute exposure to volcanic atmosphere (*i.e.* spirometry, oximetry, heart rate and blood pressure). All statistical analyses were performed using IBM SPSS Statistics 20.0 for Windows (IBM, 2011), and the level of statistical significance was set at $p \leq 0.05$.

Sample Collection

Fumarole Condensate

Fumarole condensate was collected in October of 2016 at one spot (37°46′24″N 25°18′12″W) in the Furnas locality. The samples were collected using a 97.5 x 71.5 cm plastic-glass sheet, 0.5 cm thick, placed over the fumarole with the help of four stainless steel spikes.

The gas vapours evaporated from the fumarole and condensed on the surface of the plastic-glass sheet, were then collected into 100 mL glass screw-cap bottles with the help of two rubber brushes (30 cm width) that caught the small droplets on the glass. Before starting the collection, successive passages on the glass sheet were carried out with both brushes for 20 minutes, in order to minimize any contamination from particles deposited on the glass sheet during transportation and to clean the rubber brushes. Then, the sample collection started, and ended after reaching 300 mL of condensate. Cold towels were used to cool the plastic-glass sheet in order to accelerate the collection procedure (Figure 1).

Fumarole Water

450 mL of water from the same fumarole where the condensate was collected were also collected by dipping a 500 mL glass screw-cap bottle in order to search for possible differences between the chemical composition from the fumarole water and the resulting condensate.

Chemical Characterization of the Samples

Preparation of Samples for Analysis

Three sub-samples from each sample (Fumarole Condensate and Fumarole Water) were prepared for analysis (30 mL each) adding 60 µL of ultrapure nitric acid for preservation. The ion composition of each sample was analysed by ICP-MS (Inductively Coupled Plasma Mass Spectrometry) at Activation Laboratories Ltd. (Canada). The content of the elements listed in Table 3 were evaluated.

RESULTS & DISCUSSION

Evaluation of the cardiorespiratory effects from the acute exposure to a volcanic atmosphere in a group of volunteers

The results from the pre-exposure and post-exposure oximetry, spirometry, blood pressure and heart rate measurements are presented in Table 2. Small differences between pre-exposure and post-exposure can be observed in each parameter, with exception of the Heart Rate parameter that shows a significant alteration between the two measurements.

FIGURE 1. Fumarole Condensate collection in Furnas locality.

The %SpO_2 values for both situations, pre-exposure 98.1 (± 0.2)% and post-exposure 97.6 (± 0.3)%, are normal values for healthy people (Hanning & Alexander-Williams, 1995). There is a small decrease of 0.5% from the pre-exposure to the post-exposure value, but it is not statistically significant, indicating that the exposure to the fumarole did not affect the percentage of functional oxygen saturation of arterial haemoglobin of the volunteers.

The FVC and the FEV_1 measurement values decreased after exposure, from 4.93 L (± 0.20) to 4.89 L (± 0.18) and from 4.30 L (± 0.19) to 4.26 L (± 0.18) respectively, as well as the FEV_1/FVC ratio (from 87.20% to 87.00%) but, again, this

TABLE 2. Results from the pre-exposure and post-exposure of spirometry, oximetry, blood pressure and heart rate measurements. %SpO_2, functional oxygen saturation of arterial haemoglobin; FEV_1, forced expiratory volume in one-second; FVC, forced vital capacity.

Measured Parameter	Pre-exposure	Post-exposure
%SpO_2	98.1 ± 0.2	97.6 ± 0.3
FVC (L)	4.93 ± 0.20	4.89 ± 0.18
FEV_1 (L)	4.30 ± 0.19	4.26 ± 0.18
%(FEV_1/FVC)	87.20 ± 1.30	87.00 ± 1.30
Heart Rate (n/min)	81.3 ± 3.1*	69.6 ± 2.4*
Systolic Pressure (mm/Hg)	126.6 ± 3.9	125.8 ± 2.7
Diastolic Pressure (mm/Hg)	75.8 ± 2.3	78.8 ± 2.2

* *t*-test- significant at $p \leq 0.05$

is a very small variation, thus showing that the gases from the fumarole barely affected these parameters. Considering the mean of age and height of the study group, FVC, FEV_1 and FEV_1/FVC ratio measurement values obtained are in accordance with the predicted values for healthy subjects (Quanjer *et al.*, 2012; Vitalograph, 2018).

Regarding the blood pressure values and the heart rate, the systolic pressure decreased from 126.6 mm/Hg (± 3.9) to 125.8 mm/Hg (± 2.7), the diastolic pressure raised from 75.8 mm/Hg (± 2.3) to 78.8 mm/Hg (± 2.2) and the heart rate decreased significantly from 81.3 (± 3.1) to 69.6 (± 2.4) (Table 2).

The association between the respiratory system and panic disorders has been reported since the middle of 20th century (Amaral *et al.*, 2013). In 1973, Ronald Ley and Herbert Walker administered a mixture of carbon dioxide (65%) and oxygen (35%) to 10 adult humans and compared this group with one other exposed to a normal atmosphere. The authors verified that, after gas inhalation, the exposed group showed a significant decrease in anxiety and in heart rate. Similar results were obtained by Griez & van den Hout (1982) when they tested the same gas mixture on the anxiety parameters of 12 subjects.

Although the average concentration of CO_2 in the atmosphere of Furnas is not so elevated as in the above-mentioned experiments, the higher concentrations of CO_2 that are usually found in the vicinity of the fumaroles [> 850ppm (Pedone *et al.*, 2015)] are most probably responsible for the significant decrease in the heart rate, having a relaxing effect in the subjects exposed.

Chemical characterization of the samples

Fifty-nine chemical elements, belonging to the class of metals and metalloids, were determined in the samples (fumarole condensate and fumarole water) by ICP-MS (Inductively Coupled Plasma Mass Spectrometry), being the concentration of ten of them below the limit of detection in all of the analysed samples and replicates (Table 3). The most abundant element in the fumarole condensate is calcium (Ca) with a value of 72%, followed by sodium (Na), silicon (Si) and potassium (K) (16%, 15,4% and 5,4% respectively). Magnesium (Mg), iron (Fe), zinc (Zn) and aluminum (Al) are also present but in smaller quantities (lower than 50 μg/L but higher than 10 μg/L). Several other elements are present but in far less amount (*e.g.* nickel (Ni) with 2.4 μg/L and rubidium (Rb) with 0.531 μg/L). Cadmium (Cd), chromium (Cr), beryllium (Be), lithium (Li), mercury (Hg) and selenium (Se), for example, are below the detection limit. Overall, the fumarole condensate has far less amount of each element than the water from where it is originated (*i.e.* fumarole water), *e.g.* 417 μg/L of Na in fumarole condensate *vs.* 64300 μg/L in the fumarole water, or 5.9 μg/L of manganese (Mn) in fumarole condensate *vs.* 728.7 μg/L in the fumarole water. This is expected, since different elements have different physical-chemical characteristics (*e.g.* melting and boiling points, solubility, etc.) whereby different elements boil away at different rates, so the fumarole condensate does not have the elements in the same proportions as the elements in the fumarole water.

There are other elements for which the amount difference is not so discrepant (*e.g.* 15.5 μg/L of zinc (Zn) in the fumarole condensate *vs.* 29.6 μg/L in the fumarole water) but remains below the amount in the fumarole water. However, this is not the case barium (Ba) (3.0 μg/L in fumarole condensate *vs.* 1.5 μg/L in the fumarole water) and of silver (Ag) (0.3 μg/L in the fumarole condensate *vs.*

TABLE 3. Amount (in μg/L) of each of the 59 elements analysed on the two different samples: fumarole condensate and fumarole water and, the percentage of variation between fumarole condensate and fumarole water. BDL, Bellow Detection Limit; NA, Not Applicable; SD, Standard Deviation; #, SD was not possible to calculate due to lack of replicas with at least the detection limit value.

Chemical Element (Chemical Symbol)	**Fumarole Condensate (SD)**	**Fumarole Water (SD)**	**Detection Limit (μg/L)**	**Percentage of Variation**
Calcium (Ca)	1867 (58)	7000 (200)	700	73.33
Sodium (Na)	417 (9)	64300 (2254)	5	99.35
Silicon (Si)	400 (0)	8400 (173)	200	95.24
Potassium (K)	140 (0)	13700 (755)	30	98.98
Magnesiumm (Mg)	50 (1)	2577 (102)	2	98.07
Iron (Fe)	37 (6)	703 (32)	10	94.79
Zinc (Zn)	15.5 (6.5)	29.6 (1.1)	0.5	47.63
Aluminium (Al)	12 (2)	115 (4)	2	89.88
Manganese (Mn)	5.9 (0.2)	728.7 (44.0)	0.1	99.19
Barium (Ba)	3.0 (1.4)	1.5 (0.4)	0.1	-100
Nickel (Ni)	2.4 (1.1)	99.1 (2.7)	0.3	97.58
Strontium (Sr)	1.43 (0.02)	20.70 (2.29)	0.04	93.09
Copper (Cu)	1.4 (0.2)	3.0 (0.2)	0.2	53.33
Rubidium (Rb)	0.531 (0.007)	61.200 (3.951)	0.005	99.13
Niobium (Nb)	0.310 (0.066)	BDL	0.005	NA
Silver (Ag)	0.3 (0.1)	BDL	0.2	NA
Lead (Pb)	0.30m (0.02)	3.80 (0.80)	0.01	92.10
Tungsten (W)	0.22 (0.18)	8.14 (0.24)	0.02	97.30
Tin (Sn)	0.2 (0.1)	27.7 (#)	0.1	99.28
Titanium (Ti)	0.2 (0.1)	0.3 (0.1)	0.1	33.33
Arsenic (As)	0.19 (0.01)	44.70 (0.85)	0.03	99.57
Tantalum (Ta)	0.127 (0.012)	BDL	0.001	NA
Antimony (Sb)	0.11 (0.02)	0.46 (0.02)	0.01	76.09
Zirconium (Zr)	0.11 (0.01)	0.33 (0.13)	0.01	66.67
Cobalt (Co)	0.057 (0.017)	0.191 (0.005)	0.005	70.16
Hafnium (Hf)	0.049 (0.007)	0.006 (0.003)	0.001	-716.67
Cerium (Ce)	0.036 (0.014)	0.144 (0.013)	0.001	75.00
Lanthanum (La)	0.030 (0.011)	0.080 (0.010)	0.001	62.50
Uranium (U)	0.022 (0.002)	0.004 (0.001)	0.001	-450
Germanium (Ge)	0.02 (0.01)	4.87 (0.07)	0.01	99.59
Caesiumm (Cs)	0.020 (0)	4.453 (0.083)	0.001	99.55
Lutetium (Lu)	0.020 (0.001)	0.050 (0.026)	0.001	60.00
Neodymium (Nd)	0.013 (0.008)	0.053 (0.006)	0.001	75.47
Galliumm (Ga)	0.01 (0.01)	0.14 (0.01)	0.01	92.86
Yttrium (Y)	0.010 (0.001)	0.051 (0.001)	0.003	80.39
Gadolinium (Gd)	0.003 (0.001)	0.010 (0.001)	0.001	70.00
Praseodymiumm(Pr)	0.003 (0.002)	0.015m (0.002)	0.001	80.00
Samarium (Sm)	0.002 (0.002)	0.009 (0.001)	0.001	77.78
Thorium (Th)	0.002 (0.001)	0.005 (0.001)	0.001	60.00
Dysprosium (Dy)	0.001 (0.001)	0.007 (0.001)	0.001	85.71
Erbium (Er)	0.001 (0)	0.004 (0.001)	0.001	75.00
Thallium (Tl)	0.001 (#)	BDL	0.001	NA
Ytterbium (Yb)	0.001 (#)	0.005 (0)	0.001	80.00
Beryllium (Be)	BDL	1.8 (0.1)	0.1	NA
Bismuth (Bi)	BDL	BDL	0.3	NA
Cadmium (Cd)	BDL	BDL	0.01	NA
Chromium (Cr)	BDL	BDL	0.5	NA
Europium (Eu)	BDL	0.001 (#)	0.001	NA
Mercury (Hg)	BDL	BDL	0.2	NA
Holmium (Ho)	BDL	0.001 (0.001)	0.001	NA
Indium (In)	BDL	BDL	0.001	NA
Lithium (Li)	BDL	35	1	NA
Molybdenum (Mo)	BDL	0.2 (0)	0.1	NA
Scandium (Sc)	BDL	BDL	1	NA
Selenium (Se)	BDL	BDL	0.2	NA
Terbium (Tb)	BDL	0.001 (0)	0.001	NA
Tellurium (Te)	BDL	BDL	0.1	NA
Thulium (Tm)	BDL	BDL	0.001	NA
Vanadium (V)	BDL	BDL	0.1	NA

non-existent or in such a small amount that it is below the detection limit in the fumarole water). This can be explained, at least partially, by some sort of contamination during the sample collection of the condensate. Another explanation for this is the different physical-chemical characteristics of the elements.

As it is shown in Table 3, the fumarole condensate represents a very tiny part of the total emissions from the fumarole, but regardless of that, it still presents alarming concentrations of some elements. According to WHO (2017), in order to secure a good air quality, the concentrations in the air for some elements should not surpass their guideline values for individual exposure. As so, it could be a little worrisome to see that the values of Pb (0.30 μg/L) and Mn(5.9 μg/L) in the fumarole condensate are several times higher than the values advised by WHO (2017) (0.001 μg/L for both elements). However, it is important to remember that these values are related to a one-time sampling procedure and that no sampling has been done over different periods of time, so the values may correspond to a peak of concentration related to the time of the year, week, day or place where the samples were collected. In order to clarify this, more sampling should be done at other times of the year and in different fumaroles. In addition, gaseous sampling should be carried out to verify if the condensate corresponds to what people breathe when they visit the site.

CONCLUSION

The oximetry, spirometry, blood pressure and heart rate measurement results obtained from the acute exposure to the fumaroles showed that only the heart rate was significantly affected. The decrease in the heart rate value indicates that the exposure to the fumarole surrounding environment, with a greater concentration of CO_2, had a calm and relaxing effect on the volunteers, being responsible for the reduction of anxiety and heart rate.

The chemical composition of Furnas fumarole condensate is mainly Ca, Na, Si and K. There are also other compounds in lower quantities like Mg, Fe, Zn and Al, and others in much smaller quantities, *e.g.* Ni and Rb. Despite Pb and Mn values of concentration in the fumarole condensate being several times higher than the values advised by WHO (2017), the fumarole condensate values correspond to a one-time sampling procedure, so the values may correspond to a peak of concentration. Further studies regarding gaseous sampling should be carried out to verify if the condensate corresponds to what people breathe when they visit the site.

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