Long-term health effects of the Eyjafjallajökull volcanic eruption: A prospective cohort study in 2010 and 2013

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Thesis for the degree of Master of Public Health Sciences

Centre of Public Health

HÁSKÓLI ÍSLANDS

Heilsufarslegar afleiðingar eldgossins í Eyjafjallajökli: Framsýn ferilrannsókn 2010 og 2013

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Ritgerð til meistaragráðu í lýðheilsuvísindum

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Abstract

It is estimated that at least 500 million people live within the potential exposure range of a historically active volcano. Adverse respiratory symptoms and a variety of psychological symptoms have been reported after volcanic eruptions but studies on long-term health effects of volcanic eruption are scarce, including studies on respiratory health.

The aim of the study was to examine physical and mental health of exposed residents three to four years after the Eyjafjallajökull eruption, compared to six to nine months after the eruption. Furthermore, the aim was to assess whether highly exposed residents were still at increased risk of physical and mental symptoms compared with residents who were less or not at all exposed to the effects of Eyjafjallajökull eruption.

In a population-based prospective cohort study of residents of areas close to the Eyjafjallajökull volcano, the level was divided into areas based on different level of exposure. In addition, a sample from a non-exposed population of residents of Skagafjörður in Northern Iceland was included for comparison. All participants answered a questionnaire on physical and psychological symptoms in 2010 and again in 2013. Standard questions from the screening part of the European Community Respiratory Health Survey (ECRHS) were used to assess respiratory health and underlying diseases. General Health Questionnaire-12-item-version (GHQ-12) measured psychological distress, Perceived Stress Scale (PSS-4) measured perceived stress and Primary Care PTSD (PC-PTSD) measured PTSD symptoms. The participation rate in 2010 was 72%, of those, 80% participated in the follow-up in 2013.

Compared to 2010, the following symptoms were more prevalent in the exposed group in 2013: current skin rash/eczema (OR 2.04; 95% CI 1.29 to 3.23), back pain (OR 1.44; 95% CI 1.07 to 1.93) and myalgia (OR 1.58; 95% CI 1.18 to 2.13). Also, experiencing respiratory symptoms in the last 12 months was more common in 2013 than 2010, including morning winter phlegm (OR 1.50; 95% CI 1.11 to 2.07), nocturnal or daytime winter phlegm (OR 1.64; 95% CI 1.12 to 2.41) and chronic phlegm (OR 1.85; 95% CI 1.21 to 2.82). In addition, sleep difficulties during the last three months were more common among the exposed participants in 2013, compared to 2010, such as difficulty staying asleep and having trouble falling back asleep (OR 1.55; 95% CI 1.22 to 1.96) and frequently waking up in the middle of the night (OR 1.28; 95% CI 1.02 to 1.62). Multiple symptoms (two or more) from the upper respiratory system or skin were more common in 2013 (14.5%) than in 2010 (7.6%) (OR 1.83; 95% CI 1.18 to 2.86). Further, having multiple symptoms in 2013 was associated with experiencing perceived stress (OR 2.18; 95% CI 1.09 to 4.20) and PTSD symptoms (OR 3.17; 95% CI 1.12 to 8.20). Finally, comparing different exposure areas (low, medium and high) in 2013, we found that the participants in the more exposed areas were at higher risk of experiencing respiratory and physical symptoms such as waking up feeling tightness in the chest in the last 12 months (medium exposure OR 3.09; 95% CI 1.21 to 10.46 and high exposure OR 3.42; 95% CI 1.30 to 11.79) and having a dry throat during the last month (medium exposure OR 4.66; 95% CI 1.36 to 29.30 and high exposure OR 5.71; 95% CI 1.62 to 36.26), compared to the low exposure region.

The risk of certain symptoms increased with time, and three to four years after the eruption, symptoms still reflected the severity of exposure. This study draws attention to the possibility of enduring

physical and psychological illnesses following natural hazards and has implications for planning preventive and treatment strategies.

Ágrip

Talið er að um 500 milljónir manna búi nálægt virku eldfjalli. Rannsóknir hafa sýnt fram á öndunarfæraeinkenni og andlega vanlíðan meðal einstaklinga eftir eldgos en lítið er vitað um heilsufarsleg áhrif til lengri tíma. Markmið rannsóknarinnar var að kanna líkamlega og andlega heilsu þátttakenda þremur til fjórum árum eftir eldgosið í Eyjafjallajökli borið saman við þátttakendur sex til níu mánuðum eftir eldgosið. Markmiðið var einnig að kanna hvort að mikið útsettum íbúum, þremur til fjórum árum eftir eldgosið í Eyjafjallajökli, væri ennþá hættara við líkamlegum og andlegum einkennum borið saman við samanburðarhóp eða minna útsetta íbúa.

Rannsóknin var framsýn ferilrannsókn sem samanstóð af Sunnlendingum (eldgosahópur) sem bjuggu mislangt frá eldfjallinu og samanburðarhópi frá Skagafirði. Þátttakendum, sem höfðu svarað spurningalista um líkamleg og sálræn einkenni hálfu ári eftir gosið, var fylgt eftir með rannsókn árin 2013/2014. Öndunarfæraheilsa og undirliggjandi sjúkdómar voru mældir með European Community Respiratory Health Survey (ECRHS), andleg vanlíðan var mæld með General Health Questionnaire-12-item-version (GHQ-12), streita var mæld með Perceived Stress Scale (PSS-4) og einkenni áfallastreituröskunar var mæld með Primary Care PTSD (PC-PTSD). Árið 2010 var svarhlutfallið 72% og 80% af þeim þátttakendum tóku aftur þátt í rannsókninni 2013.

Niðurstöður sýndu að miðað við árið 2010 var eldgosahópi 2013 marktækt hættara við ýmsum einkennum undanfarinn mánuð, eins og húðeinkennum (OR 2.04; 95% CI 1.29-3.23), bakverkjum (OR 1.44; CI 95% 1.07-1.93) og vöðvabólgu (OR 1.58; CI 95% 1.18-2.13). Þeim er einnig hættara við einkennum síðustu 12 mánuði frá efri öndunarvegi, þ.e. slími fyrst á morgnana á veturna (OR 1.51; 95% CI 1.11-2.07), slími á daginn, á nóttunni eða á veturna (OR 1.64; 95% CI 1.12-2.41), og slími flesta daga á hverju ári (OR 1.85; 95% CI 1.21-2.82). Eldgosahópi 2013 var einnig hættara við eftirfarandi svefnerfiðleikum undanfarna þrjá mánuði miðað við árið 2010, eins og að hafa vaknað eftir að hafa fest svefn og átt erfitt með að sofna aftur (OR 1.55; 95% CI 1.22-1.96) og hafa vaknað nokkrum sinnum á hverri nóttu (OR 1.28; 95% CI 1.02-1.62). Árið 2013 (14.5%) var eldgosahópi einnig marktækt hættara við að vera með fleiri en tvö líkamleg einkenni frá efri öndunarvegi og húð, borið saman við árið 2010 (7.6%), (OR 1.83; 95% CI 1.18-2.86). Einnig fannst samband milli þess að hafa fleiri en tvö líkamleg einkenni og upplifun streitu (OR 2.18; 95% CI 1.09-4.20) og einkenni áfallastreituröskunar (OR 3.17; 95% CI 1.12-8.20). Þegar svör frá 2013 voru skoðuð sérstaklega, kom í ljós að mikið útsettum þátttakendum í eldgosahópnum var t.d. marktækt hættara við að vakna með þyngsli fyrir brjósti síðustu 12 mánuði samanborið við lítið útsetta hópinn (miðlungs útsettir OR 3.09; 95% CI 1.21-10.46 og mikið útsettir OR 3.42; 95% CI 1.30-11.79) og upplifa þurrk í hálsi undanfarinn mánuð (miðlungs útsettir OR 4.66; 95% CI 1.36-29.30 og mikið útsettir OR 5.71; 95% CI 1.62-36.26).

Hætta á að upplifa ákveðin einkenni hafði aukist árið 2013, borið saman við 2010. Þar að auki voru einkenni algengari hjá þátttakendum sem voru mest útsettir miðað við hina hópana. Þessi rannsókn vekur athygli á möguleikanum á viðvarandi líkamlegum og andlegum einkennum í kjölfar náttúruhamfara og gæti haft þýðingu á sviði forvarna og viðbragðs áætlana.

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List of abbreviations

AlO3	Aluminium oxide
ASD	Acute stress disorder
CIs	Confidence intervals
DSM	Diagnostic and Statistical Manual of Mental Disorders
EAI	The Environment Agency of Iceland
ECRHS	European Community Respiratory Health Survey
Fe2	Iron
FeO	Iron oxide
GHQ-12	The General Health Questionnaire-12-item version measuring psychological distress
ORs	Odds ratios
PC-PTSD	The Primary Care PTSD measuring PTSD symptoms
PM_{10}	Coarse particulates (less than 10 μm in diameter)
PSS-4	The Perceived Stress Scale measuring perceived stress
PTSD	Post-traumatic stress disorder
REDCap	Research Electronic Data Capture
SiO2	Silicon dioxide
VEI	Volcanic Explosive Index
wt%	Weight percent
$\mu g/m^3$	Micrograms per cubic meter

1 Introduction

Natural disasters are complex events where individuals are exposed to various risks and dangers. They can impact large geographic areas and may have long-term consequences for individuals and their communities.[1] The health consequences of natural disasters include mortality, communicable diseases, traumatic injuries, psychological disorders and distress and long-term disability.[2]

It is estimated that at least 500 million people live within the potential exposure range of a historically active volcano.[3, 4] Around 50 volcanoes erupt each year on average.[5] Thus, eruptions and events directly related to volcanic and geothermal activity are common. In Iceland, volcanic eruptions occur every 3 to 4 years, with a wide range of consequences such as incandescent tephra or lava or jökulhlaups and contamination of air, water, and crops.[6] Volcanic eruptions can eject millions of tons of airborne pollutants into the atmosphere which can have immediate life threatening health effects. Compounds from volcanoes can be harmful, depending on their chemical composition, physical characteristics, the way they are expelled and how close to volcanoes people live.[7] The airborne pollutants can cause new respiratory diseases or exacerbate existing respiratory conditions. During the 20th century a total of 102.140 deaths were reported in relation to volcanic eruptions as well as additional 4.72 million people being affected by volcanic events.[4]

It is therefore necessary to gain epidemiological knowledge of the causes of death and the kinds of injuries and illnesses caused by volcanic eruptions so that effective interventions and preventions may be identified.[8]

1.1 Characteristics of volcanic ash

Tephra is generally described as fragments of volcanic rock and lava emitted from volcanoes regardless of composition or size, while ash refers to tephra particles less than 2 mm in diameter. [7, 9] Multiple factors influence tephra dispersal from explosive eruptions, including magma discharge, degree of magma fragmentation, plume height, vent geometry, particle size distribution and wind velocity.[6] The magnitude of volcanic eruptions is classified using VEI. The higher VEI score the greater the volume of ejecta, the greater degree of fragmentation with more fine ash being created, the higher the eruption column and the greater distances large volumes of ash travel.[5] The consequences of tephra fallout can include collapsing buildings, disruption of power and water supplies, damage to vehicle engines and extensive damage to agricultural products such as livestock.[10] Even though volcanic eruptions are usually of short duration, ashfall deposits can endure in the surrounding environment for many years.[11] The proximity of inhabited areas to the volcano is also an important factor when assessing the potential health hazard, as is analyzing characteristics of the volcanic ash.[9] Ash from explosive eruptions which contain more than 60 wt% SiO_2 have higher concentrations of crystalline silica while basaltic ash which contains between 40-50 wt% SiO_2, lacks crystalline silica.[5]

1.2 Respiratory effects of volcanic ash

Volcanic ash may cause respiratory diseases, both acute and chronic, if particles are small enough to enter the respiratory system.[12] Aerodynamic diameter of particles is the main determinant of how far particles can enter into the respiratory system.[13] Particulate matter under 10 μm in diameter (PM_{10}) is defined as thoracic and is respirable if it is less than 4 μm.[11] This is of particular concern because it can penetrate the alveolar region of the lungs where activation of particle-related respiratory diseases like silicosis and lung cancer can occur.[12] Particles under 2.5 μm diameter can enter further into the lungs, into the terminal bronchi and alveoli and may even have greater potential to cause harm.[12, 14] Ultrafine particles, < 1 μm, can reach the alveoli where oxygen and carbon dioxide exchange.[15]

1.3 Respiratory health hazards of volcanic ash

The acute and chronic health effects of exposure to volcanic ash depend on several factors such as the size of the particles (mainly the proportion of respirable particles), the mineralogical composition (including the crystalline silica content) and the physiochemical properties of their surface (especially Fe2+ content).[16]

1.3.1 Acute respiratory effects

After heavy ashfall from volcanic eruptions acute respiratory manifestations include asthma attacks, bronchitis and inflammation of the airways.[11] Increased cough, breathlessness, chest tightness and wheezing have also been reported.[11] Generally, individuals tolerate inhaled particulates quite well and are not aware of their deposition and subsequent clearance up the mucociliary escalator.[13] However, some individuals do not have this tolerance and have hyper reactive airways, such as individuals with clinical asthma, which respond to inhaled particulates with narrowing of the airways or bronchoconstriction.[13] Asthma attacks are not restricted to known asthma patients after volcanic eruptions as they can manifest in healthy individuals. Asthma attacks can be fatal in elderly people whereas asthma attacks in children are less dangerous but can lead to hospitalization.[11] Children have much smaller airways than adults (especially children under two years of age) and higher prevalence of airway hyper reactivity is found in children than adults. It might therefore be expected that children are at greater risk for airway narrowing or bronchoconstriction than adults.[13] Volcanic ash can also cause sudden, asphyxia-induced death due to acute respiratory tract irritation and symptoms in healthy individuals or in individuals with existing respiratory disorders.[17]

1.3.2 Long-term respiratory effects

Investigating long-term health effects, such as chronic lung disease or serious respiratory symptoms, following volcanic eruptions, may be difficult to accomplish since the disease may not become apparent until many years after the initial exposure.[11] Studies on long-term health effects of volcanic eruptions are scarce and limited, and in particular studies that aim to explore the long-term exposure to volcanic ash and respiratory health, because information on the quantity and content of the respirable ash is often inadequate.[11]

It is necessary to assess the mineralogical composition of volcanic ash when examining the potential harm on respiratory health because of ash exposure.[11] Silicic volcanic ash is of concern, as it frequently contains crystalline silica, as cristobalite, quartz or tridymite polymorphs.[16] Crystalline silica is considered to be the most troublesome compound produced in volcanic eruptions in relation to chronic lung pathogenesis and is classed as a Group 1 human carcinogen, a compound that can cause cancer.[14, 18] Acute symptoms of high concentrations of respirable crystalline silica cause shortness of breath, cough and pulmonary alveolar lipoproteinosis (acute silicosis). Chronic exposure to crystalline silica causes silicosis which is the most worrisome chronic respiratory health condition and is characterized by the presence of histological silicotic nodules and by fibrotic scarring of the lung.[19] Three main settings have to be present for silicosis to occur: 1) a high proportion of fine particles in the ash; 2) a high concentration of crystalline silica (cristobalite, quartz or tridymite) and 3) long-term exposure to the ash in substantial amount.[11] In industry, crystalline silica is known to cause silicosis, but no human cases of silicosis have been reported because of exposure to volcanic ash.[11, 12] Individuals who have developed silicosis may be at greater risk of developing lung cancer.[11]

Another possible health outcome in relation to long-term ash exposure is chronic obstructive pulmonary disease (COPD) defined as an irreversible narrowing of the airways and chronic mucous hypersecretion.[7] COPD is a heterogeneous disorder with components of chronic bronchitis, asthma and airflow obstruction, all being significant during the final stages of the disease.[20] COPD may progress for decades after the exposure to substances like coal and silica dust has ended.[21] Inhalation of respirable fine grained ash can also exacerbate other previously present diseases such as chronic heart problems and chronic bronchitis.[11]

1.4 Health effects and specific volcanic eruptions

Volcanic eruptions can have multifactorial effects on health.[3] The most comprehensive studies on respiratory health effects of volcanic ash are considered to be from Mt. St. Helens, Mt. Sakurajima and Soufriere Hills.[3]

1.4.1 Mt. St. Helens, USA

The eruption of Mt. St. Helens on May 18th in 1980, which resulted in wide-ranging ash fall in Washington and nearby states, raised interest in examining the health effects of volcanic ash.[11] Mineralogical studies revealed that the ash from Mt. St. Helen contained crystalline silica that raised concerns about long-term health effects such as silicosis and COPD. One study showed that in areas with high levels of airborne ash a two- to threefold increase in hospital admissions was observed as well as a three- to fivefold increase in emergency room visits for respiratory conditions, especially among people with pre-existing asthma and respiratory diseases.[22] Follow-up of those with pre-existing respiratory symptoms revealed that the ash exposure exacerbated their symptoms.[23] The lung function of children in summer-camp in Oregon was studied over a two week period in an area where about 1.2 cm of ash had fallen after the Mount St. Helen´s eruption. The children were tested regularly during these two weeks, first on arrival, then twice a day every second or third day during the period. No strong evidence of negative effects on lung function were found in these children, not even in those who had pre-existing lung disease or symptoms.[24] On the other hand hospital admissions rates for childhood asthma doubled in Spokane City in Washington two months after the eruption compared with the same period the following year.[25] Diminishing symptoms over time were found among exposed loggers following the Mt. St. Helen´s eruption. Acute symptoms like chest tightness, coughing and eye irritation were more common among exposed loggers compared to non-exposed workers shortly after the eruption. When the tests were repeated few months later, in September 1980, the symptoms had subsided and no significant differences between the groups were found.[26-28] A four year prospective study was executed to investigate long-term health effects on the exposed loggers. One year after Mt. St. Helen´s eruption lung function was found to be decreased both among exposed loggers and the comparison group, but more severe among the exposed loggers. After four years of follow-up the results indicated that there was no need of a further follow-up because the lung function tests showed normal results with no difference between the two groups.[29] Toxicological studies revealed that the ash from Mount St. Helens acted as an irritant on the airways, which lead to an increase in mucus and inflammation.[3] In conclusion, after the eruption of Mt. St. Helens in 1980, acute respiratory symptoms in the residents have been reported in epidemiological studies but these effects were transient and no long-term effects were identified.

1.4.2 Soufriere Hills, Montserrat, West Indies

The Soufriere Hills volcano on Montserrat Island, West Indies has erupted continuously since 1995. The ash from the volcano has usually contained 13-20% inhalable (<10 μm) particles, but crystalline silica content has varied between 10-27 wt% and 4-6 wt%.[30] Estimated risk of developing early radiological changes of silicosis is considered >1% for the population living in the areas mostly exposed over the 20 years. However, outdoor workers, such as gardeners, experienced higher ash exposures which lead to increased risk of contracting silicosis of between 2-3% and up to 10%.[31] In 1998 Forbes et al[32] examined the respiratory health of children living in Montserrat during the eruptions (since 1995). It was concluded that respiratory health was affected, the prevalence of wheeze in the preceding 12 months was greater among children highly exposed (23.2%) to volcanic ash compared to low exposed children (8.5%). A fourfold increase in prevalence of exercise induced bronchospasm among children currently highly exposed (31.6%) compared to low exposed children (10.3%) was also reported. It might be expected that long-term exposure to high levels of cristobalite, as found in the ashfall deposits of Soufriere Hills volcano, would be associated with reduced lung volume instead of increased bronchial reactivity. This raises the question whether bronchial reactivity may have been related to the quantity rather than the quality of the ash from Soufriere Hills.[33]

1.4.3 Mt. Sakurajima, Japan

Mt. Sakurajima, one of the most active volcanoes in the world, is located on Kyushu Island, Southeast Japan and has been erupting almost continuously since 1955.[34] The ash from Mt. Sakurajima has been found to vary substantially in its composition and grain size distribution making health risk assessment challenging.[34] Not surprisingly, consensus is lacking between the different studies examining the association between ash exposure from Mt. Sakurajima and respiratory health. The respiratory health of 30-56 year old women (N=2006), who lived in three areas exposed to ash at different levels, was examined in a cross-sectional epidemiological study. The prevalence of chronic bronchitis and other respiratory symptoms was low in all three areas, but a minor dose-response trend was observed where symptoms prevalence increased with higher level of exposure.[35] To eliminate some sources of potential error in the previous study, Yano et al.[36] repeated the study on women who lived in a high-exposure area, Kanoya located 25 km from Mt. Sakurajima, and a lower-exposed area, Tashiro located 50 km from the volcano. Among residents of this high-exposed area, there was a slightly higher prevalence of nonspecific respiratory disease compared with the residents from the low-exposed area but the difference was not significant. They concluded that the exposure to volcanic ash did not have a serious harmful effect on respiratory systems because the ash particles were usually too large to be respirable and because of the short duration of high concentrations of airborne ash. Respiratory diseases were examined over a 35 years (1968-2002) period among residents in Sakurajima-Tarumizu, which is an area located near Mt. Sakurajima.[37] Elevated mortality from respiratory diseases, including lung cancer and COPDs was found among residents from the highly exposed area. The ash from Mt. Sakurajima generally contains around 60% of SiO2 and up to 7 wt% of cristobalite, with up to 10% respirable material (<4μm).[37]

1.4.4 Other volcanoes

There are only a few studies on the respiratory health effects of the ash of other volcanoes than Mt. St. Helens, Soufriere Hills and Mt. Sakurajima, making it hard to draw firm conclusions about the possible health hazards from other volcanoes.[3]

Rojas-Ramos et al.[38] reported increased incidence of respiratory symptoms and decrease in lung function in exposed farmers only in the immediate period after the eruption in Popocatepetl in Mexico. However, seven months later the symptoms rates had decreased to normal levels. The authors attributed the reversibility of the symptoms to the low content of free silica as cristobalite, less than 3.5%, in the respirable fraction.

Gordian et al.[39] examined respiratory symptoms during the volcanic activity of Mount Spurr in Alaska in 1992 among residents in Anchorage Alaska 60 miles from the volcano. They reported an increase of 1-3% in outpatient visits for upper respiratory illnesses and about 3-6% increase in asthma related outpatient visits which were considered to be associated with an increase in particulate matter of less than 10 μm (PM_{10}). Based on the results of the study it was demonstrated that increased morbidity was not just seen among vulnerable individuals but also healthy relatively young working people as well.[39]

A retrospective study was carried out to investigate the number and type of visits to the emergency departments of hospitals near Mount Edna, Sicily, during its eruption in 2002. Compared with the same period in the year before, emergency department visits for acute health disorders of the respiratory tract and cardiovascular system had increased significantly. During the eruption, high levels of respirable sized particulate matter and almost a threefold increase in PM_{10} with a fourfold increase in sulfur dioxide were found compared to the previous year.[17]

After the Mt. Asama eruption in Japan a dose-response trend was detected among asthma patients in the most exposed region, where ashfall was over 100 g/m^2. Almost half, 42.9%, of the asthma patients suffered exacerbations, peak expiratory flow decreased and asthma medication increased.[40]

In the weeks following the eruption in Mt. Ruapehu in New Zealand in 1996, the highest rates of respiratory mortality in the 1990s were reported in the cities of Hamilton and Auckland, 166-282 km from the volcano, presumably partly due to the diffuse fine volcanic ash from Mt. Ruapehu.[41]

1.5 Sense organs hazards of volcanic ash

The eyes are particularly sensitive to ash exposure, commonly reported injuries are abrasion of the cornea and conjunctivitis due to accumulation of ash in the conjunctival sac. Symptoms not as frequently reported are swelling of the eyelids and other facial tissues around the eyes.[14] There are few reports on volcanic ash and skin irritation. Fresh ash can have acid coatings and be abrasive to the skin causing irritation and debilitation which can lead to infections.[7, 42] Symptoms of irritation in eyes and exposed skin commonly decrease shortly after the exposure to ash ceases and longer term toxic injury to these sense organs are unusual.[43]

To summarize on physical health effects, previous studies (mentioned above) on adverse respiratory effects of exposure to volcanic ash are mainly based on a short-term follow-up. The results from those studies vary due to varying particle size and content of the ash as well as the amount of exposure. The effects of ash on respiratory health also depend on individual susceptibility, as volcanic ash can exacerbate existing respiratory conditions. Investigating long-term health effects, such as chronic lung disease or serious respiratory symptoms, following volcanic eruptions, is difficult to accomplish, since the disease may not become apparent until many years after the initial exposure. Thus, studies on such long-term health effects are scarce and incomparable.

2 Mental health effects associated with disasters

Natural disasters often occur suddenly and unexpectedly and can be life threatening, causing fear and trauma. They may claim human lives as well as destroy property and livelihood, and damage both the physical and mental health of survivors.[44] Disasters are events that can challenge people´s capacity for adaptation which can lead to the onset of a variety of adverse mental health outcomes.[45] A considerable prevalence of psychological symptoms and psychiatric morbidity, especially anxiety, somatic symptoms, depression and post-traumatic stress disorder (PTSD) has been verified in children, adults and elderly people over different periods after natural disasters such as earthquakes and volcanic eruptions.[46] These psychological symptoms can result from real or anticipated loss of life, physical injury, damage or economic loss.[47]

2.1 Severity of exposure and mental health

PTSD seems to be the most commonly studied psychopathology following natural disasters.[1, 48] PTSD includes several symptoms which have been grouped into three categories or clusters: re-experiencing the event, avoidance and numbing and hyperarousal.[49] The prevalence of PTSD in the general population are considered to be between 5% and 10%.[50] The PTSD prevalence after natural disasters has been reported to range from 5% to 60% in the first one to two years after a disaster, though it is more frequently reported to be in the lower half of that range.[48] The estimated PTSD prevalence among rescue workers is lower, ranging from 10% to 20%.[50] The prevalence of PTSD following a natural disaster is often lower than after technological and human-made disasters, which may result from a lower exposure dosage to natural disasters.[50] Natural disasters generally affect wide-ranging geographic areas which can result in mixed population being examined, including both direct and indirect victims[50]. Where studies of natural disasters usually include people in the overall community who were possibly affected by the disaster.[48] Furthermore, it has been repeatedly reported that the prevalence of PTSD is higher among individuals closer to a disaster than those farther away [50]. After the eruption of Mt. St. Helens in 1980, Shore et al.[47] reported an exposure-related onset of depression, generalized anxiety disorder and PTSD. The results indicated a dose-response pattern as the rates for all disorders combined during the first year after the eruption were 21% among high exposed females, 6% among low exposed females and 2% among a comparison group. The same applied to men where the rates were 11% of exposed men, 2.5% among low exposed men and 1% in a comparison group. A cross-sectional study was undertaken in 2013 to measure the impact of the Mount Merapi eruption in Indonesia which erupted in 2010, resulting in 300 casualties, over 200 people were injured and more than 300,000 evacuating from their homes.[44] Two years after the Merapi eruption, the study found that survivors were still traumatized, psychosocial distress or PTSD was significantly higher in residents closest to the eruption (measured with Impact of Event Scale Revised) compared with a low exposure area. Proximity to the volcano, being female, between 18-59 years of age, owning a home or having experienced a death of a family member due to the eruption, increased the risk of psychosocial problems among the survivors.[44]

2.2 Long-term mental health effects following a disaster

Studies on long-term mental effects after a natural disaster are scarce but generally, longitudinal studies show that symptoms reach peak severity during the first year, followed by a recovery period with a gradual decline in symptoms.[1] In a Japanese study on 248 evacuees from an area close to Mount Unzen following a volcanic eruption, 66% showed signs of psychological distress (measured with GHQ-30) six months after the evacuation.[51] Depression rates began to decline 44 months later, but still the rate was 46%, while dysfunction in interpersonal relationships showed no improvement at that time. Recovery from psychological distress was found to be harder for middle-aged and older individuals than younger ones.[51] Shortly after a cyclone disaster, 58% of evacuees reported psychological dysfunction, by 10 weeks after the disaster the rate had decreased to 41% and further down to 22% 14 months after the disaster.[52]

However, other studies have also shown an increase or a persistent course in the prevalence of psychological morbidity over time. Among evacuees of a volcanic eruption in Colombia 68% reported emotional distress at seven months after the eruption, followed by an increase to 78% after 24 months. After five years the rate of emotional distress had decreased to 31%.[53] A longitudinal study on 469 firefighters who participated in bush fire rescue work in Australia in 1983 indicated a 21% prevalence of PTSD after two years.[54]

2.2.1 Psychological trauma and somatic symptoms

Traumatic events have frequently been found to be associated with PTSD but in many cases traumatized individuals do not meet the DSM (Diagnostic and Statistical Manual of Mental Disorders) criteria for PTSD, but instead display a variety of somatoform symptoms.[55] Complaints of physical symptoms not attributable to any known conventionally defined disease, not adequately supported by clinical or paraclinical findings, are common in individuals seeking primary care following disasters.[56, 57] These medically unexplained symptoms are usually called functional somatic symptoms and are common in all areas of medicine.[57] Somatoform disorders, that are excessively reported by the general public at health-care services can be severely disabling and can cause much emotional pain.[56] Thus, somatoform disorders can be very expensive for the society not only because of increased health-care costs but also because of lost working time and increased risk of early retirement pension in patients.[56] Around 11-60% of patients with chronic pain report co-morbidity of various anxiety disorders.[58] In addition, higher rates of psychiatric distress, more intense pain and greater disability is reported among individuals with PTSD and chronic pain combined compared with individuals with either chronic pain or PTSD.[59]

Common signs of distress in the aftermath of disasters are somatic complaints such as musculoskeletal pains, headaches, fatigue and irritable bowel syndrome and it has been pointed out that physical symptoms should be recognized to a greater extent after disaster.[45, 57, 60] Musculoskeletal symptoms, such as tense and aching muscles or physical weakness, are reportedly the most common and long lasting type of symptoms after disaster.[61] Although, longitudinal studies of somatic symptoms often show a decrease in the incidence of somatic symptoms in the years following a disaster, these symptoms may persist for a long time.[59, 62] They can even last longer than psychological problems after disasters as reported by Nijrolder et al.[63] after the Enschede fireworks disaster study in the year 2000. In that two-wave longitudinal survey (two-three weeks and 18 months after the disaster) the rates of psychological problems decreased over time whereas physical attributed symptoms did not. Physical symptoms were reported to be mainly from the general, neurological, respiratory and musculoskeletal categories.[63]

2.2.2 Sleep difficulties and traumatic events

Sleep disorders are among the most prevalent mental disorders and core symptoms of some other mental disorders such as anxiety and mood disorders.[64] While sleep disturbance in the aftermath of trauma is transient for most people it may become a long-term problem, usually occurring as a part of the acute stress disorder (ASD) and PTSD.[65] Difficulty falling and staying asleep (insomnia) and frequently having nightmares in relation to trauma are two of the diagnostic criteria for PTDS.[66]

Symptoms of long-term sleep disturbances reported by trauma victims commonly include difficulties falling asleep, frequent awakenings from sleep and trouble falling back asleep, shorter sleep duration, restless sleep, fatigue during the day, nonrestorative sleep and particularly nightmares and anxiety dreams.[67] Some of these symptoms are among the most significant predictors of PTSD [64]. Sleep disturbances were identified in 23% of the 160 studies reviewed by Norris et al.[1] on 102 disasters affecting 60,000 individuals in 29 countries.

A few longitudinal studies have investigated the effects of extreme situational stress on sleep. Van der Velden et al.[68] reported that individuals exposed to the Enschede fireworks disaster in Netherlands were more likely to suffer from sleep problems and chronic anxiety symptoms 10 years after the disaster than the comparison group. Exposure to a severe disaster significantly predicted persistent symptoms for 10 years after the disaster. In a study on the long-term effects of the L´Aquila earthquake in Italy, reduced sleep quality and increased frequency of disruptive nocturnal behavior were found to be more prevalent among the residents exposed to the earthquake two years after it took place, compared to residents living in the surrounding areas.[69] Thordardottir et al.[70] examined long-term health status among avalanche survivors and a non-exposed comparison group 16 years after exposure to avalanches in western Iceland. After 16 years, avalanche survivors were in increased risk of PTSD hyperarousal symptoms, sleep-related problems, sleep disturbances related to PTSD, musculoskeletal and nervous system problems and gastrointestinal problems compared to the non-exposed group.

2.3 Predictors for mental health following disasters

After a natural disaster, the severity of the exposure may indicate the possible psychological health impact on the population but it is also necessary to consider sensitive subgroups that may be particularly vulnerable.[71] A majority of trauma victims may experience symptoms such as depression or anxiety to a mild degree but there is a considerable individual differences in psychological reactions to trauma.[72] Risk factors for mental problems after disasters include pre-disaster factors such as prior mental health problems, female gender and low socioeconomic status as well as postdisaster factors such as lack of social support and loss of one´s home[1, 50, 71, 73] Exposure during the disaster, especially severe injury, loss of a loved one and threat to one's life are considered to be great risk factors for psychological symptoms.[50, 71]

Risk factors for functional somatic symptoms after a disaster have rarely been studied. The female gender and high levels of damage experienced have been identified as a risk factors.[74] In a longitudinal study by van den Berg et al.[75] after the fireworks disaster in Netherlands, it was concluded that following a disaster health care workers should particularly look out for physical symptoms among females, immigrants and individuals with pre-disaster psychological problems in order to prevent the development and the risk of long-term physical symptoms.

To summarize on the mental health effects, despite the aforementioned research regarding the longevity of psychological reactions to disasters it is difficult to draw firm conclusions because of the various assessment strategies, sampling methods and time frame of the study designs.[76] However, it is generally considered that people´s distress following a natural disaster decreases over time. Nevertheless a minority of individuals show persisting psychological morbidity which may continue for years and even decades.[77] It is therefore advised that individuals severely exposed to a disaster should be targeted for an early intervention as they seem to be at greater risk of persisting and severe mental and sleeping problems.[68] It is also important to bear in mind that people do not necessarily meet the criteria for DSM diagnoses after disasters and therefore it could be useful to measure nonspecific distress such as somatic symptoms.

3 Volcanic eruption in Eyjafjallajökull volcano in spring 2010

Eyjafjallajökull is an ice-covered volcano located on the southern coast of Iceland, about 150 km from Reykjavík metropolitan area, with agricultural land on its southern slopes and farms located quite close to the volcano summit.[9] On April 14th 2010, an explosive eruption started in Eyjafjallajökull depositing ash over a region of more than 3000 km^2 to the east and southeast.[78] The eruption ended about six weeks later, on May 22, and was classified as a moderate size eruption with index 3 according to the Volcanic Explosive Index (VEI, range 0 to 8) based on the maximum plume height and magma discharge from the volcano.[6] Ash fall from the eruption is estimated to have been 270 million m^3 and the plume height peaked at 10 km.[79] The eruption had four explosive phases and showed signs of both a water-involved and water-free phases. Fine ash was produced in all phases.[80] The fine grained ash dispersed widely and was detected over Europe.[6] The reason for this widespread suspension by wind is assumed to be a combination of the fine brittle fragmentation of the magma and the irregular shape of the ash particles.[6] The Eyjafjallajökull eruption made headlines around the world due to major disruptions in air traffic in large parts of Europe.[9] The exposed area in South Iceland is mostly farmland with a few villages, residents in the area are mostly farmers who stayed in the exposed area during the eruption despite the ashfall, to work on their farms and tend their livestock.[81] Re-suspension of the ash by wind and human activity in the nearby farmed area raised substantial concerns about the potential effects inhaling the ash might have on respiratory health.[82]

3.1.1 Characteristics of Eyjafjallajökull volcanic ash

The ash from Eyjafjallajökull was mainly composed 60% of SiO2 (silicon dioxide), 16% AlO3 (aluminium oxide) and 10% FeO (iron oxide).[9] The ash from Eyjafjallajökull contained low (1.4-3.2 wt%) abundance of crystalline silica (quartz or cristobalite) and consequently the persistence of the deposited ash in the soil and environment was considered to be a non-significant silicosis hazard.[83, 84]

The fresh ash from Eyjafjallajökull contained up to 25% respirable particles (<10 µm) and, as mentioned above, ash deposits can be remobilized by wind or human activities for many years to come.[82] Therefore, the exposure to ash is not limited to the duration of the eruption and the risk of negative health effects can be ongoing for a long period following an eruption. The Eyjafjallajökull ash has been re-suspended on windy days resulting in unusually high particulate matter concentration levels in the air in southern and southwestern Iceland.[85] Thirty wind erosion events were reported in the summer following the 2010 eruption, and one of the storms is considered the most extreme wind erosion events ever recorded on earth.[86] The re-suspended fine ash frequently caused the PM_{10} levels to exceed the 24 hours average health limit used in Iceland for environmental particulate matter (50 µg/m^3) in the vicinity of Eyjafjallajökull.[87]

3.2 Health effects following the Eyjafjallajökull eruption

A study of early health effects of the Eyjafjallajökull eruption was conducted shortly after the eruption ended.[81] Residents living closest to the volcano who had suffered the most exposure to the ash fall were examined on 31 May and 1 June 2010. A total of 207 individuals answered questionnaires about physical and mental health and were examined by physicians. Almost half of the adult participants reported symptoms from the upper airways and eyes during the ash fall as well as exacerbation of pre-existing asthma, but there were few serious health problems or signs of impaired lung function. Most of the residents reported that the use of protective eye wear and respiratory masks relieved symptoms. However, 39% of the residents showed symptoms of psychological morbidity (as measured with GHQ-12).[81]

A larger study of self-reported physical and psychological symptoms among residents near the Eyjafjallajökull volcano (N=1148) was conducted six to nine months after the eruption.[88] Six to nine months following the Eyjafjallajökull eruption, residents from exposed areas reported several symptoms such as increased wheezing, cough and phlegm as well as psychological morbidity-especially in those living closest to the volcano. In addition, a dose-response pattern was observed; those living closest to the volcano had the highest prevalence of symptoms. Psychological morbidity, however, was found to be lower (20-26%) than found in the survey of the most exposed area six to eight weeks after the eruption ended (39%). There was also an association between reporting more than one physical symptom and psychological morbidity.

In conclusion, the chemical and physical properties of volcanic ash can vary considerably between eruptions, even from the same volcano, which makes it hard to generalize findings about the toxicity of ash from each eruption.[87] Thus, health effects can vary between volcanic eruptions which can make comparisons of specific effects difficult. It is important to assess the quantity and the content of the respirable ash from volcanoes to determine if acute and chronic respiratory diseases can occur. The Eyjafjallajökull eruption demonstrated that high degrees of fragmentation can happen in quite modest eruptions.[6] The fresh ash from the Eyjafjallajökull eruption was very well characterized which offers a great opportunity to examine possible long-term effects of ash deposition on the health of humans. Six to nine months following the Eyjafjallajökull eruption, residents from exposed areas reported several symptoms such as increased wheezing, cough and phlegm, especially residents closest to the volcano. It is therefore necessary to conduct a follow-up study to examine the long-term health effects after the eruption to evaluate the long-term development of the physical and mental health of the exposed residents.

Aims

The overall aim of this study was to examine the association between exposure to a volcanic eruption and long-term development of physical and mental health. More specifically, the aims were to investigate:

1. The physical and mental health of exposed residents three to four years after the Eyjafjallajökull eruption compared to six to nine months after the eruption.

2. Whether highly exposed residents, were still at increased risk of physical and mental symptoms compared with residents who were less or not at all exposed to the effects of the Eyjafjallajökull eruption, three years later.

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Article

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Long-term health effects of the Eyjafjallajökull volcanic eruption: A prospective cohort study in 2010 and 2013

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Abstract

Objectives: To examine the long-term development of physical and mental health following an exposure to a volcanic eruption.

Design: Population-based prospective cohort study.

Setting: The Icelandic volcano Eyjafjallajökull erupted on 14 April 2010. This study compared self-reported health at two points in time: in November 2010-February 2011 and December 2013-February 2014.

Participants: Participants were adult residents of areas close to the Eyjafjallajökull volcano, which were divided according to exposure level, as well as a comparison population of residents of Skagafjörður in Northern Iceland. They answered questionnaires on physical and psychological symptoms in 2010 and again in 2013. The participation rate in 2010 was 72%, of those, 80% participated in the follow-up in 2013.

Main outcome measures: The questionnaire included questions on physical symptoms (the screening part of the European Community Respiratory Health Survey (ECRHS)) and on psychological distress (General Health Questionnaire-12-item version (GHQ-12)) perceived stress (the Perceived Stress Scale (PSS-4)) and PTSD symptoms (the Primary Care PTSD (PC-PTSD)).

Results: Compared to 2010, the following symptoms were more prevalent in the exposed group in 2013: current skin rash/eczema (OR 2.04; 95% CI 1.29 to 3.23), back pain (OR 1.44; 95% CI 1.07 to 1.93) and myalgia (OR 1.58; 95% CI 1.18 to 2.13). Also, having experienced respiratory symptoms in the last 12 months was more common in 2013 than 2010, including morning winter phlegm (OR 1.51; 95% CI 1.11 to 2.07), nocturnal or daytime winter phlegm (OR 1.64; 95% CI 1.12 to 2.41) and chronic phlegm (OR 1.85; 95% CI 1.21 to 2.82). Multiple symptoms (two or more) from the upper respiratory system or skin were more common in 2013 (14.5%) than in 2010 (7.6%) (OR 1.83; 95% CI 1.18 to 2.86). Furthermore, having multiple symptoms in 2013 was associated with experiencing perceived stress (OR 2.18; 95% CI 1.09 to 4.20) and PTSD symptoms (OR 3.17; 95% CI 1.12 to 8.20). Finally, when comparing different exposure areas (low, medium and high) in 2013, we found that participants in the more exposed areas were at higher risk of experiencing respiratory and physical symptoms such as waking up feeling tightness in the chest in the last 12 months (medium exposure OR 3.09; 95% CI 1.21 to 10.46 and high exposure OR 3.42; 95% CI 1.30 to 11.79) and having a dry throat during the last month (medium exposure OR 4.66; 95% CI 1.36 to 29.30 and high exposure OR 5.71; 95% CI 1.62 to 36.26), compared to the low exposure region.

Conclusions: The risk of certain symptoms increased with time, and three to four years after the eruption, symptoms still reflected the severity of exposure.

Introduction

On April 14th 2010, an explosive eruption began in the Icelandic volcano Eyjafjallajökull. It ended six weeks later and was classified as a moderate size eruption with index 3 according to the Volcanic Explosive Index (VEI) based on the maximum plume height and magma discharge.[1] Ash fall from the eruption is estimated to have been 270 million m^3 and the fine grained ash dispersed widely and traveled thousands of kilometers over Europe.[1] In addition, the re-suspension of the ash by wind and human activity in the nearby farmed area raised substantial concerns about the potential long-term effects inhaling the ash might have on respiratory health.[2] Fresh ash from the Eyjafjallajökull eruption contained up to 25% respirable particles (<10 µm), that can jeopardize respiratory health.[3] The ash from Eyjafjallajökull was composed of about 60% SiO2 and contained negligible crystalline silica which is considered to be the most toxic mineral in volcanic ash, capable to cause severe respiratory diseases.[2-4]

Adverse respiratory symptoms have been reported following exposure to volcanic ash[5-8] and increased cardiovascular disease[9, 10], respiratory disease[10-13] and mortality[14] have been identified in hospitals or other health care facilities.

There is a scarcity of studies on long-term health effects of volcanic eruptions, in particular studies that aim to explore the effects of long-term exposure to volcanic ash on respiratory health.[15] However, it has been reported that long-term exposure to ash fall is associated with high mortality from respiratory diseases, including chronic obstructive pulmonary disease (COPD) and lung cancer[16] and a small short-term reversible decline in lung function among highly-exposed loggers.[17]

Experiencing a volcanic eruption may affect mental as well as physical health. Psychological symptoms and psychiatric morbidity have been observed in people at different time points after natural disasters.[18] In a Japanese study, 66% of evacuees exposed to a volcanic eruption showed signs of psychological distress six months after the evacuation, while depression rates had declined to 46% 44 months later.[19] Dose response patterns after volcanic eruptions have also been reported, with higher rates of psychological distress, such as PTSD, among residents who were more exposed to the eruption.[20, 21]

Volcanic eruptions vary greatly in duration and the proportion of respirable ash, which makes comparisons of specific health effects between different eruptions difficult. However, the fresh ash from the Eyjafjallajökull eruption was very well characterized which offers a great opportunity to examine long-term effects of ash deposition on human health. We aimed to examine the association between exposure to the Eyjafjallajökull eruption, and the development of self–reported physical and mental health three to four years after the eruption ended compared to six to nine months after the eruption. Furthermore, we aimed to assess whether highly exposed residents were still at increased risk of physical and mental symptoms compared with residents who were less or not at all exposed to the volcanic eruption.

Methods

Study area

The study area near the volcano in South Iceland was divided into low, medium and high-exposure regions (figure 1). To classify different ash exposure levels around the volcano, information based on satellite images of the eruption plume (coarse time resolution) was used as well as information about the emission intensity and observations on the ground.[8] We also included a non-exposed comparison area, Skagafjörður in North Iceland.

Lastly, The Environment Agency of Iceland (EAI) provided data on PM_{10} in 2011 to 2013, from Raufarfell in South Iceland.

Study population

The source population in 2010 included all residents living close to the Eyjafjallajökull volcano (N=2066). The study population included 1615 residents who were 18-80 years of age, lived in the exposed area during the eruption, could be contacted and spoke Icelandic fluently. The comparison group consisted of a sample of 697 residents of Skagafjörður in Northern Iceland (matched to the exposed population with regards to age, gender and urban/rural habitation). In the first study (6-9 months following the eruption), completed questionnaires were obtained from 71% of the exposed population (1148/1615) and 73% of the non-exposed population (510/697).

Three years later, those who had participated in 2010 were contacted again (December 2013 to February 2014). Fifty two members of the exposed group and thirty five of the non-exposed group could not be found in registers or had moved abroad, leaving the study population including 1096 participants from the exposed area and 475 participants from the non-exposed area.

Data collection

In the 2010-study, participants were given the choice to fill out the questionnaire on paper or online (for detailed description of the 2010 study, see Carlsen et al.[8]). Their choice then determined the form of questionnaire they received in 2013. Participants in the exposed region got an introductory letter ahead of the questionnaire while the introductory letter was sent along with the questionnaire to participants in the non-exposed region. Questionnaires were sent to the exposed population on December 4-16 2013 and latest questionnaires were recieved in March 2014. The comparison group received questionnaires on February 19-25 2014, and the latest questionnaires were recieved in May 2014. Everyone got a thank-you/reminder card a few weeks after the questionnaires had been sent out. Participants who had not answered the questionnaire within a certain time period were also reminded with email or/and by phone.

All questionnaires had a running number which could be matched with the participant‘s separately stored ID number. All participants had the same ID number as in the previous study to enable the investigation of long-term health effects.

Questionnaires

The questionnaires were aimed at various physical and psychological symptoms, as well as demographic information on age, gender, marital status, education level, occupational status, financial situation and household size. Standard questions from the screening part of the European Community Respiratory Health Survey (ECRHS) were used to assess respiratory health and underlying diseases.[22] Details on ECRHS have been described elsewhere.[8] Psychological distress was measured with the General Health Questionnaire-12-item version (GHQ-12),[23, 24] a well-known and widely used instrument translated into variety of languages, including Icelandic.[25] The GHQ-12 measures psychological distress in three domains, anxiety, loss of confidence and social dysfunction.[24] The GHQ-12 is a self-reported screening tool that consists of 12 items, used to assess the severity of mental distress over the past few weeks. Each item on the GHQ-12 list has four response options and is scored on a bimodal scale as 0-0-1-1. A binary cut-off score of >2 was used in the current study. Perceived stress during the last month was evaluated with the Perceived Stress Scale (PSS-4) which is designed to measure the degree to which situations in one´s life are appraised as stressful, unpredictable, uncontrollable and overloading.[26, 27] The inital scale includes 14-items but in our study a validated four-item version of the PSS-4 list was used, with each of the four items scored on a 5-point Likert scale (0-4) with a total score ranging from 0 to 16.[26] A binary variable was made with a cut off point at the 90th percentile of the PSS-4 scores, identifying individuals in the top 10th percentile as having stress symptoms.[28] The Primary Care PTSD (PC-PTSD) was used to measure PTSD symptoms and was originally designed to detect the PTSD diagnosis in busy primary care clinics.[29, 30] The 4-item screening tool reflects four factors that are specific to the PTSD construct: re-experiencing, numbing, avoidance and hyperarousal. PC-PTSD has a test-retest reliability of 0.83.[29] Binary cut off score of >2 was used in our study.

Database and coding

The online survey was built with REDCap (Research Electronic Data Capture).[31] Participants answering the questionnaire online were sent a unique link to the online survey by e-mail so they could access the survey. Questionnaires on paper forms were entered into a Redcap database.

Statistical analysis

Demographic characteristics were compared between the exposed population in 2010 and 2013; the exposed and non-exposed populations from 2013 were also compared using χ^2 test. We matched the same participants by ID number in the exposed region in 2010 and 2013, resulting in 633 matched pairs who had replied to the same questions on both occasions. To account for the matching variables, conditional logistic regression analysis was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) of the association between suffering physical and psychological symptoms in 2013 and 2010. Conditional logistic regression was used to further analyze those who reported two or more physical symptoms (morning winter phlegm, nocturnal or daytime winter phlegm and/or chronic nocturnal or daytime winter phlegm and skin rash/eczema). Logistic regression analysis was conducted to estimate the relationship between multiple physical symptoms and psychological distress or PTSD symptoms or perceived stress in 2013. Logistic regression was used to calculate ORs and 95% CIs for the association between physical and psychological symptoms and residence in (1) the low, medium and high exposure areas and non-exposed area and (2) the low, medium and high exposure areas within the exposed region. These models were adjusted for a priori selected variables, possible confounders were; gender, age category, education level and smoking status (never, former, current). Results were considered statistically significant when p values were less than or equal to 0.05 or the CIs did not include 1.0. Descriptive statistics for the 24-hour average concentrations values of environmental data were performed.

All statistical analyses were performed with RStudio version 0.98.501.[32]

The study was approved by The Icelandic Data Protection Authority (no. S4878/2010) and The Science Bioethics Committee (no. 10-099-V3).

Results

Exposure data

PM_{10} measurements were obtained for 851 days of 1095 days (2011-2013), where 244 days were missing, mostly in 2013, due to inactive measuring devices. In the high exposure area the PM_{10} offical health limit of 50 µm/m^3 daily average was exceeded 34 times during the whole follow-up period; 6% (18/313) of days measured in 2011, 3% (8/290) in 2012 and 3% (8/248) in 2013. The average 24-hour concentration values were 15.3 µm/m^3 in 2011, 15.2 µm^3 in 2012 and 15.1 µm^3 in 2013. In addition, the maximum 24-hour average PM_{10} values measured were 307.4 µm/m^3 in 2011 549.9 µm/m^3 in 2012 and 152.0 µm/m^3 in 2013.

Participants

Valid questionnaires were received from 874 of 1096 in the exposed population (80%) and 381 of 475 (80%) in the non-exposed population (figure 2). Those who had not provided the required information on gender, age and education, were excluded from the analysis (59 from the exposed population and 16 from the non-exposed population). Table 1 describes characteristics of the study population by study year (2010 and 2013), as well as the non-exposed group in 2013. The exposed group differed significantly between 2010 and 2013 regarding age, education, marital status, household size, occupational status and financial status, but was similar regarding gender and smoking status. In 2013 the exposed and non-exposed groups were comparible regarding gender, age, education, marital status, financial situation and smoking status.

Development of health effects in the exposed group between 2010 and 2013

Table 2 presents the development of physical and psychological health of the exposed participants between 2010 and 2013. In 2013, exposed participants reported a significant increase in the following respiratory symptoms compared with 2010: morning phlegm during winter (OR 1.51; 95% CI 1.11 to

2.07), winter phlegm during the day or night (OR 1.64; 95% CI 1.12 to 2.41) and chronic nocturnal or daytime winter phlegm (OR 1.85; 95% CI 1.21 to 2.82). The exposed participants in 2013 reported a significant increase during the last month in the skin rash/eczema (OR 2.04; 95% CI 1.29 to 3.23), back pain (OR 1.44; 95% CI 1.07 to 1.93) and myalgia (OR 1.58; 95% CI 1.18 to 2.13). In addition, the exposed participants in 2013 reported a significant increase during the last three months in sleep difficulties such as difficulty staying asleep and having trouble falling back asleep (OR 1.55; 95% CI 1.22 to 1.96) and frequently waking up in the middle of the night (OR 1.28; 95% CI 1.02 to 1.62) compared with 2010.

No changes were observed between 2010 and 2013 in physician-diagnosed conditions (e.g. asthma, emphysema and COPD), psychological distress, perceived stress, PTSD and regular drugs use.

Multiple symptoms

The prevalance of having two or more symptoms increased from 7,6% in 2010 to 14.5% in 2013 (OR 1.83; 95% CI 1.18 to 2.86). Furthermore, having multiple symptoms in 2013 was associated with perceived stress (OR 2.18; 95% CI 1.09 to 4.20) and PTSD symptoms (OR 3.17; 95% CI 1.12 to 8.20), but not psychological distress (adjusting for gender, age, smoking and education).

Health effects by level of exposure and non-exposure in 2013 as a reference

In 2013, the level of volcanic exposure was significantly associated with an increased risk of several respiratory symptoms (after adjusting for gender, age, education and smoking status). Compared to the non-exposed group, these respiratory symptoms were; wheezing for the last 12 months (medium exposure OR 1.88; 95% CI 1.13 to 3.21; high exposure OR 2.20; 95% CI 1.29 to 3.83), coughing without a cold (medium exposure OR 1.64; 95% CI 1.07 to 2.55; high exposure OR 2.01; 95% CI 1.28 to 2.44) and morning phlegm during the winter (medium exposure OR 1.89; 95% CI 1.14 to 3.21; high exposure OR 1.94; 95% CI 1.14 to 3.38). Low exposure was significantly associated with increased risk of two physican-diagnosed diseases: emphysema (OR 5.91; 95% CI 1.30 to 31.66) and COPD (OR 26.49; 95% CI 2.81 to 642.89; table 3) compared with the non-exposure group.

Compared to the non-exposed group, volcanic exposure was associated with greater risk of cough during the last month, both for medium (OR 2.05; 95% CI 1.13 to 3.86) and high (OR 2.28; 95% CI 1.21 to 4.42) exposed groups. Phlegm and skin rash/eczema during the last month were only increased for highly exposed individiuals; phlegm (OR 2.81; 95% CI 1.48 to 5.55) and skin rash/eczema (OR 1.93; 95% CI 1.09 to 3.49). Compared to the non-exposed group, participants in the low and medium exposure regions were significantly less prone to recent musculoskeletal symptoms; back pain (low exposure OR 0.5; 95% CI 0.25 to 0.95; medium exposure OR 0.61; 95% CI 0.40 to 0.93), myalgia (low exposure OR 0.49; 95% CI 0.25 to 0.91; medium exposure OR 0.64; 95% CI 0.42 to 0.97). Participants in the low exposure region were significantly less prone to experiencing dry throat during last month (OR 0.18; 95% CI 0.03 to 0.67; (table 4)) compared to the non-exposed group.

Participants in the low exposure region were also significantly less prone to insomnia compared with the non-exposed population (OR 0.43; 95% CI 0.19 to 0.90). Participants in the low and high exposure region were significantly less likely to use analgesics regularly (low exposure OR 0.16; 95% CI 0.04 to 0.45) and (high exposure OR 0.44; 95% CI 0.25 to 0.78; table 5) compared with the non-exposure group.

Health effects by level of exposure in 2013

Adjusting for gender, age, education and smoking, the likelihood of having woken up with a feeling of tightness in the chest in the last 12 months was higher in the medium and high exposure regions compared with the low exposure region; (medium exposure OR 3.09; 95% CI 1.21 to 10.46 and high exposure OR 3.42; 95% CI 1.30 to 11.79). Risk of chronic nocturnal or daytime winter phlegm was also higher in the medium- and high exposure regions (OR 3.64; 95% CI 1.26 to 15.42) and (OR 3.87; 95% CI 1.31 to 16.63). The risk of allergic rhinitis was only increased in the high exposure region (OR 2.03; 95% CI 1.16 to 3.67). Whereas the risk of dyspnoea was only increased in the medium exposure region (OR 2.66; 95% CI 1.02 to 9.11) compared with the low exposure region. Compared with the low exposure region the participants in the medium and high exposure regions were significantly less prone to have COPD (medium exposure OR 0.15; 95% CI 0.03 to 0.75; high exposure OR 0.16; 95% CI 0.03 to 0.85; table 3).

Dry throat during the last month was more prevalent for participants in the medium and high exposure regions (OR 4.66; 95% CI 1.36 to 29.30) and (OR 5.71; 95% CI 1.62 to 36.26) compared with the low exposure region. The risk of recent physical symptoms only increased in the high exposure region including shortness of breath (OR 3.56; 95% CI 1.16 to 15.54), phlegm (OR 2.72; 95% CI 1.16 to 7.50) and skin rash/eczema (OR 2.41; 95% CI 1.03 to 6.62; table 4). Logistic regression was not applicaple for the PTSD scores since there were no reports of PTSD symptoms in the reference category, the low exposure region. No difference was detected between reported PTSD symptoms among the medium exposed participants and high exposed participants in 2013 ($p = 0.842$).

The risk of regular use of medication (at least once per week) increased significantly for the most exposed participants; including depression medication (OR 3.85; 95% CI 1.07 to 24.63) and any drug for depression, anxiety, sleeping problems and other mental symptoms (OR 3.85; 95% CI 1.07 to 24.63) compared with the low exposure region. The use of analgesics was only increased in the medium exposure region (OR 4.52; 95% CI 1.56 to 19.20; table 5), but not in high exposed region.

Discussion

The findings from this study on a population exposed to a volcanic eruption in 2010 indicate that respiratory and physical symptoms increased between the years 2010 and 2013. In 2013, exposed participants reported respiratory symptoms, particularly increased risk of phlegm in the winter, in addition to symptoms like skin rash/eczema, back pain and myalgia. In addition, exposed participants in 2013 were likelier to experience sleep difficulties and having two or more physical symptoms, compared to 2010. In a further analysis by exposure level, participants living in exposed areas in 2013 reported more wheezing, coughing without a cold and morning phlegm during winter than those living in the non-exposed region. Participants from medium and high-exposure regions were at significantly increased odds of upper respiratory symptoms compared with those from the low-exposure region. These results imply that three to four years following the volcanic eruption, a dose-response relationship between ash exposure and physical symptoms still exists. [8]

Studies on such long-term health effects are scarce with varying results. Investigating long-term health effects, such as chronic lung disease or serious respiratory symptoms following volcanic eruptions, may be difficult, since the disease may not become apparent until many years after the initial exposure.[4] Previous studies have shown adverse respiratory effects from exposure to volcanic ash, but these studies are based on short-term follow-ups (few weeks to less than a year).[5-8, 10-12] Our findings differ from the results of Rojas-Ramos et al.[6] who reported increased incidence of respiratory symptoms and decrease in lung function in the immediate period after the eruption in Popocatepetl in Mexico. However, seven months later the symptoms rates had decreased to normal levels. The authors attributed the reversibility of the symptoms to the low content of free silica as cristobalite, less than 3.5%, in the respirable fraction. Diminishing symptoms over time were also found among exposed loggers following the Mt. St. Helen´s eruption. Acute symptoms like chest tightness, coughing and eye irritation were more common among exposed than non-exposed loggers few weeks after the eruption. When the tests were repeated a few months later, the symptoms had subsided and no significant differences were found between the groups.[33-35] One year after the Mt. St. Helen´s eruption lung function was found to be decreased both among exposed loggers and the comparison group, but more severe among the exposed loggers. A four year follow-up study indicated no need of a further follow-up as those affected seemed to have recovered.[36]

Our previous study on health effects six to nine months after the Eyjafjallajökull eruption showed a dose-response tendency between certain symptoms and level of exposure to the volcano.[8] The present study indicates that this dose-response pattern still exists, three to four years later. Previous studies comparing health effects by level of exposure to volcanic ash have yielded similar findings.[37-40] Respiratory diseases were examined over a 35 years period (1968-2002) among residents in Sakurajima-Tarumizu, near Mt. Sakurajima in Japan, one of the most active volcanoes in the world which has erupted every 10-30 years for the past 100 years.[16] Elevated mortality from respiratory diseases, including lung cancer and COPDs was found among residents from the highly exposed area. The ash from Mt. Sakurajima generally contained around 60% of SiO2 and up to 7 wt% of cristobalite, with up to 10% respirable material (<4μm).[16] Silicic volcanic ash frequently contains crystalline silica, such as cristobalite, quartz or tridymite polymorphs, and is considered to be the most troublesome compound produced in volcano eruptions in relation to chronic lung pathogenesis.[41, 42] The Eyjafjallajökull ash contained 1.4-3.2 wt% crystalline silica (quartz or cristobalite) and consequently the persistence of the deposited ash in the soils and environment was considered to be a non-significant hazard for silicosis (a fibrotic lung disease).[43, 44]

However, the fresh ash from Eyjafjallajökull volcano contained up to 25% respirable particles (<10μm) and during the summer and fall of 2010, the official health limit of PM_{10} respirable particles (50 μm/m^3 daily average) was exceeded 25 times.[8] Following a volcanic eruption ash deposits can be remobilized by wind or human activities for many years to come and the risk of negative health effects can be ongoing for years.[2] Re-suspension of the ash on windy days results in unusually high particulate matter concentration levels in the air in southern and southwestern Iceland.[45] Thirty wind erosion events were reported in the summer following the 2010 eruption, and one of the storms is considered the most extreme wind erosion event ever recorded on earth.[46] The re-suspended fine ash caused the PM_{10} levels to frequently exceed the 24-hour air quality guideline limit (50µg/m^3) in the vicinity of Eyjafjallajökull during and after the eruption.[47] During the follow-up time of the current study, the daily average PM_{10} values did not decrease during the study period and the maximum values remained high in the high exposed area according to the data from EAI. This indicates continued exposure to ash, in the years following the eruption.

Our findings on exposure to volcanic eruption and long-term skin irritation are novel and to the best of our knowledge no previous studies have shown this long-term effect. Fresh ash can have acid coatings and be abrasive to the skin causing skin irritation and debilitation which can lead to infections.[48, 49] Eye and skin irritation commonly decreases shortly after exposure to ash and longer term toxic injury to these organs are unusal.[42] In the present study, however, the prevalence of skin rash/eczema more than doubled between 2010 and 2013 and was most common in the high exposure region, even three to four years after the eruption ended.

Regarding mental health, rates of psychological distress and PTSD symptoms decreased between 2010 and 2013. This is similar to the findings of Ohta et al[19] on volcanic eruption evacuees who reported that psychological distress decreased, with time (between six and 44 months) after the evacuation. Dose response patterns have been found between psychological distress and exposure to Mount St Helens and Mount Merapi volcanic eruptions.[20, 21] The present study does not suggest decisive conclusions about exposure and psychological symptoms, whereas the rates of perceived stress and psychological distress were similar in the exposed regions. However, PTSD symptoms were only found in the medium and high exposure areas in 2013. In addition, those who reported two or more physical symptoms in 2013, were more likely to show symptoms of PTSD and perceived stress. This indication of a susceptible subgroup at greater risk of developing psychological problems may guide provision of preventive and treatment measures to focus on this vulnerable group.

Sleep difficulties among exposed participants in 2013 had increased since 2010. Norris et al[50] reviewed 160 studies on disaster victims and identified sleep disturbances in 23% of the studies reviewed. Our findings on long-term sleep impairments after a disaster are consistent with previous studies where sleep difficulties have been reported as long as 16 years after a disaster.[51-53] Open ended questions revealed that participants in the exposed region were alert at night because of the possibility of another volcanic eruption and evacuation, as reflected in the following comments *"Many people cannot sleep unless they have their phone nearby, in case of an evacuation announcement, that feeling is stressful"*. *"I always sleep with a mobile phone on my nightstand. People or companies should not send text messages during the night, it seriously disrupts my sleep, making me think it is an evacuation warning"*.

Our study shows that musculoskeletal symptoms, back pain and myalgia, had increased significantly between 2010 and 2013. Somatic complaints are a common signs of distress in the aftermath of disasters. These include musculoskeletal pains, headaches, fatigue and irritable bowel syndrome.[54-56] It has been pointed out that physical symptoms merit more attention after disasters.[54, 55]

Musculoskeletal symptoms, such as tense and aching muscles or physical weakness, are the most common and long lasting physical symptoms after disasters.[57]

As to strengths and weaknesses of the present study, the fact that the study is longitudinal and population-based with a large cohort of participants increases the credibility of the findings. Second, the response rate was high both in 2010 and 2013, with 80% of the original study sample participating, which minimizes selection bias in the 2013 follow-up. Third, we used multiple measuring tools for psychological outcomes: psychological distress, perceived stress and PTSD symptoms, based on standardized psychological tests.

Regarding limitations, non-participation may have influenced the results. Selective attrition may have led to that participants, who were lost to follow-up because of severe sickness or death, included more people with physical symptoms who may possibly have developed more serious respiratory symptoms. Their non-response in our follow-up study could thus underestimate the true risk associated with long-term ash exposure. However, it is also possible that individuals who experience symptoms are more likely to participate, which would lead to overestimation of ORs. High response rate in 2013 does on the other hand lower this potential selection bias. It is also possible that recall bias may have influenced the self-reported data. However, the specific dose-response relationship found between ash exposure and physical symptoms renders that unlikely. Information bias may have occurred in our study if participants in the higher exposed areas are more concerned or informed about the health effects following a volcanic eruption, making them more aware of symptoms and thus affecting their replies on the questionnaires. The same classification of exposure areas (low, medium and high) was used in 2010 and 2013, based on information on satellite images, emission intensity and observations on the ground.[8] Re-classification of the exposed region might have been valid in the present study, as exposure to re-suspended ash may differ from the original exposure. The PM_{10} measurements in the current study were only obtained from one measurement station in Raufarfell, located in the high exposure region, and therefore we do not have any information whether the exposure levels in the medium and low-exposure regions had changed or remained the same during the follow-up period. However, the dose-response patterns of physical symptoms are consistent between the two studies, indicating that the classification of exposure levels had not changed.

Conclusions

Our findings indicate an association between long-term exposure to volcanic ash and increased respiratory and physical symptoms among participants in the exposed area. The findings indicate a dose-response relationship between exposure and symptoms, with participants in the more exposed areas at greatest risk of developing respiratory and physical symptoms. Also, reporting two or more physical symptoms were more common in 2013 than in 2010 and those with multiple symptoms were more prone to having psychological problems.

It is important to embark on long-term clinical or epidemiological studies to determine the possible long-term health effects of volcanic ash exposure. The present study shows a need for continued health monitoring and adequate treatment of residents in the exposed region. The potential risks of long-term exposure to ash must not be underestimated and finding a way to prevent or minimize the risk to exposed residents is of great importance. This study draws attention to the possibility of enduring physical and psychological illnesses following natural hazards and has implications for planning preventive and treatment strategies.

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Tables

Table 1. Demographic characteristics of the population (South Iceland) exposed to the Eyjafjallajökull volcanic eruption in 2010 and non-exposed population (North Iceland)

	Exposed 2010 (n = 1132)	**Exposed 2013 (n = 815)**	**Non-exposed 2013 (n = 365)**	**p Value***	**p Value***
	% (n/N)	**% (n/N)**	**% (n/N)**	**Exp. 2010 vs. exp. 2013**	**Exp. 2013 vs. non-exp. 2013**
Demographic characteristics					
Gender				0.17	0.81
Male	49.1 (556/1132)	45.9 (374/815)	44.9 (164/365)		
Female	50.9 (576/1132)	54.1 (441/815)	55.0 (201/365)		
Age categories				<0.001	0.5
18-23	11.3 (128/1132)	4.0 (33/815)	1.7 (6/363)		
24-30	8.7 (99/1132)	9.3 (76/815)	9.4 (34/363)		
31-40	15.4 (174/1132)	13.1 (107/815)	14.0 (51/363)		
41-50	20.5 (232/1132)	19.0 (155/815)	17.6 (64/363)		
51-60	19.3 (218/1132)	23.6 (192/815)	25.6 (93/363)		
61-70	15.7 (178/1132)	18.4 (150/815)	19.6 (71/363)		
≥71	9.1 (103/1132)	12.5 (102/815)	12.7 (46/363)		
Education				0.004	0.14
No formal education	5.3 (60/1132)	6.0 (49/815)	5.5 (20/365)		
Primary education	36.0 (407/1132)	29.0 (236/815)	24.7 (90/365)		
Secondary education	33.5 (379/1132)	33.5 (273/815)	35.1 (128/365)		
Professional or university education	20.7 (234/1132)	24.7 (201/815)	30.1 (110/365)		
Other education*	4.6 (52/1132)	6.9 (56/815)	4.7 (17/365)		
Marital status				0.006	0.85
Married or cohabitating	72.3 (818/1132)	75.9 (616/812)	77.5 (282/364)		
Single or divorced	18.4 (208/1132)	13.7 (111/812)	13.7 (50/364)		
Relationship-no cohabitation	6.9 (78/1132)	6.2 (50/812)	5.2 (19/364)		

Table 1. *Continued*

	Exposed 2010 (n = 1132)	Exposed 2013 (n = 815)	Non-exposed 2013 (n = 365)	p Value*	p Value*
	% (n/N)	% (n/N)	% (n/N)	Exp. 2010 vs. Exp. 2013	Exp. 2013 vs. Non-exp. 2013
Widow or widower	2.5 (28/1132)	4.3 (35/812)	3.6 (13/364)		
Household size				0.009	<0.001
1 adult	13.7 (149/1088)	19.3 (145/751)	28.7 (96/335)		
2 adults	51.3 (558/1088)	50.1 (376/751)	51.9 (174/335)		
3 adults	21.4 (233/1088)	18.9 (142/751)	12.8 (43/335)		
≥4 adults	13.6 (148/1088)	11.7 (88/751)	6.6 (22/335)		
Occupational status				<0.001	<0.001
Full-time job	60.8 (679/1117)	63.1 (487/772)	57.7 (207/359)		
Part-time job	9.0 (101/1117)	9.3 (72/772)	12.5 (45/359)		
Unemployed	3.6 (40/1117)	1.7 (13/772)	1.4 (5/359)		
Student	7.0 (78/1117)	5.3 (41/772)	5.0 (18/359)		
Homemaker or maternity leave	8.5 (95/1117)	3.8 (29/772)	3.3 (12/359)		
Retired	6.1 (68/1117)	12.4 (96/772)	4.2 (15/359)		
On disability or sick leave	5.0 (56/1117)	4.4 (34/772)	15.9 (57/359)		
Financial situation				0.038	0.38
Very good	4.6 (52/1121)	5.4 (43/794)	5.0 (18/360)		
Good	24.0 (269/1121)	29.8 (237/794)	34.7 (125/360)		
Acceptable ("making ends meet")	55.6 (623/1121)	50.9 (404/794)	45.8 (165/360)		
Bad	13.3 (149/1121)	12.1 (96/794)	13.3 (48/360)		
Very bad ("indebted or bankruptcy")	2.5 (28/1121)	1.8 (14/794)	1.1 (4/360)		
Smoking status 2013				0.08	0.36
Never smoker	56.2 (624/1110)	56.1 (444/791)	51.7 (186/360)		
Former smoker	25.9 (288/1110)	29.3 (232/791)	32.8 (118/360)		
Current smoker	17. 8 (198/1110)	14.5 (115/791)	15.6 (56/360)		

*P-values based on the chi square test

Table 2. Risk of respiratory symptoms (ECHRS), recent symptoms (physical and psychological) and drug use in a population long-term exposed to Eyjafjallajökull volcanic eruption in 2010 and 2013.

ECRHS	Exposed 2010 (n = 633) % (n/N)	Exposed 2013 (n = 633) % (n/N)	OR (95% CI)†
Wheezing (last 12 months)	17.9 (108/603)	19.1 (115/603)	1.01 (0.74 to 1.39)
If yes,breathlessness at the same time	9.3 (56/603)	11.8 (71/603)	1.28 (0.86 to 1.91)
If yes, do you wheeze without a cold	12.4 (75/603)	14.4 (87/603)	1.18 (0.83 to 1.68)
Nocturnal chest tightness (last 12 months)	11.5 (70/607)	13.3 (81/608)	1.16 (0.83 to 1.63)
Breathlessness at rest	7.2 (43/598)	8.1 (49/602)	1.20 (0.77 to 1.88)
Coughing without a cold	28.2 (174/607	28.9 (177/613)	1.00 (0.78 to 1.28)
Nocturnal cough (last 12 months)	24.4 (147/602)	22.5 (137/609)	0.91 (0.70 to 1.18)
Morning winter cough	13.1 (79/603)	11.7 (70/599)	0.85 (0.59 to 1.20)
Nocturnal or daytime winter cough	11.7 (70/600)	11.5 (68/591)	0.97 (0.68 to 1.38)
If yes, is it chronic‡	7.3 (44/600)	9.5 (56/591)	1.32 (0.86 to 2.00)
Morning winter phlegm	15.1 (90/598)	21.4 (128/597)	**1.51 (1.11 to 2.07)**
Nocturnal or daytime winter phlegm	8.6 (51/590)	14.1 (82/583)	**1.64 (1.12 to 2.41)**
If yes, is it chronic‡	6.8 (40/590)	12.3 (72/583)	**1.85 (1.21 to 2.82)**
Dyspnoea	13.5 (81/598)	12.0 (72/601)	0.90 (0.64 to 1.29)
Nasal allergy and hay fever	19.9 (121/607)	20.8 (124/596)	1.17 (0.86 to 1.58)
Allergic rhinitis	29.5 (178/603)	34.8 (207/594)	1.25 (0.97 to 1.61)
Physician diagnosed conditionsφ			
Asthma	13.1 (79/603)	13.8 (82/595)	1.08 (0.76 to 1.54)
Asthma diagnosis was confirmed by an MD	10.8 (65/603)	12.6 (75/595)	1.24 (0.85 to 1.79)
Heart disease	8.2 (50/607)	10.1 (61/605)	1.17 (0.79 to 1.74)
Chronic bronchitis	8.1 (49/602)	8.7 (52/599)	1.02 (0.68 to 1.54)
Emphysema	2.3 (14/603)	4.2 (25/595)	2.00 (1.00 to 4.00)
Chronic obstructive pulmonary disease (COPD)	1.7 (10/598)	1.8 (11/608)	1.10 (0.47 to 2.59)
Physical symptoms			
Respiratory symptoms‡			
Shortness of breath	7.7 (44/574)	9.1 (52/574)	1.13 (0.73 to 1.74)
Feeling of tightness in chest	4.0 (23/570)	4.7 (27/572)	1.14 (0.64 to 2.05)

Table 2. *Continued*

ECRHS	Exposed 2010 (n = 633) % (n/N)	Exposed 2013 (n = 633) % (n/N)	OR (95% CI)†
Cough and phlegm‡			
Cough	16.1 (94/584)	13.3 (77/581)	0.76 (0.54 to 1.07)
Phlegm	10.7 (62/578)	14.1 (82/582)	1.25 (0.86 to 1.83)
Irritation symptoms‡			
Dry throat	10.6 (62/584)	9.8 (57/582)	0.91 (0.62 to 1.34)
Eye irritation and itch	14.2 (84/592)	13.5 (78/579)	0.90 (0.64 to 1.26)
Skin rash/eczema	5.4 (31/571)	12.0 (69/573)	**2.04 (1.29 to 3.23)**
Musculoskeletal symptoms‡			
Back pain	17.5 (100/570)	22.7 (131/577)	**1.44 (1.07 to 1.93)**
Myalgia	17.7 (101/570)	25.5 (151/593)	**1.58 (1.18 to 2.13)**
Psychological symptoms			
Sleep and mental health			
Insomnia‡	13.4 (77/576)	17.5 (103/587)	1.31 (0.95 to 1.81)
Psychological distress§	11.1 (55/497)	9.4 (45/479)	0.81 (0.52 to 1.27)
Perceived stressΩ	9.1 (55/600)	10.8 (63/582)	1.19 (0.79 to 1.78)
PTSD¥	5.4 (33/606)	3.2 (19/601)	1.02 (0.78 to 1.35)
Sleep difficulties			
Difficulty falling asleep (yes: sometimes, often and always/every night)	32.7 (200/611)	38.8 (238/613)	1.27 (1.00 to 1.61)
Difficulty staying asleep and having trouble falling back asleep (yes: sometimes, often and always/every night)	33.0 (200/606)	43.3 (260/601)	**1.55 (1.22 to 1.96)**
Feeling well-rested after a night´s sleep (yes: often and always/every night)	46.4 (277/597)	49.4 (298/603)	1.13 (0.90 to 1.42)
Frequently wake up in the middle of the night (yes: sometimes, often and always/every night)	53.0 (323/610)	59.1 (363/614)	**1.28 (1.02 to 1.62)**
Regular drugs use (at least once per week)			
Asthma medication	3.6 (23/632)	5.2 (33/633)	1.45 (0.85 to 2.50)
Analgesics	9.8 (62/632)	10.7 (68/633)	1.09 (0.76 to 1.57)
Any drug for depression, anxiety, sleeping and other mental symptoms	30.3 (192/632)	35.9 (227/633)	1.25 (0.99 to 1.57)
Drugs for other mental symptoms	0.5 (3/632)	0.6 (4/633)	1.33 (0.30 to 5.96)
Depression medication	4.4 (28/632)	6.8 (43/633)	1.18 (0.93 to 1.49)
Anxiety/sedative medication	4.9 (31/632)	5.7 (36/633)	1.13 (0.69 to 1.85)
Hypnotics	7.0 (44/632)	7.3 (46/633)	1.58 (0.96 to 2.58)
Blood pressure-lowering medication	26.1 (165/633)	29.5 (187/633)	1.18 (0.93 to 1.49)

†OR and 95% CI from conditional logistic regression
‡ Answers “Yes to a moderate extent” or “Yes, to much extent” to the question “Have any of the following symptoms disturbed your daily activities during the last month”.

ǂChronic: more than 3 months/year
φAnswering ”Yes” to “Has physician ever told you that you had (the disease)?”
§Psychological distress was derived from GHQ-12 referring to “the previous weeks”, using a binary cut-off score of >2.
ΩPerceived stress was derived from PSS-4 referring to “the recent month” using a binary cut-off score of 90^{th} percentile.
¥ Primary care PTSD was derived from PC-PTSD referring to “the recent month” using a binary cut-off score of >2.

Table 3. Risk of respiratory symptoms (ECHRS) in 2013 in a population exposed to the 2010 Eyjafjallajökull volcanic eruption, by exposure level.

ECRHS	Non-exposed 2013 (n = 365)		Low exposure 2013* (n = 90)		Medium exposure 2013* (n = 428)		High exposure 2013* (n = 267)	
	OR (95% CI)†	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**
Wheezing (last 12 months)	1 (ref)	11.4 (40/351)	1.42 (0.64 to 2.98)	14.9 (13/87)	**1.88 (1.13 to 3.21)**	17.1 (71/416)	**2.20 (1.29 to 3.83)**	19.0 (48/253)
			1 (ref)		1.34 (0.70 to 2.76)		1.59 (0.81 to 3.35)	
If yes,breathlessness at the same time	1 (ref)	7.1 (25/351)	1.36 (0.74 to 2.55)	9.2 (8/87)	1.05 (0.39 to 2.54)	10.1 (42/416)	1.49 (0.79 to 2.87)	10.7 (27/253)
			1 (ref)		1.33 (0.60 to 3.37)		1.50 (0.65 to 3.90)	
If yes, do you wheeze without a cold	1 (ref)	8.0 (28/351)	1.78 (0.98 to 3.48)	12.6 (11/87)	1.65 (0.69 to 3.79)	12.3 (51/416)	**2.35 (1.27 to 4.47)**	15.0 (38/253)
			1 (ref)		1.08 (0.53 to 2.39)		1.46 (0.70 to 3.3)	
Nocturnal chest tightness (last 12 months)	1 (ref)	10.4 (37/357)	0.43 (0.12 to 1.16)	4.6 (4/87)	1.31 (0.77 to 2.25)	12.9 (54/420)	1.40 (0.80 to 2.49)	13.2 (34/252)
			1 (ref)		**3.09 (1.21 to 10.46)**		**3.42 (1.30 to 11.79)**	
Breathlessness at rest	1 (ref)	7.9 (28/355)	0.68 (0.22 to 1.81)	7.0 (6/86)	0.90 (0.47 to 1.75)	7.9 (33/417)	0.77 (0.38 to 1.56)	7.1 (18/253)
			1 (ref)		1.39 (0.56 to 4.23)		1.18 (0.44 to 3.72)	
Coughing without a cold	1 (ref)	19.0 (67/353)	1.31 (0.69 to 2.44)	24.1 (21/87)	**1.64 (1.07 to 2.55)**	25.2 (107/424)	**2.01 (1.28 to 2.44)**	29.1 (74/254)
			1 (ref)		1.26 (0.73 to 2.28)		1.53 (0.86 to 2.82)	
Nocturnal cough (last 12 months)	1 (ref)	19.4 (69/355)	0.85 (0.43 to 1.61)	17.4 (15/86)	1.18 (0.77 to 1.82)	21.6 (91/421)	1.30 (0.83 to 2.07)	22.6 (57/252)
			1 (ref)		1.40 (0.78 to 2.68)		1.55 (0.83 to 3.03)	
Morning winter cough	1 (ref)	10.8 (38/351)	1.17 (0.48 to 2.64)	11.0 (9/82)	1.44 (0.82 to 2.56)	12.3 (51/416)	1.24 (0.67 to 2.30)	10.7 (27/253)
			1 (ref)		1.25 (0.60 to 2.85)		1.08 (0.49 to 2.58)	
Nocturnal or daytime winter cough	1 (ref)	9.3 (32/345)	1.34 (0.56 to 3.02)	14.1 (12/85)	1.18 (0.65 to 2.20)	10.1 (42/415)	0.99 (0.51 to 1.96)	8.6 (21/245)
			1 (ref)		0.90 (0.44 to 2.01)		0.76 (0.34 to 1.77)	
If yes, is it chronic‡	1 (ref)	5.2 (18/345)	1.73 (0.83 to 3.82)	8.2 (7/85)	1.13 (0.34 to 3.32)	7.7 (32/415)	1.69 (0.76 to 3.89)	7.3 (18/245)
			1 (ref)		1.56 (0.62 to 4.77)		1.51 (0.57 to 4.8)	
Morning winter phlegm	1 (ref)	12.0 (42/349)	1.79 (0.87 to 3.59)	18.6 (16/86)	**1.89 (1.14 to 3.21)**	19.8 (81/410)	**1.94 (1.14 to 3.38)**	20.4 (51/250)
			1 (ref)		1.08 (0.60 to 2.05)		1.09 (0.59 to 2.14)	
Nocturnal or daytime winter phlegm	1 (ref)	7.4 (26/349)	0.85 (0.29 to 2.17)	7.1 (6/85)	1.68 (0.92 to 3.19)	12.7 (52/408)	1.63 (0.86 to 3.18)	12.9 (31/241)
			1 (ref)		2.02 (0.88 to 5.46)		1.97 (0.83 to 5.47)	
If yes, is it chronic‡	1 (ref)	6.3 (22/349)	1.83 (0.95 to 3.68)	3.5 (3/85)	0.51 (0.11 to 1.65)	11.0 (45/408)	1.92 (0.97 to 3.95)	12.0 (29/241)
			1 (ref)		**3.64 (1.26 to 15.42)**		**3.87 (1.31 to 16.63)**	

Table 3. *Continued*

ECRHS	Non-exposed 2013 (n = 365)		Low exposure 2013* (n = 90)		Medium exposure 2013* (n = 428)		High exposure 2013* (n = 267)	
	OR (95% CI)†	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**
Dyspnoea	1 (ref)	10.1(36/355)	0.47 (0.13 to 1.28)	5.7 (5/88)	1.15 (0.65 to 2.08)	10.6 (44/415)	1.06 (0.57 to 2.0)	10.6 (26/246)
			1 (ref)		**2.66 (1.02 to 9.11)**		2.45 (0.91 to 8.59)	
Nasal allergy and hay fever	1 (ref)	19.0 (66/348)	0.86 (0.42 to 1.66)	16.7 (14/84)	1.10 (0.71 to 1.73)	19.4 (79/408)	1.19 (0.73 to 1.92)	19.8 (49/247)
			1 (ref)		1.28 (0.70 to 2.5)		1.38 (0.72 to 2.76)	
Allergic rhinitis	1 (ref)	27.6 (96/348)	0.72 (0.40 to 1.29)	23.5 (20/65)	1.11 (0.76 to 1.62)	30.8 (126/409)	1.45 (0.97 to 2.18)	37.6 (92/245)
			1 (ref)		1.57 (0.92 to 2.78)		**2.03 (1.16 to 3.67)**	
Physician diagnosed conditions§								
Asthma	1 (ref)	10.3 (36/349)	0.99 (0.43 to 2.14)	12.8 (11/86)	0.99 (0.57 to 1.73)	11.9 (49/412)	0.97 (0.53 to 1.76)	11.8 (29/246)
			1 (ref)		1.00 (0.50 to 2.21)		0.97 (0.46 to 2.21)	
Asthma diagnosis was confirmed by an MD	1 (ref)	9.2 (32/349)	1.01 (0.57 to 1.83)	12.8 (11/86)	1.12 (0.48 to 2.47)	11.2 (46/412)	0.94 (0.50 to 1.76)	10.6 (26/246)
			1 (ref)		0.90 (0.44 to 1.98)		0.83 (0.38 to 1.90)	
Heart disease	1 (ref)	8.7 (31/356)	1.49 (0.65 to 3.30)	13.8 (12/87)	0.69 (0.35 to 1.34)	6.5 (27/417)	0.93 (0.48 to 1.84)	8.8 (22/251)
			1 (ref)		0.46 (0.22 to 1.00)		0.63 (0.29 to 1.41)	
Chronic bronchitis	1 (ref)	5.1 (18/355)	2.42 (0.92 to 6.19)	10.3 (9/87)	1.80 (0.87 to 3.95)	7.2 (30/414)	1.86 (0.86 to 4.22)	7.7 (19/247)
			1 (ref)		0.76 (0.35 to 1.78)		0.77 (0.34 to 1.88)	
Emphysema	1 (ref)	1.1 (4/349)	5.91 (1.30 to 31.66)	5.8 (5/86)	2.23 (0.59 to 10.78)	2.2 (9/412)	2.60 (0.66 to 12.84)	2.8 (7/248)
			1 (ref)		0.38 (0.12 to 1.34)		0.44 (0.13 to 1.63)	
Chronic obstructive pulmonary disease (COPD)	1 (ref)	0.3 (1/356)	26.49 (2.81 to 642.89)	4.6 (4/87)	3.66 (0.45 to 79.38)	1.0 (4/418)	3.88 (0.42 to 86.87)	1.2 (3/254)
			1 (ref)		**0.15 (0.03 to 0.75)**		**0.16 (0.03 to 0.85)**	

*Regions are seen in figure 1.
†OR and 95% CI from multivariate logistic regression adjusted for age category, gender, education and smoking status.
‡Chronic: more than 3 months/year
§Answering "'Yes" to "Has physician ever told you that you had (the disease)?"

Table 4. Risk of recent symptoms (physical) in 2013 in a population exposed to the 2010 Eyjafjallajökull volcanic eruption, by exposure level.

Physical symptoms	Non-exposed 2013 (n = 365)		Low exposure 2013* (n = 90)		Medium exposure 2013* (n= 428)		High exposure 2013* (n = 267)	
	OR (95% CI)†	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**
Respiratory symptoms‡								
Shortness of breath	1 (ref)	5.7 (19/334)	0.62 (0.14 to 2.07)	3.6 (3/84)	1.52 (0.73 to 3.29)	6.7 (27/401)	2.10 (0.99 to 4.64)	9.4 (22/233)
			1 (ref)		2.40 (0.80 to 10.37)		**3.56 (1.16 to 15.54)**	
Feeling of tightness in chest	1 (ref)	3.3 (11/333)	0.56 (0.08 to 2.4)	2.4 (2/84)	1.01 (0.39 to 2.76)	3.8 (15/399)	1.08 (0.39 to 3.03)	4.3 (10/234)
			1 (ref)		1.80 (0.47 to 11.84)		2.05 (0.50 to 13.79)	
Cough and phlegm‡								
Cough	1 (ref)	9.4 (31/331)	1.24 (0.48 to 2.98)	9.2 (8/87)	**2.05 (1.13 to 3.86)**	12.4 (50/404)	**2.28 (1.21 to 4.42)**	13.9 (33/238)
			1 (ref)		1.69 (0.80 to 4.06)		1.85 (0.84 to 4.54)	
Phlegm	1 (ref)	7.5 (25/333)	1.03 (0.35 to 2.69)	7.1 (6/84)	1.86 (1.0 to 3.64)	11.1 (45/404)	**2.81 (1.48 to 5.55)**	16.0 (38/237)
			1 (ref)		1.80 (0.78 to 4.91)		**2.72 (1.16 to 7.50)**	
Irritation symptoms‡								
Dry throat	1 (ref)	7.9 (27/340)	**0.18 (0.03 to 0.67)**	2.4 (2/84)	0.86 (0.46 to 1.63)	9.1 (37/408)	1.04 (0.54 to 2.01)	11.0 (26/236)
			1 (ref)		**4.66 (1.36 to 29.30)**		**5.71 (1.62 to 36.26)**	
Eye irritation and itch	1 (ref)	7.1 (24/336)	0.85 (0.29 to 2.18)	7.1 (6/84)	1.70 (0.93 to 3.21)	11.8 (48/407)	1.83 (0.97 to 3.55)	13.3 (31/233)
			1 (ref)		1.92 (0.83 to 5.21)		2.06 (0.87 to 5.74)	
Skin rash/eczema	1 (ref)	11.6 (39/337)	0.77 (0.27 to 1.90)	7.4 (6/81)	1.24 (0.71 to 2.22)	10.8 (44/406)	**1.93 (1.09 to 3.49)**	16.3 (38/233)
			1 (ref)		1.58 (0.69 to 4.28)		**2.41 (1.03 to 6.62)**	
Musculoskeletal symptoms‡								
Back pain	1 (ref)	26.5 (91/344)	**0.50 (0.25 to 0.95)**	16.5 (14/85)	**0.61 (0.40 to 0.93)**	19.3 (77/399)	0.85 (0.54 to 1.33)	24.5 (58/237)
			1 (ref)		1.20 (0.65 to 2.35)		1.71 (0.90 to 3.40)	
Myalgia	1 (ref)	27.5 (95/346)	**0.49 (0.25 to 0.91)**	18.6 (16/86)	**0.64 (0.42 to 0.97)**	24.2 (99/409)	0.71 (0.45 to 1.10)	25.4 (62/244)
			1 (ref)		1.30 (0.72 to 2.46)		1.45 (0.78 to 2.81)	

*Regions are seen in figure 1.
†OR and 95% CI from multivariate logistic regression adjusted for age category, gender, education and smoking status.
‡Answers “Yes to a moderate extent” or “Yes, to much extent” to the question “Have any of the following symptoms disturbed your daily activities during the last month”.

Table 5. Risk of recent symptoms (psychological) and drug use in a population exposed to the 2010 Eyjafjallajökull volcanic eruption by exposure level.

Psychological symptoms	**Non-exposed 2013 (n = 365)**		**Low exposure 2013* (n = 90)**		**Medium exposure 2013* (n = 428)**		**High exposure 2013* (n = 267)**	
	OR (95% CI)†	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**	**OR (95% CI)†**	**% (n/N)**
Sleep and mental health								
Insomnia‡	1 (ref)	20.7 (70/338)	**0.43 (0.19 to 0.90)**	10.6 (9/85)	0.80 (0.51 to 1.26)	17.3 (70/405)	0.63 (0.38 to 1.04)	14.9 (36/242)
			1 (ref)		1.88 (0.93 to 4.25)		1.50 (0.71 to 3.50)	
Psychological distress§	1 (ref)	24.5 (80/327)	1.08 (0.57 to 2.0)	22.6 (19/84)	0.92 (0.59 to 1.42)	21.7 (84/387)	1.10 (0.70 to 1.76)	24.0 (58/242)
			1 (ref)		0.87 (0.49 to 1.59)		1.07 (0.59 to 1.99)	
Percieved stressΩ	1 (ref)	11.1 (38/341)	0.92 (0.36 to 2.14)	10.7 (9/84)	0.87 (0.48 to 1.58)	10.5 (42/401)	0.93 (0.49 to 1.77)	10.4 (25/241)
			1 (ref)		0.98 (0.46 to 2.38)		1.09 (0.48 to 2.73)	
PTSD¥	1 (ref)	–						
			1 (ref)	0 (0/88)	N/A¶	3.2 (13/410)	N/A¶	4.8 (12/248)
Sleep difficulties								
Difficulty falling asleep (yes: sometimes, often and always/every night)	1 (ref)	40.6 (145/357)	1.09 (0.64 to 1.85)	36.4 (32/88)	1.05 (0.73 to 1.52)	35.8 (151/422)	1.11 (0.75 to 1.65)	38.8 (99/255)
			1 (ref)		0.99 (0.60 to 1.64)		1.05 (0.62 to 1.79)	
Difficulty staying asleep and having trouble falling back asleep (yes: sometimes, often and always/every night)	1 (ref)	41.5 (147/354)	1.02 (0.60 to 1.73)	41.2 (35/85)	1.14 (0.80 to 1.64)	41.3 (171/414)	1.09 (0.74 to 1.64)	41.4 (104/251)
			1 (ref)		1.15 (0.70 to 1.88)		1.12 (0.67 to 1.89)	
Feeling well-rested after a night´s sleep (yes: often and always/every night)	1 (ref)	50.1 (176/351)	0.89 (0.53 to 1.51)	43.7 (38/87)	1.23 (0.86 to 1.77)	51.9 (217/418)	0.87 (0.59 to 1.29)	43.8 (109/249)
			1 (ref)		1.39 (0.86 to 2.27)		0.99 (0.59 to 1.66)	
Frequently wake up in the middle of the night (yes: sometimes, often and always/every night)	1 (ref)	64.2 (228/355)	0.67 (0.40 to 1.15)	54.7 (47/86)	0.69 (0.48 to 1.0)	53.9 (227/421)	0.95 (0.63 to 1.42)	62.1 (157/253)
			1 (ref)		1.08 (0.66 to 1.77)		1.49 (0.88 to 2.52)	
Regular drugs use (at least once per week)								
Asthma medication	1 (ref)	4.9 (18/365)	0.68 (0.15 to 2.3)	4.4 (4/90)	0.84 (0.36 to 1.97)	3.7 (16/428)	0.95 (0.40 to 2.29)	4.5 (12/267)
			1 (ref)		1.22 (0.38 to 5.46)		1.50 (0.45 to 6.86)	
Analgesics	1 (ref)	21.7 (65/365)	**0.16 (0.04 to 0.45)**	3.3 (3/90)	0.67 (0.41 to 1.1)	11.7 (50/428)	**0.44 (0.25 to 0.78)**	8.6 (23/267)
			1 (ref)		**4.52 (1.56 to 19.20)**		2.92 (0.96 to 12.7)	
Any drug for depression, anxiety, sleeping and other mental symptoms	1 (ref)	28.8 (105/365)	1.11 (0.62 to 1.97)	31.1 (28/90)	1.46 (0.98 to 2.19)	33.4 (143/428)	1.31 (0.86 to 2.02)	33.7 (90/267)
			1 (ref)		2.98 (0.85 to 18.87)		**3.85 (1.07 to 24.63)**	
Drugs for other mental symptoms	1 (ref)	1.1 (4/365)		0 (0/90)		0.5 (2/428)		0.7 (2/267)
			1 (ref)		N/A¶		N/A¶	

Table 5. *Continued*

Psychological symptoms	Non-exposed 2013 (n = 365)		Low exposure 2013* (n = 90)		Medium exposure 2013* (n = 428)		High exposure 2013* (n = 267)	
	OR (95% CI)†	% (n/N)	OR (95% CI)†	% (n/N)	OR (95% CI)†	% (n/N)	OR (95% CI)†	% (n/N)
Depression medication	1 (ref)	6.0 (22/365)	0.37 (0.06 to 1.41)	2.2 (2/90)	1.11 (0.53 to 2.38)	6.1 (26/428)	1.48 (0.70 to 3.22)	7.9 (21/267)
			1 (ref)		2.98 (0.85 to 18.87)		**3.85 (1.07 to 24.63)**	
Anxiety/sedative medication	1 (ref)	5.5 (20/365)	0.59 (0.13 to 1.97)	3.3 (3/90)	1.19 (0.56 to 2.6)	5.8 (25/428)	0.83 (0.35 to 1.95)	4.5 (12/267)
			1 (ref)		2.00 (0.66 to 8.80)		1.39 (0.41 to 6.37)	
Hypnotics	1 (ref)	8.8 (32/365)	1.96 (0.62 to 8.68)	3.3 (3/90)	0.97 (0.49 to 1.89)	5.6 (24/428)	0.86 (0.43 to 1.73)	7.5 (20/267)
			1 (ref)		2.08 (0.69 to 9.04)		2.35 (0.75 to 10.37)	
Blood pressure-lowering medication	1 (ref)	23.0 (84/365)	1.21 (0.65 to 2.24)	27.8 (25/90)	1.44 (0.94 to 2.22)	27.1 (116/428)	1.29 (0.82 to 2.05)	28.1 (75/267)
			1 (ref)		1.22 (0.69 to 2.21)		1.08 (0.59 to 2.01)	

*Regions are seen in figure 1.
†OR and 95% CI from multivariate logistic regression adjusted for age category, gender, education and smoking status.
‡ Answers “Yes to a moderate extent” or “Yes, to much extent” to the question “Have any of the following symptoms disturbed your daily activities during the last month”.
§Psychological distress was derived from GHQ-12 referring to “the previous weeks”, using a binary cut-off score of >2.
ΩPerceived stress was derived from PSS-4 referring to “the recent month” using a binary cut-off score of 90th percentile.
¥ Primary care PTSD was derived from PC-PTSD referring to “the recent month” using a binary cut-off score of >2.
— The non-exposed group did not receive questions regarding PTSD symptoms specifically related to the Eyjafjallajökull eruption
¶ Data not applicable

Figures

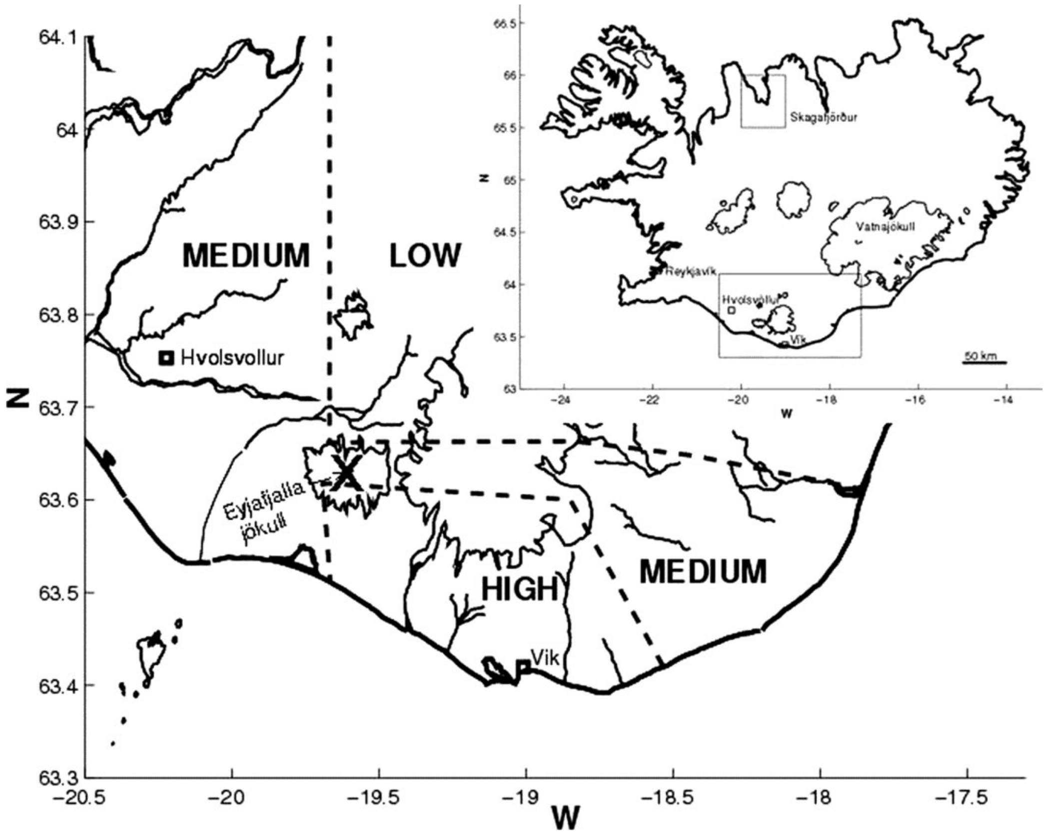

Figure 1 Map of Iceland and study areas. Inserted map of Iceland in the right corner shows the location of Skagafjörður in Northern Iceland (non-exposed area) and the exposed area in South Iceland. The larger map shows the exposed area with Eyjafjallajökull marked as X and the exposed areas divided to low, medium and high exposed areas.

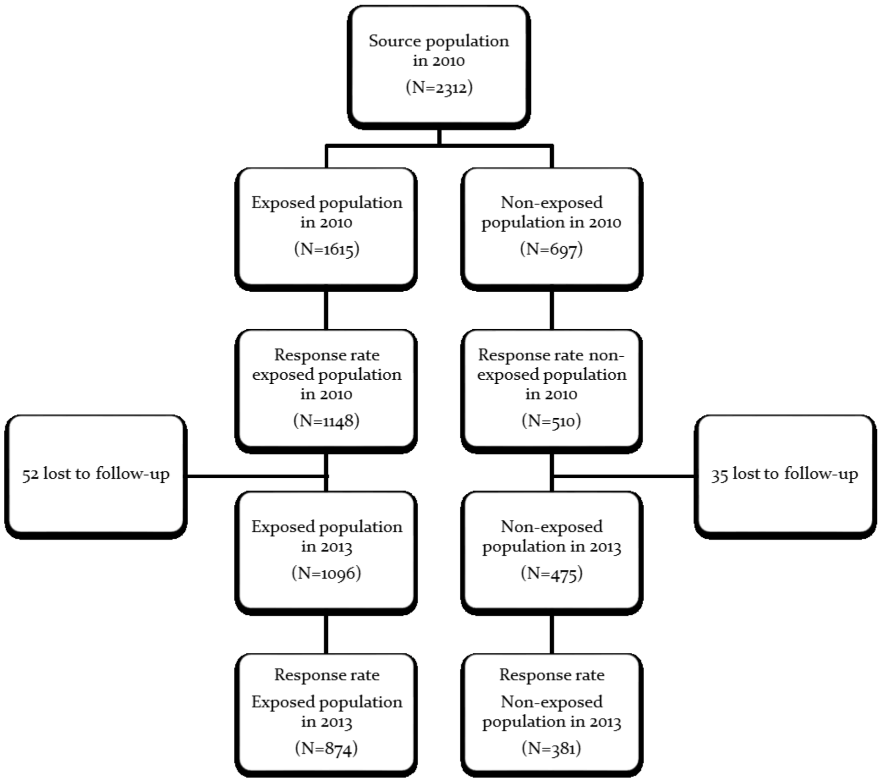

Figure 2 Flow chart of the study population