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Healthy professionals working at the Holuhraun volcanic eruption site were tested to investigate if exposure to high levels of volcanic SO2 gas negatively influenced their health. Lung function and inflammation parameters were not clinically relevantly changed, showing that healthy individuals can work in volcanic environments using gas monitors and protective masks without clinical changes in lung function or inflammation.

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Key terms: exposure; occupational exposure; occupational exposure; respiratory health; SO2; sulfur dioxide; volcanic environment; volcanic eruption; volcanic gas

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Respiratory health among professionals exposed to extreme SO_2 levels from a volcanic eruption

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Objective The Holuhraun eruption of fall and winter 2014–15 produced large amounts of sulfur dioxide (SO_2). The aim of this study was to determine if exposure to extreme SO_2 levels affected the health of individuals working at the eruption site.

Methods During January–March 2015, earth scientists, technicians, and law enforcement personnel who were about to work at the eruption site were invited to a respiratory health examination. Symptom reports and lung function measures, forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) were collected before and after an eruption site visit. Those with previous exposure (N=27) reported symptoms retrospectively.

Results Altogether, 41 individuals were invited to participate, 32 underwent a clinical examination at a hospital respiratory health clinic (baseline); 27 reported symptoms during earlier visits to the eruption site (retrospective symptom reports), 17 were re-examined 1–6 days after visiting the eruption site (follow-up). All participants' lung function was within normal range both before and after exposure. At baseline, average FEV_1 was 107.4% of predicted versus 106.6 at follow-up (P =0.82); average FVC was 107.0% of predicted at baseline versus 107.4% at follow-up (P=0.35). Eye and nasal irritation were more frequently reported during eruption site exposure by 24% versus 6% (P =0.37) for both.

Conclusion Although "healthy-worker" effects cannot be excluded, our data indicate that SO_2 exposure was associated with relatively mild and transient respiratory symptoms with no clinical signs of airway inflammation or airway obstruction.

Key terms exposure; occupational exposure; sulfur dioxide; volcanic environment; volcanic gas.

The Holuhraun volcanic eruption (2014–2015) was the largest Icelandic eruption since Laki (1783–1784) (1). It emitted ≥11 million tons of SO_2 (2). At low concentrations, SO_2 exposure causes eye and respiratory tract irritation and, at high levels, triggers acute asthma symptoms, pulmonary oedema and respiratory distress in susceptible individuals. In epidemiological studies, urban SO_2 was associated with increases in respiratory morbidity and mortality, and PM_{10} and cold weather increases the effects on asthmatic individuals (3). In volcanic environments, SO_2 and acid aerosols are associated with increased risk of respiratory symptoms, (4) morbidity,

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and mortality (5). Occupational SO_2 exposure is associated with persisting lung injury (6), bronchoconstriction and reactive airways dysfunction syndrome (RADS), ie, persisting asthma symptoms appearing within 24 hours of high exposure events. RADS overlaps somewhat with irritant-induced asthma, which is caused by exposure to lower SO_2 concentrations where symptom-onset is up to a week from exposure (7). For SO_2, the 10-minute occupational health limit is 500 µg/m^3 (3), although UK occupational guidelines allow exposure of ≤13mg/m^3 (5 ppm) for 15 minutes (8)

The objective of this study was to determine if exposure to volcanic SO_2 was associated with changes in lung function, lung inflammation, and symptoms among professionals working at the Holuhraun eruption site.

Methods

The Holuhraun volcanic eruption began in a remote area of Iceland on 31 August 2014 and ended 27 February 2015. Personnel from the Meteorological Institute, the Earth Science Institute of the University of Iceland, and the Civil Protection Agency who worked at, or near, the Holuhraun eruption site either monitoring, measuring, or conducting safety activities were invited to participate in a health examination at either Landspitali – the National University Hospital in Reykjavík – or Akureyri Hospital in North Iceland from 31 January 2015 to 31 March 2015. During that time, 41 employees visited the eruption site, after which (being exposed) they were asked to attend a follow-up clinical examination as soon as possible. Exposure time was 4–5 days at a time, followed by a period of ≥4 days of non-exposure. Personnel working at the eruption site were instructed to wear gas protection (either half- or full-face) masks with the appropriate gas filters when personal SO_2 monitors indicated SO_2 levels ≥1 ppm. Masks were fitted and personnel was advised to keep facial hair to a minimum. SO_2 monitors worn at Holuhraun measured 10-minute SO_2 concentrations as high as 100 mg/m^3 (35.59 ppm) and median daily 10-minute SO_2 concentration was 360 µg/m^3 (0.128 ppm).

At the baseline health examination, participants answered a questionnaire about background respiratory health (9), current symptoms, and symptoms during exposure. Lung function was measured using EasyOne spirometer according to a standardized protocol (10). Furthermore, the fraction of NO in exhaled air (FeNO) was measured using an electrochemical analyzer, NIOX MINO, among participants in Reykjavík. At the follow-up examination, testing was repeated and participants were asked again about current symptoms, symptoms during exposure, and to report any change in their health in free-text replies. Mixed linear models and McNemar's test were used to analyze if lung function outcomes or symptom rates were significantly different before and after exposure, analyses were performed in R Studio.

Results

Ultimately, 32 individuals (participation rate 78%) were enrolled into the study, answered the baseline questionnaires and underwent clinical examination. All had normal spirometry and FeNO was within the normal range. No one reported having underlying diseases. After visiting the eruption site, 17 individuals (participation rate 53%) were followed-up 1–6 (median 3) days after eruption site exposure and included in the study group. In the study group, 2 were smokers (12%), and 3 (18%) had doctor-diagnosed asthma, 2 (12%) had previously used asthma medication (1 of whom reported having doctor-diagnosed asthma) and 1 (6%) individual with doctor-diagnosed asthma also had hay fever. Additionally, 27 of the 32 baseline participants (84%) were exposed before the study began. For those, median time from exposure to reporting was 3–194 (median 25) days. Of the 27 pre-exposed participants, 4 (15%) were current smokers, 4 (15%) had asthma, 2 (7%) had previously used asthma medication (again 1 did not report doctor-diagnosed asthma), and 2 (7%) had hay fever.

In the spirometry analysis, all participants had normal lung function and FeNO levels both before and after exposure. Only ΔFEV_1 was significantly lower after exposure, 4.6% *vs* -0.3%, $P<0.001$. There were no associations between FEV_1, FVC or FeNO and days since exposure, and neither was different individuals with asthma.

Among the study participants there were no statistically significant difference between the frequency of symptoms at baseline and after exposure although absolute symptom rates were higher during exposure (table 1).

Furthermore, 27 individuals reported symptoms from previous exposure. The most commonly reported symptom during exposure was nasal irritation followed by eye irritation, reported by 14 (52%) and 13 (48%) respectively, significantly increased from baseline exam of 4 (15%) and 3 (11%) (P=0.004 for both). Cough was reported by 10 participants (37%) during exposure versus 6 (22%) at the clinical examination; 4 (15%) reported experiencing shortness of breath during exposure (1 had doctor-diagnosed asthma) versus 0 at the clinical examination; 3 (11%) had experienced wheezing versus 1 at the time of the clinical examination; an 1 (4%) had used inhalation drugs for asthma at previous exposure.

Table 1. Lung function (post-bronchodilator) and symptoms at baseline and follow-up in individuals exposed to SO2 gas at the Holuhraun volcanic eruption site (N=17). FEV1=forced expiratory volume in one second; FVC=forced vital capacity; FeNO (ppb)=fraction of NO in exhaled air (parts per billion)]

	Baseline	Follow-up		P-value [a]
	Level (range)	Level (range)		
Lung function				
FEV_1 (% of predicted)	107.7 (85–130)	106.6 (92–130)		0.47
FVC (% of predicted)	107.4 (92–131)	107.4 (94–129)		0.64
ΔFEV_1 (%points)	4.6 (-1–14)	-0.3 (-5–2)		<0.001
FeNO (ppb) [b]	21.2 (11–40)	19.3 (10–24)		0.48
	Unexposed (reported at baseline)	During exposure (reported at baseline)	Unexposed (reported at follow-up)	P-value [c]
	N (%)	N (%	N (%	
Symptoms				
Eye irritation	1 (6)	4 (24)	0 (0)	0.37
Nasal irritation	1 (6)	4 (24)	0 (0)	0.37
Cough	3 (18)	1 (6)	1 (6)	0.48
Shortness of breath	0 (0)	1 (6)	1 (6)	-
Wheezing/whistling in chest	0 (0)	0 (0)	0 (0)	-

[a] Paired t-test of difference in lung function (spirometry post bronchodilation).
[b] N=9 for this test is, as it was only performed in participants in Reykjavík.
[c] McNemar's test comparing frequency at baseline (unexposed) with frequency during exposure (reported at follow-up). The test does not report a P-value when a strata has 0 cases.

In open-ended questions, 4 subjects (15%) reported taste of SO_2, sulphur or match sticks in the mouth, and throat or palate irritation. There were also individual reports of "more frequent coughing", "stress and sleeping problems", "headaches", "increased sensitivity to SO_2 so it can be tasted at lower concentrations now (January 2015) than back in September-October 2014", and "weakness, concentration problems and headaches".

Discussion

In this small study of healthy professional adults who were clinically examined before and after exposure to high SO_2 levels at the active eruption site, we found no changes in lung function, airway restriction or inflammation after exposure. Reversibility of airway obstruction was statistically significantly decreased from 5% to 0% after the visit to the eruption site, but FEV_1 changes of <10% points are not considered clinically significant. During exposure, reports of eye and nasal symptoms at the eruption site were common, similar to findings in other studies of SO_2-exposed healthy volunteers (4), but in our study, the symptoms had resolved by the time of the clinical examination. Both before and after exposure, FeNO values were within normal range. Health effects of SO_2 are enhanced or occur at lower concentration in mixtures with other air pollutants and in cold conditions and physical exercise, both likely phenomenon at Holuhraun (1–3). In addition to self-reported physical symptoms, symptoms such as stress, sleeping problems, weakness, and concentration problems were reported, and although similar symptoms are known in SO_2 exposure (8), they could also be stress-related and associated with being in a potentially hazardous environment. In this study, many participants reported eye and nose symptoms during previous exposure in the early phase of the eruption, before the study period, correlating with higher SO_2 emissions in earlier phases of the eruption (1, 2).

The strengths of this study include detailed, clinical assessment of professionals before and after volcanic gas exposure. Weaknesses include the small study size, and loss to follow-up. Also, we have no individual exposure measurements of SO_2 concentration at the eruption site, nor do we know the extent to which study subjects followed the recommendations for mask-wearing, an effect-modifying factor of the SO_2 exposure. The median delay from last exposure to the clinical examination was three days, which may be too long to capture any respiratory health effects of SO_2, which are widely agreed to be transient (3). In the retrospective symptom reports, some participants reported their symptoms as long as 194 days after exposure, which may cause significant bias, both due to faulty recall, but also because a short, temporal comparison is preferable as the study period included both cold and flu seasons. A factor which limits the generalizability of the study is the extremely healthy workers who self-selected into the study. Furthermore, we have no information about individuals who declined participation or individuals who visited the eruption site early and experienced symptoms and consequently could have either avoided going back or sought health care elsewhere. This would not be recorded in the study protocol, and it is thus possible that our results present an underestimate of the true effect by including healthy individuals who endured repeated exposure to the volcanic gasses. However, individuals who visited the eruption site must have had sizeable exposure to SO_2 as several individuals in the free-text replies reported SO_2 odor, which is detectable at concentrations between 860−4000 $\mu g/m^3$ (6). The reported SO_2 odor also indicates that although masks were used, they were either not used at all times, did not fit perfectly, or had full filters.

In this study, respiratory symptoms were reported during volcanic SO_2 exposure but resolved without clinical signs one to six days later, indicating that in healthy individuals using protective masks, respiratory health effects after exposure to volcanic gases are minimal. However, our findings may be biased toward the null due to a very healthy, self-selected study population.

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The authors declare no competing interests.

Ethics approval

The participants gave their informed consent for their data to be analyzed in the study. The Science Bioethics Committee approved the study (VSNb2015040002/03.03)

References

1. Schmidt A, Leadbetter S, Theys N, Carboni E, Witham C, Stevenson JA, et al. Satellite detection, long-range transport, and air quality impacts of volcanic sulfur dioxide from the 2014–2015 flood lava eruption at Bárðarbunga (Iceland). J Geophys Res Atmos 2015:120:2015JD023638.

2. Ilyinskaya E, Schmidt A, Thamsin AM, Pope FD, Witham C, Baxter P, et al.Understanding the environmental impacts of large 1 fissure eruptions: Aerosol and gas emissions from 2 the 2014-2015 Holuhraun eruption (Iceland). Earth Planet Sc Lett 2017:472:309–22. https://doi.org/10.1016/j.epsl.2017.05.025.

3. WHO. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Risk summary assessment. Geneva, Switzerland: World Health Organisation. 2007. Available from; http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf.

4. Ishigami A, Kikuchi Y, Iwasawa S, Nishiwaki Y, Takebayashi T, Tanaka S, et al. Volcanic sulfur dioxide and acute respiratory symptoms on Miyakejima island. Occup Environ Med 2008:65(10):701–7. https://doi.org/10.1136/oem.2007.033456.

5. Hansell AL, Horwell CJ, Oppenheimer C. The health hazards of volcanoes and geothermal areas. Occup Environ Med 2006:63(2):149–56. https://doi.org/10.1136/oem.2005.022459.

6. Baxter PJ. Gases. In: Baxter, PJ, Aw C-T, Cockcroft A, Durrington P, Harrington JM. Eds. Hunter's Diseases of Occupations, 10th edn. Boca Raton, FL: Taylor and Francis 2010:253–309.

7. Ayres JG . Reactive airway dysfunction syndrome and irritant-induced asthma. In: Baxter, PJ, Aw C-T, Cockcroft A, et al. Eds. Hunter's diseases of occupations. 10th edn. Boca Raton, FL: Taylor and Francis 2010:310–3.

8. IVHHN - The International Volcanic Health Hazard Network. Sulphur dioxide (SO2) (cited 2017 Sep 11) Available from: http://www.ivhhn.org/index.php?option=com_content&view=article&id=82.

9. Burney PG, Luczynska C, et al. The European Community Respiratory Health Survey. Eur Respir J 1994:7:954–60. https://doi.org/10.1183/09031936.94.07050954.

10. Vollmer WM, Gíslason T, Burney P, Enright PL, Gulsvik A, Kocabas A, et al. Comparison of spirometry criteria for the diagnosis of COPD: results from the BOLD study. Eur Respir J 2009:34(3):588–97. https://doi.org/10.1183/09031936.00164608.

11. Ricciardolo FLM. Revisiting the role of exhaled nitric oxide in asthma. Curr Opin Pulm Med 2014:20(1):53–9. https://doi.org/10.1097/MCP.0000000000000006.

12. Dweik RA, Boggs PB, Erzurum SC, Irvin CG, Leigh MW, Lundberg JO, et al. An Official ATS Clinical Practice Guideline: Interpretation of Exhaled Nitric Oxide Levels (FeNO) for Clinical Applications. Am J Respir Crit Care Med 2011.184:602–15.

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