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Factors motivating the use of respiratory protection against volcanic ashfall: A comparative analysis of communities in Japan, Indonesia and Mexico

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Abstract

Communities living near active volcanoes may be exposed to respiratory hazards from volcanic ash. Understanding their perception of the risks and the actions they take to mitigate against those risks is important for developing effective communication strategies. To investigate this issue, the first comparative study of risk perceptions and use of respiratory protection was conducted on 2003 residents affected by active volcanoes from three countries: Japan (Sakurajima volcano), Indonesia (Merapi and Kelud volcanoes) and Mexico (Popocatépetl volcano). The study was designed to test the explanatory value of a theoretical framework which hypothesized that use of respiratory protection (i.e., facemask) would be motivated by two cognitive constructs from protection motivation theory: threat appraisal (i.e., perceptions of harm/ worry about ash inhalation) and coping appraisal (i.e., beliefs about mask efficacy). Using structural equation modelling (SEM), important differences in the predictive ability of the constructs were found between countries. For example, perceptions of harm/ worry were stronger predictors of mask use

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Declarations of Interest
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in Japan and Indonesia than they were in Mexico where beliefs about mask efficacy were more important. The SEM also identified differences in the demographic variants of mask use in each country and how they were mediated by the cognitive constructs. Findings such as these highlight the importance of contextualising our understanding of protection motivation and, thus, the value of developing targeted approaches to promote precautionary behaviour.

Keywords

Threat appraisal; Coping appraisal; Volcanic ash; Respiratory protection; Risk perception; Protection motivation

1 Introduction

1.1 Background

Around 600 million people around the world live in areas potentially affected by volcanic hazards [1]. During a volcanic crisis, populations may be evacuated to remove them from life-threatening hazards (e.g., pyroclastic flows), but they may still be exposed to potentially hazardous airborne volcanic emissions. Volcanic ash is a pervasive hazard, with distribution potentially over thousands of square kilometres. Inhalation of the ash can exacerbate existing asthma and bronchitis symptoms as well as respiratory symptoms such as cough and breathlessness [2,3]. The respiratory health hazard of the volcanic ash does, however, depend upon its physicochemical composition which can vary substantially among eruptions and even within a single eruption sequence [4–6]. Other studies have indicated that personal attributes such as gender, age, and cultural beliefs and existing respiratory health conditions may also affect health outcomes [7,8].

Although there is limited clinical/epidemiological evidence on the pathogenic potential of chronic exposures to ash [3], the ash is often rich in crystalline silica [9,10] which, for industrial exposures, is known to cause silicosis and is classed as a Group 1 carcinogen [11]. So, consideration of the respiratory hazard associated with chronic exposure is important and agencies generally take a precautionary approach: individuals are advised to protect themselves from ash inhalation, by staying indoors or wearing light-weight disposable respiratory protection such as a facemask (see www.ivhhn.org/information/global-ash-advice). That being said, very little is known about the precautions that communities affected by volcanic ash actually take. It is important to document whether people follow even the most basic advice that might be offered, such as staying indoors, or what types of respiratory protection (if any) they rely upon and believe to be effective.

Research, to-date, on this issue is limited to a small survey conducted in Yogyakarta, Indonesia in the days following the eruption of Kelud volcano in February 2014 [12]. The interviewers recorded the types of masks people wore, where they had got the masks from, why people wore masks, who advised them to wear a mask, and whether people thought their respiratory protection was effective. They found that 65% of the 125 respondents were observed wearing disposable surgical masks of the type distributed by government agencies and easily procurable from shops, and 16% were using some form of cloth over their mouth

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and nose which they had been advised to use when masks were unavailable. Their motivation for using respiratory protection (or not) was, however, unclear given that a substantial proportion of the respondents were not convinced of the effectiveness of their chosen protection. Understanding how people choose actions and make decisions in the face of risk is critical [13], so that, if mask wearing is encouraged, agencies can tailor advice to ensure better uptake.

This pilot paved the way for the research reported in this paper, which was conducted as part of the Health Interventions in Volcanic Eruptions (HIVE) project (http://community.dur.ac.uk/hive.consortium/). The aim of the HIVE project was to provide an evidence base on effective respiratory protection against volcanic ash for community use. This evidence base includes not only identifying which types of respiratory protection are effective and wearable [the results of which are published in: 14–16] but, also, understanding the factors that influence people's motivation to protect themselves and the actions they take when ash is in the air, including whether or not they wear masks.

In this study, we were particularly interested in how the motivations and actions taken differ among communities that are diverse not only in their experiences of different kinds of volcanic eruptions and ashfall but, also, in their socio-demographic and cultural make-up. Comparisons were made, therefore, among three communities from Japan, Mexico and Indonesia. These communities not only represent very different cultures but, as set out below, they have lived with very different experiences of volcanic activity. The types of official intervention in response to volcanic ashfall have also been variable. This study therefore provides a unique insight into how different communities perceive and respond to the potential hazards of volcanic ash in the air.

In the sections that follow, we describe the three volcanic communities selected for comparison and the theoretical framework designed for the collection and analysis of data.

1.2 Three different volcanic communities

1.2.1 Japan (Sakurajima volcano)—Since 2009, Sakurajima Volcano on Kyushu Island, Japan, has been in a phase of enhanced activity with frequent eruptions (sometimes several per day) totalling between 450 and 1000 times per year (http://www.jma-net.go.jp/kagoshima/vol/data/skr_exp_num.html). In 2011, there were 996 eruptions and, at its peak, 150 eruptions were recorded for a 1-month period. During times of volcanic activity, communities in the city of Kagoshima and surrounding rural districts of Kihoku, Ushine, Kaigata and Sakurajima Island, itself, have been exposed to frequent ashfall events. The city has well organised ash removal practices including regular use of ash road sweepers and issuing people with yellow plastic bags to collect the ash from their properties. The ash also has economic benefits in terms of its use in pottery studios which incorporate volcanic ash into their creations (e.g., https://www.ougaku.com/kamamoto/ogakutogei/). Although the Kagoshima City local government do recommend exposure reduction, including refraining from going out and wearing a mask when there is heavy ashfall (see http://www.city.kagoshima.lg.jp/kenkofukushi/hokenjo/hoyobo-yobou/kenko/kenko/sejin/kohai.html), the advice is not well advertised and there are no public announcements when eruptions occur. Although the local government stores stockpiles of masks for use in a flu

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pandemic, masks are not routinely distributed so, if residents or visitors want to use them, they need to obtain their own.

1.2.2 Mexico (Popocatépetl)—

Millions of people, in the metropolises of Mexico City and Puebla, as well as smaller towns and villages, live in the shadow of Popocatépetl volcano, one of Mexico's most active volcanoes. Since 1994 it has been producing powerful explosions at irregular intervals. Small amounts of ash are detected relatively often (sometimes several times a week) and heavy ashfall on the survey area occurred less than a month before the survey was conducted [17–20]. Civil protection authorities typically issue advice to residents affected by the ashfall, to cover their noses and mouths with masks or damp handkerchiefs, close windows, and remain at home or stay indoors during ashfall. When there is increased activity with ashfall, the State governments are advised by the National Center for Disaster Prevention (CENAPRED) to distribute masks to the population. Masks are obtained mainly through State and Federal funds. Some are stockpiled and some are bought when activity increases. However, volcanic risks do not seem to feature particularly highly in the list of hazards that are worrisome to people who live near the volcano [21], which raises questions about whether this advice is taken and the masks are used.

1.2.3 Indonesia (Merapi and Kelud Volcanoes)—

Over the past decade, communities living in Yogyakarta and Sleman district in Java, Indonesia have been exposed to volcanic ash following major eruptions of Merapi in 2010 and, more recently, Kelud in 2014. In the aftermath of the 2014 eruption, the sudden deposition of several centimeters of ash on the city of Yogyakarta, which is situated 200 km west of Kelud volcano, was surprising and had not been anticipated. In 2010, the eruption of Merapi (which is just 30 km north of Yogyakarta city) was the largest in a century, and killed at least 300 people. These were, therefore, very different ashfall experiences compared to those of the communities around Sakurajima and Popocatépetl for whom airborne ash is relatively commonplace. This difference may be reflected not only in the response of government agencies and NGOs to the ashfall but also the community reaction. When ashfall is unexpected, it might evoke substantial anxiety in the population, even if the ash is only airborne for a matter of days and the hazard is short-lived. Concerns might also have been heightened by the disaster management approach taken by government agencies to the eruptions. As documented in Horwell et al. [12], more than a million disposable surgical facemasks were quickly distributed by government agencies and hospitals to the general public in Yogyakarta, and residents were also advised to use some form of cloth over their mouth and nose.

1.3 Theoretical model

To understand people's motivations in these communities, and the factors which affect their use of respiratory protection, the collection and analysis of the data were informed by the theoretical model shown in Fig. 1. This model was designed to explain variance in the use of protective actions using a range of socio-demographic variables (i.e., geographical location, age, gender, education level, self-reported medical history of respiratory problems) and selected cognitive constructs informed by Protection Motivation Theory (PMT) [22,23].

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PMT has been widely adopted as a framework to explain and predict protective health behaviours [24], with recent research successfully applying the theory to understand behaviours in response to natural hazards such as fires [25,26], floods [27–30], earthquakes [31], and tsunamis [32]. Little is known, however, about mitigation behaviour in response to volcanic ashfall.

PMT proposes that protective responses arise from cognitive appraisals of the harm or damage associated with the threatening event (threat appraisal) along with the belief that the occurrence of the threatening event can be effectively avoided (coping appraisal). Taking inspiration from this theory and recognising the importance of affect as well as cognition in guiding perceived risk [33], we propose that residents who protect themselves from inhaling volcanic ash (protective action) would perceive inhaling ash to be more harmful to their health (perceived harm) and be more worried about the effects of the ash on their health (perceived worry) than residents who do not protect themselves. In addition, they would be more likely to use respiratory protection if they perceive it to be effective at protecting them from the harmful effects of the ash (perceived response efficacy PMT also identifies beliefs about self-efficacy as determinants of protective action. A person needs to believe they can successfully enact the recommended behaviour and if someone thinks, for example, that wearing a mask will be difficult, they will not wear one. In our model, this type of self-efficacy belief is captured within the costs and barriers construct where we also consider a broad range of resource-related attributes of the type conceptualised within Lindell and Perry's [34] Protective Action Decision Model (PADM) as potential barriers against the use of respiratory protection (e.g., cost, inconvenience, lack of availability, discomfort, social unacceptability/ norms).

The structural nature of our model also allowed us to ask questions about whether the effects of socio-demographic variables on protective actions can be explained indirectly through their effects on either threat or coping appraisals. For example, if we find that older people are more likely than younger people to use a facemask for respiratory protection, we could establish, through structural modelling, whether this difference can be explained by corresponding differences in threat appraisal (i.e., older people perceive that ash is more harmful to their health/ are more worried about the effect of the ash) or coping appraisal (i.e., older people perceive that masks are more effective at protecting them from inhaling ash). Moreover, a multi-level approach was taken to the structural modelling to compare the explanatory value of the constructs between each volcanic community. This allowed us to identify both the similarities and differences in the factors which influence people's motivations to take precautionary action and, where we find the results are consistent, we can be more confident about generalising our findings to other communities affected by ashfall around the world.

2 Method

2.1 Sample and sampling procedure

A survey was conducted between May and September 2016 on residents from communities exposed to volcanic ashfall from three different countries – Japan (Sakurajima volcano) (N = 749), Mexico (Popocatépetl volcano) (N = 654), and Indonesia (Merapi and Kelud

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volcanoes) (N = 600). Respondents aged 13 and over were recruited both from the major urban areas that have been affected by ashfall from these volcanoes (i.e., Kagoshima city in Japan, Puebla city in Mexico, and Yogyakarta city in Indonesia) and from rural communities (i.e., Sakurajima Island and surrounding districts of Kihoku, Ushine and Kaigara in Japan; the small town of Santiago Xalitzintla in Mexico; and villages in the Sleman District in Indonesia). This allowed us not only to make comparisons among different countries but also between the residents of urban and rural communities within those countries.

The use of a random sampling method from the populations of interest was not deemed practical. In Japan, for example, since the 1990s and 2000s, there have been well-documented problems of declining response rates to social survey research due to concerns in Japanese society about the criminal use of their personal information [35]. So, even if the planned sample is drawn randomly from the population, a low response rate could produce a biased sample. In Indonesia, randomly sampling was also difficult because, at the research sites, permissions for interviews first had to be obtained from community leaders (e.g., village heads). In Mexico, the situation was similar where different groups are represented by their community leaders who recommend participation or not. A non-probability quota sampling method was used instead, and was designed to produce a sample with a mix of residents that was broadly comparable to the demographics of the populations of each country and region, as determined from local census data [36–40].

Descriptive statistics for the samples are shown in Table 1, along with the available census data. The census data clearly show how the demographics differ among the three countries, particularly in terms of age and education level. The target population in Japan includes a much higher percentage of older people (39.0% over 60) than the populations of Mexico and Indonesia (19.0% and 13.5% over 60). The Japanese and Indonesian populations are also more highly educated than the Mexican population with 65.7% and 51.5% of residents graduating high school compared to 28.1%. Although not shown here, there are also differences in the characteristics of the populations between the urban and rural regions within each country. For example, in all three countries, the populations of the urban areas included a higher percentage of people who had graduated high school, with a particularly large difference in Mexico (Japan: urban 69.7% rural 61.7%; Mexico: urban 49.8% rural 6.6%; Indonesia: urban 55.0% rural 48.0%). Also the rural populations in Japan and Mexico in particular included a higher percentage of over 60 s (Japan: rural 47% urban 31%; Mexico: rural 24% urban 14%; Indonesia: rural 15% urban 12%).[1]

As shown in Table 1, these demographic differences in the populations of the different countries and regions were reflected in the samples that were recruited. The sample quotas obtained were not, however, an exact match to the population statistics, due to practical difficulties recruiting respondents from certain groups. For example,the Japanese sample did not contain quite enough respondents in the youngest age-group and the most highly educated respondents were slightly over-represented in the Japanese and Mexican samples. The commonly used correction technique of weighting adjustment was therefore applied to

[1]A breakdown of the census data and demographic characteristics of the samples in the rural and urban locations within each country is available on request from the first author.

the data to obtain estimates of the population means or frequencies, although it made little difference to our results.[2]

The recency of the ashfall experiences of the survey respondents are also shown in Table 1. Ashfall was a more recent event in Mexico (56.1% of respondents stated that they had experienced ashfall a week or month ago) compared to Japan (57.4% few months ago) and Indonesia (93.7% more than a year ago). Although we had expected the Indonesian sample to have the most distant experience of ashfall (the Kelud eruption in 2014 was the last time volcanic ash fell on Yogyakarta Province), when we designed the study we were expecting that the Japanese sample would have experienced the most recent ashfall. As noted previously, Sakurajima is known for its frequent activity and, in the summer months, the urban area chosen for the survey (Yoshino district of Kagoshima city) has, in recent years, experienced frequent ashfall, quite often on a daily basis. However, during the period the survey was conducted, there were only two explosions which produced ashfall at the Kagoshima observation point (www.jma-net/go.jp/kagoshima/vol/data/skr_ash_vol.html). That does not mean to say that there would have been no airborne ash affecting residents, because ash lying on the streets or on roofs and buildings can be remobilised by traffic and winds.

Table 1 also provides information about the self-reported incidence of respiratory health problems in each sample. Respiratory health problems were reported by about one in four of the Japanese sample (23.6%) and about one in seven of the Mexican (14.5%) and Indonesian (16.2%) samples. Allergic rhinitis was, by far, the most frequently reported symptom by the Japanese (19.0%), which is consistent with the high incidence of hay fever caused by sensitisation to Japanese cedar pollen [41]. Allergic rhinitis did not affect as many Mexicans (7.2%) or Indonesians (3.8%), but Indonesians reported a slightly higher incidence of asthma than the other countries (7.2% vs. 6.4% and 3.4%). None of the other respiratory conditions affected more than 3.1% of respondents.

2.2 Survey method

The survey was administered by trained researchers in a face-to-face interview lasting around 20–30 min. An English language version was first produced by the HIVE project team and revised at a workshop also involving members of the project advisory board, held in November 2015. Translations into Indonesian, Japanese, and Spanish were checked using back translation (i.e., the survey was translated back into English by an independent translator). The survey was then piloted in the local communities and then revised, twice. The translations of all revisions were checked again using back translation. The revisions made following piloting included changing the wording of some questions to improve understanding and reducing the number of questions to keep the survey to a more manageable length.

[2]Adjustment weights were assigned to each survey respondent based on their age, gender, and education level. By dividing the population percentage by the corresponding response percentage, respondents in under-represented groups therefore get a weight greater than 1 and those in over-represented groups get a weight less than 1. These weighted values can then be used in the computation of means and percentages and compared alongside the unweighted values. It should be noted, however, that the weighted values produced very similar responses to the unweighted values and did not change the conclusions derived from our results. Therefore, unweighted values are reported in the paper but weighted values are available on request from the first author.

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The survey items relevant to the analyses reported in this paper are outlined below.[3]

Protective actions—Respondents were asked which actions they had taken in the past to protect themselves from breathing in the volcanic ash. A list was provided: wet or remove ash outdoors, clean the house, limit time outdoors, keep windows and doors closed, wear a hat, use an umbrella/ parasol, hold a hand over mouth/nose, hold a handkerchief or cloth over mouth/nose, tie a scarf or bandana over mouth/nose, wear a shawl or veil over face, wear a facemask (any type), other, take no action. For mask use, they were asked additional questions in which they rated the frequency of usage of five different types of masks (surgical mask, fashion mask, scooter mask, hard cup mask, highefficiency mask[4]) when ash is in the air, on a scale from never, sometimes, often, and always.

Perceived harm, worry and mask efficacy—The three single-items shown below were used to measure each of these constructs.

Harm—Respondents were asked if they thought that breathing in volcanic ash might harm their health on a scale from 0 (no harm) to 3 (very harmful).

Worry—Respondents were asked whether they were worried about breathing in volcanic ash on a scale from 0 (not at all worried) to 3 (very worried).

Mask efficacy—Respondents were asked how effective they thought each of the different types of masks would be in protecting them from breathing in the volcanic ash on a scale from 0 (not at all effective) to 3 (very effective).

Although there can be psychometric advantages to using multipleitems when it is important to capture the broader range of meanings associated with a complex, multifaceted psychological construct, singleitems have comparable or equal predictive validity when used to assess uni-dimensional constructs, such as ours, that are easy to define, have high face-validity, and are unambiguous in their interpretation [42,43]. Single-item measures are also less repetitive and time-consuming for respondents, which was an important consideration for our study. Respondents had limited time to complete the survey and, in our pilot work, we found that using multiple items to measure similar constructs led to less engagement in the interview. During the pilot phase, respondents complained that their time was being wasted by repeating questions that they felt they had already answered. For example, we found that some respondents were resistant to being asked two measures of perceived harm – one to measure how much harm they thought breathing the ash would have on their health (perceived severity) and one to measure how likely they thought it was that they would be harmed by breathing in the ash (perceived probability). Feedback from the pilot suggested

[3]The survey included some additional questions that are not relevant to this paper but will be reported elsewhere. For example, there were questions in which respondents were asked about the health symptoms they think occur or are made worse by volcanic ash, if they used a mask where they got it from, where they had received information from about the health effects of volcanic ash, and (if they had children aged 12 or under) how they protected them from the ashfall.

[4]Mask types were identified based on the pilot study in Indonesia (Horwell et al., [12]), local knowledge from the HIVE project team of masks distributed in their communities, and confirmation through piloting in this study that these were recognised forms of protection. Pictures were shown of each type of mask (available on request) and a type of N95 mask was used to represent what we called the 'high-efficiency mask'.

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that the distinction between the two questions was not clear-cut to the respondents. In particular, they considered probability of harm when answering the perceived severity question (i.e., the degree to which the ash is harmful to their health depends upon how likely it is to affect them). Their perception of the amount of harm caused by the ash could not easily be divorced from its probability of occurrence. Therefore, to avoid what some respondents regarded as a repetitive survey, a single measure of perceived harm, which did not differentiate between perceived severity and perceived probability, was employed. The piloting also highlighted the importance of keeping the rating scales quite short with response options that were clearly distinguishable. In piloting we had originally designed 5-point scales with ‘extremely X’ as the fifth point. However, feedback from the interviewers indicated that some respondents found it difficult to discriminate between the response options. Substantial time was being spent on these questions and interviewers were running out of time to complete the survey. We therefore removed the top item and reduced the ordinal scales to 4-points.

Costs and barriers (mask use)—Respondents who said they did not use a facemask to protect themselves from breathing in the volcanic ash were asked to give any reasons for not wearing a mask. The following reasons were provided for them to choose from – wearing a mask is difficult, breathing ash doesn’t bother me, breathing ash doesn’t worry me, don’t think I need to wear a mask, don’t think masks are effective, never considered wearing a mask, don’t have a mask, masks are expensive, don’t know where to get a mask from, inconvenient to carry mask around, wearing a mask is uncomfortable, wearing a mask would make me too hot, wearing a mask would affect my breathing, wearing a mask would create humidity/ moisture, wearing a mask is embarrassing, it's unfashionable to wear a mask, no-one else/few people wear a mask, masks not easily available, other reasons.

2.3 Data analysis

The statistical software IBM SPSS with AMOS 22 was used to analyse the data. For descriptive information regarding the actions taken during ashfall, ratings of mask use frequency, perceived harm, perceived worry, and reasons for not wearing a mask, percentages or mean values were computed from the ordinal rating scales. Percentages or mean ratings were computed both for the sample as a whole (pooled) and within each country (Japan, Mexico, Indonesia). Hierarchical logistic regressions were used to examine predictors of these actions and ratings with country dummies entered at step 1 and socio-demographic covariates (age, gender, education level, and respiratory illness) entered at step 2. Coefficients are reported as odds-ratios. Since the dependent variables were dichotomous (actions taken, reasons for not wearing a mask) or ordinal (ratings of mask use frequency, mask efficacy, perceived harm, perceived worry) many of the key assumptions of linear regression and general linear models regarding linearity, normality, and homoscedascity do not apply. The main assumptions for conducting binomial or logistic regression set out by SPSS were, however, met (https://statistics.laerd.com/spss-tutorials/ordinal-regression-using-spss-statistics.php; https://statistics.laerd.com/spsstutorials/binomial-logistic-regression-using-spss-statistics.php).

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The dependent variables were measured on either a dichotomous or ordinal scale; the independent variables are ordinal (age, education level) or categorical (country, gender, respiratory illness); and there is no multicollinearity between the independent variables (Variance Inflation Factors (VIFs) were no greater than 1.18); there is a linear relationship between any continuous independent variable or ordinal variable treated as continuous (age, education level) and the dependent variable (this was checked using the Box-Tidwell procedure and in the reporting of the results we highlight a couple of cases where the linearity assumption did not hold); observations are independent and the dependent variables have mutually exclusive and exhaustive categories. However, the assumption of proportional odds was not met for any of the ordinal regressions. The tests of parallel lines were significant which suggest that the coefficients are different across response categories. Although we can determine which of our independent variables have a significant effect on our dependent variables, we cannot assume that they had identical effects at each cumulative split of the dependent variable. In our results we therefore highlight cases where the significance of the coefficients is not consistent at each cumulative split.

Structural modelling was also used to estimate the coefficients for our theoretical model. The coefficients (non-standardized b values) were estimated using Markov chain Monte Carlo (MCMC) maximum likelihood (ML) estimation. Although the statistical assumptions for ML estimation would require that the endogenous (dependent) variables are continuous with a normal distribution, MCMC is an increasingly recognised approach to handling nonstandard conditions of the data, including situations like ours where the data are non-normal and have ordinal rather than interval or ratio properties [44].

3 Results

3.1 Protective actions

The actions taken by the residents of each country to protect themselves from inhaling ash during heavy ashfall are shown in Table 2. Averaged across all three countries, over 80% of residents kept their windows and doors closed (96.1%), cleaned the house (90.3%), limited their time outdoors (84.6%), and wetted/ cleaned the ash outdoors (80.3%). The other types of actions were not so universally adopted although over half took actions like wearing facemasks (75.0%), hats (67.5%), or covering their mouth and nose with handkerchiefs (56.3%) or hands (54.3%). Umbrellas/ parasols (46.4%), scarfs/ bandanas (35.4%), or shawls/ veils (24.8%) were only used by a minority across the whole sample although there were some notable regional differences.

To test for differences between the odds of the actions being adopted in each country, binomial logistic hierarchical regressions were conducted with country dummies entered at step 1 and socio-demographic covariates (age, gender, education level, and respiratory illness) entered at step 2. If the odds-ratio for the country dummy is significant at step 1 and step 2 then the difference between the countries cannot be fully accounted for by differences in the demographic covariates.

No single country was significantly more or less likely to adopt all types of actions. There were, however, differences in the relative popularity of actions used in each country. The

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Japanese were most likely to hold a handkerchief or hand over their mouth/ nose, or use an umbrella/parasol, and least likely to wear a scarf/ bandana over their mouth/ nose. The Indonesians were most likely to clean the house, limit their time outdoors, wet/ clean ash outdoors, and wear a facemask but least likely to hold a handkerchief or hand over their mouth/nose. The Mexicans were more likely than the Japanese to clean their houses and wear a scarf/bandana over their mouth/ nose but less likely than both of the other countries to wear a hat.

It was also notable that, in all but two country contrasts, the inclusion of the demographic covariates at step 2 did not change the significance of the odds-ratios. The differences in the actions adopted among the countries were, therefore, not accounted for by differences in the demographic profiles of the samples. This implies that other factors, such as culture or accessibility issues, are probably more important in shaping which actions are most popular. The exceptions were the differences in limiting time outdoors and facemask use between the Japanese and Mexicans. These country contrasts were significant at step 1 but not at step 2. So, although limiting time outdoors and using masks was more common in the Japanese sample than the Mexican sample, these differences were probably accounted for by differences noted earlier between the samples in education levels (the Japanese sample included more highly educated respondents than the Mexican sample) and/or the incidence of respiratory illness (the incidence of respiratory illness was higher in the Japanese sample) which, as shown in Table 2, were significant covariates in step 2 of the model.

The covariates identified as significant at step 2 also highlight some interesting differences in the actions taken by different demographic groups irrespective of which country they came from. Older people were more likely to wet/ clean ash outdoors and wear a hat whereas younger people were more likely to hold a handkerchief or hand or tie a scarf/ bandana over their mouth/ nose. Females were more likely to keep windows/doors closed, clean the house, limit time outdoors, wear a facemask, hold a handkerchief over their mouth/ nose, use an umbrella/parasol, or wear a shawl/veil over their face. Males, on the other hand, were more likely to wear a hat. More highly educated people were more likely to clean the house, limit time outdoors, wet/clean ash outdoors, wear a facemask, hold a handkerchief over their mouth/nose, or use an umbrella/parasol. Less well educated people were more likely to wear a hat, tie a scarf/bandana over the mouth/nose or wear a shawl/ veil over their face. Finally, people with a respiratory illness were more likely to wear a facemask or shawl/ veil over their face.

3.2 Frequency of mask use

As shown in Table 3, respondents' ratings of their frequency of usage of different types of masks identified that surgical masks were, by far, the most commonly used type of mask in all three countries. However, they were not used all of the time during ashfall by everyone. In Japan and Mexico, less than half of the people who said they had used a surgical mask said they used it all of the time. Consistent use was more common in Indonesia, with over half of the people who said they had used a surgical mask wearing one all of the time.

To test for differences between the countries in mask use frequency, ordinal logistic hierarchical regressions were conducted with country dummies entered at step 1 and demographic covariates entered at step 2. For this analysis, mask use frequency was coded 0 (never), 0.5 (sometimes or often), and 1 (always). If the coefficient for the country dummy is significant at step 1 and step 2, then the difference between the countries cannot be fully accounted for by differences in the demographic covariates included in the model.

As shown in Table 4, the country contrasts that were significant indicate that ratings of mask use frequency were higher in the Indonesian sample (M = 0.80) compared to the Mexican (M = 0.45) and Japanese sample (M = 0.44). Although females, more highly educated people, and people with respiratory illness wore masks more often, these effects did not account for these differences (the country contrasts were still significant at step 2). However, it is worth noting that, although the analysis reported previously showed that the Mexicans were less likely to use facemasks than the Japanese, this contrast shows that the *frequency* of mask use was not significantly different. If the Mexicans wore a mask, they were more likely than the Japanese to use it ‘always’ (27.1% vs. 20.3%) rather than ‘sometimes/ often’ (34.9% vs. 47.3%). This illustrates how our measure of mask use frequency provides a more sensitive measure of the extent of people's mitigation behaviour than the simple yes/ no question which asks whether or not they used a mask which does not tell us whether people are using masks consistently or not.

Table 4 also shows descriptive statistics for the ratings of mask efficacy, perceived harm and perceived worry. The results show that the Indonesians (who used masks most frequently) gave the highest ratings of mask efficacy, perceived harm and perceived worry. The Mexicans also rated these constructs significantly higher than the Japanese. This pattern of results is therefore not entirely consistent with our theoretical model which predicted that people who used masks more often would perceive masks to be more effective protection (perceived mask efficacy) and would perceive inhaling the ash to be more harmful to their health and be more worried about the effects of the ash on their health (perceived harm/ worry). Although the Indonesians’ higher ratings of efficacy, harm and worry matched their higher frequency of mask use, the Mexicans’ higher ratings of these cognitive constructs did not. A more formal test of our theoretical model was conducted by estimating structural equation models for each country in IBM SPSS AMOS 22. The models estimated the total effects and direct effects of the geographical and demographic variables on mask use and the indirect effects through perceptions of mask efficacy and harm/ worry. Harm/ worry was represented by a latent variable measured by two highly correlated indicator variables, Harm and Worry (Mexico rs = 0.536***, Japan rs = 0.714***, Indonesia rs = 0.550***), each of which each of which have measurement error terms (e1 and e2).

Coefficients (unstandardized b values) for each structural effect shown in Fig. 2 were estimated using Markov chain Monte Carlo (MCMC) maximum likelihood estimation. To test whether the structural models were equivalent or not between the countries, multiple group analysis was conducted in AMOS 22.

Table 5 shows the estimated coefficients for the total effects, indirect effects and direct effects with significant covariances and paths illustrated in Fig. 3. Some important similarities and differences in the estimated coefficients are apparent.

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In terms of similarities, in all three countries it is notable from Fig. 3 that there was significant covariance between location and educational level (positive coefficients: Japan b = 0.069, Indonesia b = 0.064, Mexico b = 0.345) and age and education level (negative coefficients: Japan b = −0.194, Indonesia b = −0.061; Mexico b = −0.267). These effects show that older people were less well educated than younger people and people living in the urban locations were more highly educated than people living in the rural locations. The effects were particularly strong in the Mexican sample which is in line with the census data where less than 10% of people in the rural location are educated to high school level compared to nearly 50% in the urban location. When interpreting the total effects of these variables we therefore need to be mindful of the possibility of multicollinearity whereby the estimated coefficient for any one variable (i.e., education) will depend on which other variables are included in the model (i.e., location and age). That being said, the Variance Inflation Factors (VIFs) for location, education and age, even in the Mexican data, are all below the conservative cutoff value of 2.50 (VIFs Mexico ≤ 1.96, Indonesia ≤ 1.04, Japan ≤ 1.18).

In terms of differences, although the coefficients for the total effects of mask efficacy were positive and significant in all three countries (i.e., residents who rated masks as more effective wore masks more frequently), multiple group analysis showed that the coefficient was significantly larger in Mexico compared to Japan ($\chi 2$ (1) = 27.8, p < .001) and Indonesia ($\chi 2$ (1) 10.4, p = .001). Also, the coefficients for the total effects of harm/ worry were significant and positive in Japan and Indonesia (residents who rated the ash as more harmful, and were more worried about the ash, wore masks more frequently) but not significant in Mexico. Multiple group analysis also showed that the coefficient was significantly larger in Japan compared to Indonesia ($\chi 2$ (1) = 13.2, p < .001). The relative strengths of these coefficients also has implications for the ability of the harm/ worry and mask efficacy constructs to explain the total effects of the demographic and geographical variants of mask use.

Fig. 3 also illustrates the differences in the total and indirect effects found for each country by showing only paths with significant coefficients (indirect effects are shown by a path from the variant to mask use via either mask efficacy or harm/ worry). The direction of the indirect effects can only be confirmed, however, by the data provided in Table 5. In some instances outlined below, where the sign of the coefficient for the indirect effect is opposite to the sign of the coefficient for the total effect, there is evidence of inconsistent mediation [47].

3.2.1 Location (Urban vs. Rural)—In Mexico, the total effect of location was positive and partially mediated by mask efficacy. This suggests that residents from the urban location of Puebla city used masks more frequently than residents from the rural location of Santiago Xalitzintla partly because they had a stronger belief in the efficacy of masks.

The positive total effect of location that was found in Indonesia (i.e., residents from the urban location of Yogyakarta city used masks more frequently than residents from the rural location of Sleman district) could not however be explained in this way. Although the indirect effect via mask efficacy was significant, it is notable from Table 5 that the sign of the coefficient for the indirect effects was the opposite sign (–0.024) to the coefficient for the total effect (0.047). This, therefore, reflects inconsistent mediation [47] and suggests that, although the overall effect of living in the urban Indonesian location, rather than rural location, was to increase mask use, this particular mediational path had the opposite effect. People living in the urban location had weaker beliefs about mask efficacy than people in the rural location which reduced their frequency of mask use. To produce the total effect, other factors unrelated to beliefs about mask efficacy must, therefore, have been increasing mask use in the urban sample.

Although the total effect of location in the Japanese sample was not significant, a significant and negative indirect effect via mask efficacy was found. So, like the urban Indonesian sample, people living in the Yoshino district of Kagoshima city had weaker beliefs about mask efficacy than those living in the rural areas around Sakurajima Island which reduced their frequency of mask use. To end up with a nonsignificant total effect of location, other factors not included in our analysis must have increased mask use in the urban sample to cancel out the negative, indirect effect via mask efficacy.

3.2.2 Age—The positive total effect of age that was found in Japan was partially mediated by perceived harm/ worry which suggests that one of the reasons why older people in Japan were more likely to use masks than younger people was because they perceived the ash to be more harmful and were more worried about the effects of the ash.

According to the results of this study, neither harm/worry or mask efficacy mediated the negative total effect of age in the Mexican sample. Factors not included in our model must have reduced the frequency of mask use in older people relative to younger people.

The total effect of age was not significant in the Indonesian sample and no significant indirect effects were found.

3.2.3 Gender—Neither harm/ worry or mask efficacy mediated the negative total effect of gender in the Japanese sample. Males were less likely to use masks than females and this difference was not explained by differences in their perceptions of mask efficacy or perceived harm/ worry.

Results shown here indicate that the total effect of gender was not significant in either Mexico or Indonesia and no significant indirect effects were found.

3.2.4 Education level—The positive total effect of education level that was found in the Japanese sample was partially mediated by mask efficacy. This suggests that one of the reasons why more highly educated people in Japan were more likely to use masks was because they perceived masks to be more effective.

Although the model showed that the total effect of education level was not significant in the Mexican sample, an indirect effect via mask efficacy was significant and positive. Although this might suggest that other factors, not included in our analysis, reduced mask use in the more highly educated sample to cancel out the positive indirect effect via mask efficacy, it is perhaps more likely that the non-significant total effect was attributable to the inclusion of other predictors in the model that were significantly related to education level (i.e., location and age). This interpretation is supported by the finding that the removal of either age or location from the model resulted in a significant total effect of education. This suggests that the better educated people in the sample were using masks more frequently because they perceived masks to be more effective, but that this relationship might be partly attributable to the fact that they were younger or more likely to be living in the urban areas.

The total effect of education was not significant in the Indonesian sample and no significant indirect effects were found.

3.2.5 Respiratory illness—The positive total effect of respiratory illness in the Japanese sample was partially mediated by perceptions of harm/ worry. People with respiratory illness were more likely to use masks more frequently because they perceived the ash to be more harmful and were more worried about the effects of the ash.

The positive total effect of respiratory illness in the Indonesian sample could not however be explained in this way. No significant indirect effects were found.

The total effects of respiratory illness were not significant in Mexico and no significant indirect effects were found.

3.3 Reasons for not wearing masks

The structural models show that beliefs about mask efficacy and/ or perceptions of harm/ worry make significant contributions to determining the frequency of mask use and to explaining some sources of variance in mask use. However, their predictive ability is not entirely consistent across all three countries. Perceptions of harm/ worry played a stronger role in the Japanese sample whereas beliefs about mask efficacy played a stronger role in the Mexican sample. To some degree, therefore, different factors motivate mask use in the different countries. This difference can also be illustrated by differences in the types of reasons given by residents who said they had not worn a mask, as shown in Table 6.

In the Japanese sample 243 respondents had not worn a mask during ashfall and the most common reasons were that they had never considered wearing a mask (46.1%) or that the mask would affect their breathing (41.2%). Around a third of the sample who did not wear a mask considered masks as inconvenient to carry around (33.7%) and around a quarter were not bothered by breathing in the ash (24.7%) and/or thought masks were uncomfortable (24.7%). Notably, self-efficacy and cost or accessibility issues were not frequently given reasons. Only 4.2% of respondents gave the reason that wearing a mask was difficult and only 1.2% of respondents gave the reason that masks were too expensive, 0.8% that they were not easily available and no one said that they did not know where to get a mask from. Being unfashionable (3.7%) or embarrassing to wear (4.1%) were also rarely given reasons.

In the Mexican sample 249 people had not worn masks and not having a mask was the most common reason (57.3%). Comfort was also an important factor (42.6%) and, to a lesser degree, factors such as the perceptions that no one else was wearing a mask (34.9%). Around a quarter to a third of those who did not wear a mask had just not considered wearing one (31.3%), didn't think they needed to wear one (28.3%), were not bothered by the ash (27.7%), or didn't know where to get one (24.1%). Although a slightly higher percentage of the non-mask wearers in Mexico identified self-efficacy and cost as issues compared to Japan, the numbers finding masks difficult to wear (6.0%) or expensive were still in a minority (12.4%).

Only 4 of the Indonesians said they had not worn a mask so analysis of the reasons for not wearing a mask in this sample is somewhat limited. But reasons identified by at least two of the four included issues with humidity/ moisture (50%), never considered wearing a mask (50%), or didn't think they needed to wear a mask (50%).

Within the Japanese and Mexican samples, we also explored whether the reasons for not using masks differed according to socio-demographic covariates (location, age, gender, education level, and respiratory illness) using binomial logistic regressions. These analyses were only conducted on reasons given by at least 10% of the sample and for most of the reasons there were no significant covariates.

In the Japanese sample the following reasons for not wearing a mask were more likely to be given by: people living in rural locations ('Wearing a mask would make me too hot' OR=2.04, p = 0.040); males or more highly educated people ('Wearing a mask is uncomfortable' OR = 2.72, p = 0.015, OR = 1.74, p = 0.038); and people with respiratory illness ('Breathing ash doesn't bother me' OR = 2.68, p = 0.023).

In the Mexican sample the following reasons for not wearing a mask were more likely to be given by: people living in rural locations ('Don't think I need to wear a mask' OR=2.75, p = 0.018; 'Don't know where to get a mask from' OR=2.69, p = .032; 'Masks not easily available' OR=4.86, p = 0.025; 'None else/few people wear masks' OR = 3.05, p = 0.006); younger people ('Breathing ash doesn't bother me', OR = 1.54, p = 0.034; 'Wearing a mask would make me too hot' OR = 1.72; p = 0.021); and males or people with respiratory illness ('Don't think masks are effective' OR=2.97, p = 0.018, OR = 3.56, p = 0.022).

4 Discussion

The aim of this study was to document the types of respiratory protection from volcanic ash used by communities living near volcanoes in three countries – i.e., Japan (Sakurajima), Mexico (Popocatépetl) and Indonesia (Merapi, Kelud). We also investigated how the use of respiratory protection varied according to a range of geographical and demographic characteristics and tested whether there are differences in the factors which influence people's motivations to take precautionary action.

The survey demonstrated that the large majority of respondents from all three communities used basic methods to protect themselves from inhaling ash, such as keeping windows and doors closed, limiting time outdoors, cleaning the house, and wetting the ash outdoors. This is encouraging as it seems that people are following national and international guidelines on ash protection (e.g., those issued by CENAPRED (www.cenapred.unam.mx), the World Health Organization (https://www.paho.org/disasters/index.php?Itemid=1171&lang=en) or the International Volcanic Health Hazard Network (https://www.ivhhn.org/ash-pamphlets)).

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Some actions were, however, more popular in certain countries – i.e., umbrellas/ parasols in Japan, wearing scarf or bandana over mouth/ nose in Mexico, and use of facemasks in Indonesia.

These differences were not fully accounted for by differences in the demographic profiles of the communities which suggests they might reflect more general cultural or contextual differences. For example, umbrellas have long been a feature of daily life in Japan. It is commonplace for Japanese people to carry umbrellas as protection from either the sun or the rain (see, e.g., https://www.insidejapantours.com/blog/2015/12/04/brolly-wet-june/). So, using an umbrella as protection against ashfall when there is an eruption is a convenient extension to its other uses.

The increased facemask use in Indonesia might also have reflected differences in the context in which the community experienced the ashfall. As documented in Horwell et al. [12], the ashfall in Yogyakarta in the aftermath of the Kelud eruption in 2014 was unexpected and prompted a quick response from local government and NGOs which included distributing facemasks and issuing advice (through a large volunteer network) to residents to use facial protection. This contrasts with the ashfall experiences of the communities living near Popocatépetl and Sakurajima, where eruptions are relatively frequent and ashfall is not an unusual occurrence.

The unexpected nature of the Kelud ashfall in Yogyakarta Province, and the government response, at least partially explains the increased facemask use (nearly 62% of residents said they had used a facemask all of the time) but this might also have contributed to raising concerns about the possibility that the ash might be harmful and beliefs about the effectiveness of masks (perceptions of harm/ worry and beliefs about mask efficacy were significantly higher in the Indonesian sample than the other two samples). Being advised to use facial protection and being provided with a mask not only sends a strong message that there must be something to worry about but also implies that the masks being distributed (which were basic surgical masks) provide some useful level of protection.

The roles of perceived harm/ worry and beliefs about mask efficacy in determining facemask use were central cognitive constructs in the theoretical model we proposed to explain variance in protective actions. The model's premises that people who used masks most frequently would be more concerned and worried about the harmful effects of the ash and believe masks to be more effective were supported. However, the multi-group modelling showed that the predictive ability of each construct was not entirely consistent across the communities.

Although the Japanese sample were, on average, less concerned and worried about the harmful effects of the ash than either the Mexican or Indonesian samples (possibly due to the lack of intervention and information from governmental agencies), perceptions of harm/ worry were a stronger predictor of variations in mask use frequency within the Japanese sample. The Japanese residents who were most concerned and worried about the ash used masks more frequently. Perceived harm/ worry was also a significant (if somewhat weaker) predictor of variations in mask use frequency within the Indonesian sample but, within the

Mexican sample, it was not significant. The degree to which the Mexican residents were concerned and worried about the ash did not influence their mask use and the more worried residents did not use masks more frequently than the less worried residents. Perhaps the costs and barriers to mask use are more influential than their concerns about the ash, particularly for those Mexicans living in the rural areas who are also less convinced, than those living in the urban areas, about whether masks offer effective protection.

Beliefs about mask efficacy predicted variations in mask use frequency in all three communities and the effect was strongest in Mexico. Residents recruited from the urban areas of Puebla city, who were generally more highly educated, used masks more frequently and believed masks were more effective than residents recruited from the rural community of Santiago Xalitzintla. Stronger beliefs about mask efficacy also mediated differences in mask use frequency between the urban and rural residents in Japan and Indonesia. However, in both of these locations, it was the residents from the rural rather than urban locations who perceived masks as more effective.

Although these findings highlight the explanatory value of the cognitive constructs as mediators of variants in mask use, a number of effects were left unaccounted for. For example, beliefs about mask efficacy could only partly account for differences in mask use between the rural and urban communities and we need to consider what additional unmeasured factors might be increasing mask use in the urban residents or reducing mask use in rural residents. People who live in cities may simply have better access to masks and the use of masks for a range of reasons, such as avoiding urban air pollution or for protection against communicable health threats, may have become normalised. We have some evidence of this from our analysis of the reasons for not wearing masks where, in the Mexican sample, residents from the rural location were more likely to give reasons which suggested that masks were not easily available or that they perceived very few people to be wearing masks.

The more widespread use of masks in urban settings is also evident in Japan and Indonesia. Mask use is a common sight in Japanese city dwellers and has become embedded in the culture as routine practice to protect themselves and others against a range of health threats [48]. It has also become quite common for people to wear facemasks in Indonesia, especially when riding on mopeds, to protect from vehicle emissions and road dust (see e.g., http://www.thejakartapost.com/news/2014/09/18/commuters-complain-worsening-air.html).

The effects of gender in the Japanese sample were also unaccounted for. Females used masks more frequently than males but gender had no effect either on perceptions of harm/ worry or beliefs about mask efficacy. Additional factors therefore need to be considered to explain these effects: women's decisions to wear masks (or men's decisions not to wear masks) could depend on several factors that have nothing to do with protection motivation from ash, such as custom, affordability, availability, comfort, and aesthetics. We have some evidence from this study that men might be less inclined to wear masks because they find them more uncomfortable (the Japanese males in our study were more likely than females to give ‘wearing a mask is uncomfortable’ as a reason for not wearing one). The reasons why women might be more inclined to wear masks is more speculative, however. Perhaps women

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are more likely to use masks for social reasons such as combatting shyness, hiding their emotions, protecting their modesty or because they view masks as a fashion item [49,50]. However plausible these suggestions might be, given the increasing recognition of the impact of gender on health outcomes [e.g., 51], further study is warranted to understand why mask use differs between males and females.

Whilst we can conclude that mask use for ash protection is relatively common across our three geographical locations, in Japan and Mexico, approximately one third of study participants never wear one for this purpose. The primary reasons given were different, however. In Japan, almost half of those respondents had simply never considered wearing a mask (for this purpose). People were also bothered by the inconvenience of carrying a mask and 41% were concerned it would affect breathing. In Mexico, the primary reason (57%) was that people did not have a mask, which might relate to the fact that 38% said they didn't think they needed to wear one and 35% said nobody else/ few people wore a mask, indicating an influence of peer learning and pressure. However, 43% stated that they found masks to be uncomfortable. It was notable, however, that fewer respondents in Japan or Mexico said that they wouldn't wear a mask due to being too hot (24% and 19%) or due to creation of humidity/ moisture (11% and 14%) despite daytime temperatures averaging above 25 °C over the summer months. This suggests that the warm climate in these survey regions was not a major barrier to mask use, a conclusion supported by the high uptake of mask wearing in Indonesia (96%) where the climate is very humid and hot throughout the year. Given that the most common mask used is a surgical mask, which tends to fit loosely, this result is not surprising. If agencies start to distribute more effective and well-fitting, industrycertified masks, climate may become more of a barrier to their uptake.

5 Conclusions and implications

This study has contributed to our understanding of the reasons why people take actions to protect themselves from inhaling volcanic ash. From a theoretical perspective, it was particularly notable that the predictive ability of the perceived harm/ worry and mask efficacy cognitive constructs varied among the three communities. The relative contributions that each construct makes at explaining mask use frequency is not equivalent and highlights the importance of not assuming that theoretical constructs identified as important predictors in one sample will necessarily be important predictors in other samples. This unique insight could only be gained from the methods employed here, where exactly the same methods were used to collect and analyse the data from all three communities.

That being said, our theoretical model was, by design, quite simple, which limits the breadth of our understanding of the factors which motivate people to protect themselves. Although the two central psychological constructs were derived from the threat appraisal (harm/ worry) and coping appraisal (mask efficacy) constructs of PMT, the single-items used to measure these constructs did not enable us to separate out, for example, the predictive abilities of perceptions of severity of harm from perceptions of probability of harm. But this limitation should not detract from the importance of our findings and the implications that they could have for policy and intervention.

By understanding the reasons why people take actions to protect themselves from ashfall, we have identified some approaches that might be used if agencies wanted to encourage people in these communities to use masks more consistently. For example, in all three communities, people were more likely to wear masks if they believed them to be more effective, so if agencies can convince people that the masks offered will protect them (assuming that effective protection is offered), they may be able to increase people's motivation to use masks more often, if climatic factors do not demotivate them. We might expect that this approach would be most effective in the Mexican communities where beliefs about mask efficacy were the strongest predictor. Moreover, less well-educated Mexicans, who live in the rural area, are probably most worth targeting with this type of approach because they have weaker beliefs about mask efficacy than more highly educated Mexicans who live in the urban area. In Japan and Indonesia, on the other hand, it might be more beneficial to focus on raising people's knowledge about the potentially harmful effects of volcanic ash, perhaps through providing information or education.

However, there could be ethical issues involved in interventions which target beliefs about mask efficacy or perceptions of harm/ worry. These interventions assume, of course, that it is correct for people to believe that breathing the ash is harmful to their health and something they should be concerned about and that a given mask is a highly effective form of protection. Both of these assumptions are questionable. Although ash inhalation might exacerbate respiratory problems in susceptible people [2], and limiting chronic exposure is probably advisable [52], there is a lack of evidence that it will have serious health consequences for most people [3], although the toxicity of ash appears to vary even within the same eruption sequence [5]. An intervention approach which specifically aims to raise concerns and worry people about the harmful effects of ash might, therefore, be unadvisable. An approach which addresses beliefs about mask efficacy will be more ethically sound. People need to know what level of protection is offered by different types of masks or respiratory protection so that they can make an informed choice about what to wear [53]. Results from another workstream within the HIVE project provide the first data on the effectiveness of different forms of respiratory protection worn when volcanic ash is in the air [14,15]. What these studies show is that the most effective respiratory protection for adults is to wear a well-fitting, industry-certified mask such as an N95 mask (referred to in this study survey as a high efficiency mask). Other types of masks, like the standard surgical mask, will provide less protection; although they may effectively filter ash [14], they often do not fit well to the face [15]. Updated advice on the IVHHN website emphasises the importance of a good fit and provides illustration of how to ensure a good fit (https://www.ivhhn.org/ash-protection and http://www.ivhhn.org/information/public-information-material/fitting-a-facemask-leaflet).

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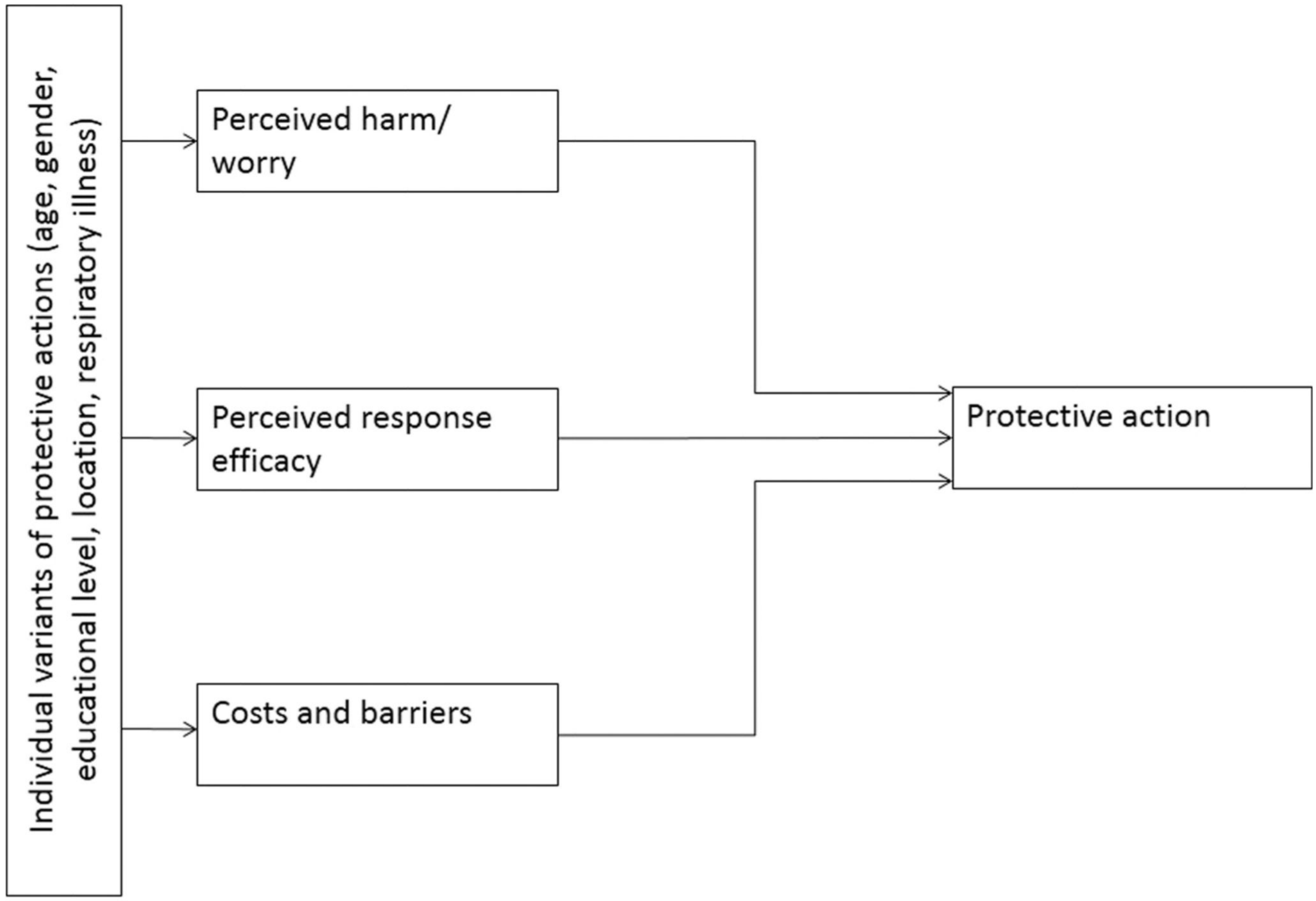

Fig. 1.
Proposed model to explain variance in protective actions.

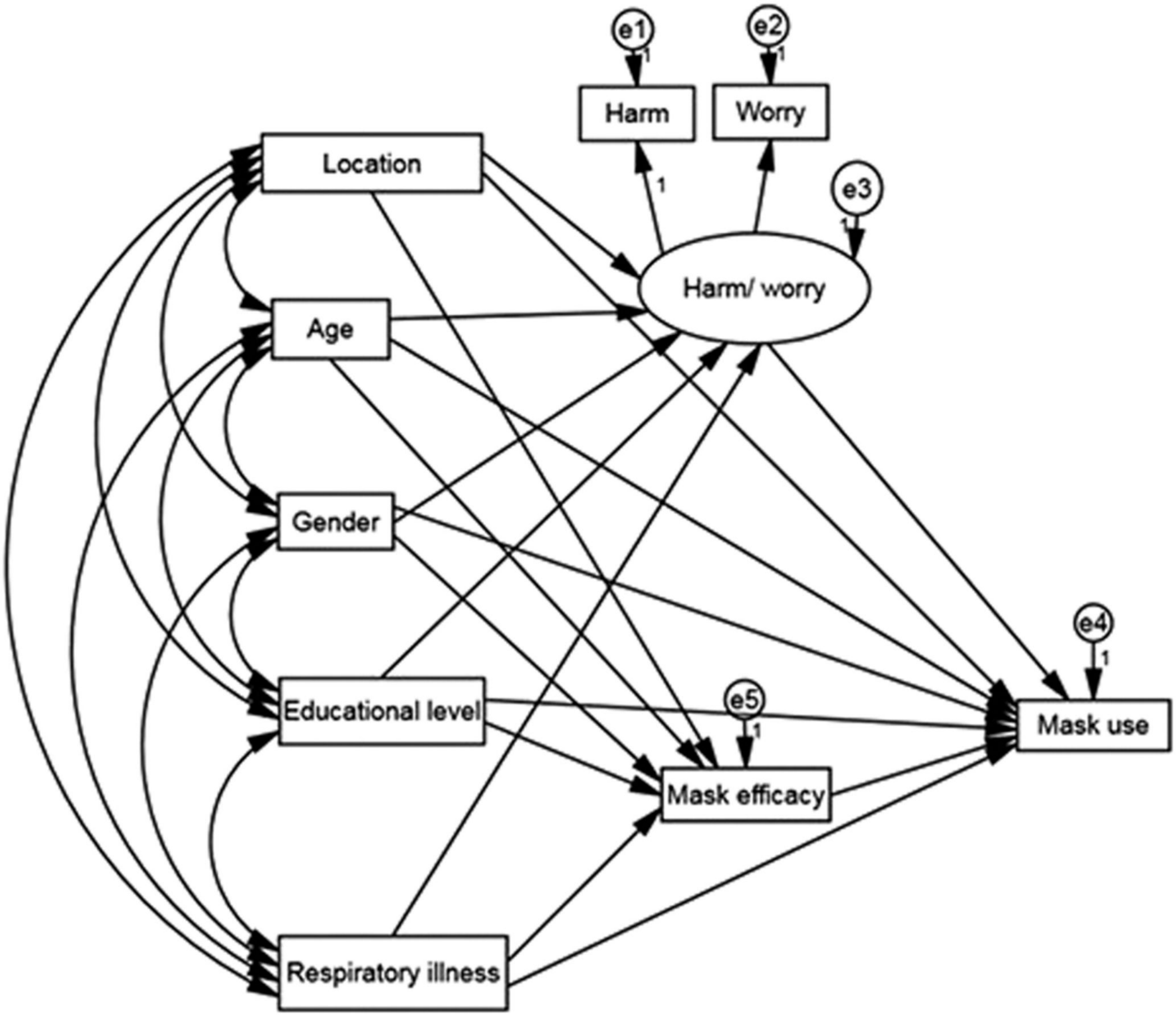

Fig. 2.
Structural Equation Model estimated in AMOS 22 (all coefficients). Observed (measured) variables are shown in rectangles and unobserved (latent/unmeasured) variables in circles or ellipses. In this model the latent variable (Harm/ worry) is measured by two indicator variables, Harm and Worry, each of which have measurement error terms (e1 and e2). Residual error terms (or disturbances) are also associated with each dependent (endogenous) variable in the structural model (e3-e5). Some of the paths shown in the diagram are labelled with the number “1”. This means that those paths’ coefficients have fixed values set to 1.00. These fixed values are necessary to set the scale of measurement for the latent factors and residuals. Covariances between the exogenous variables are shown with double ended arrows.

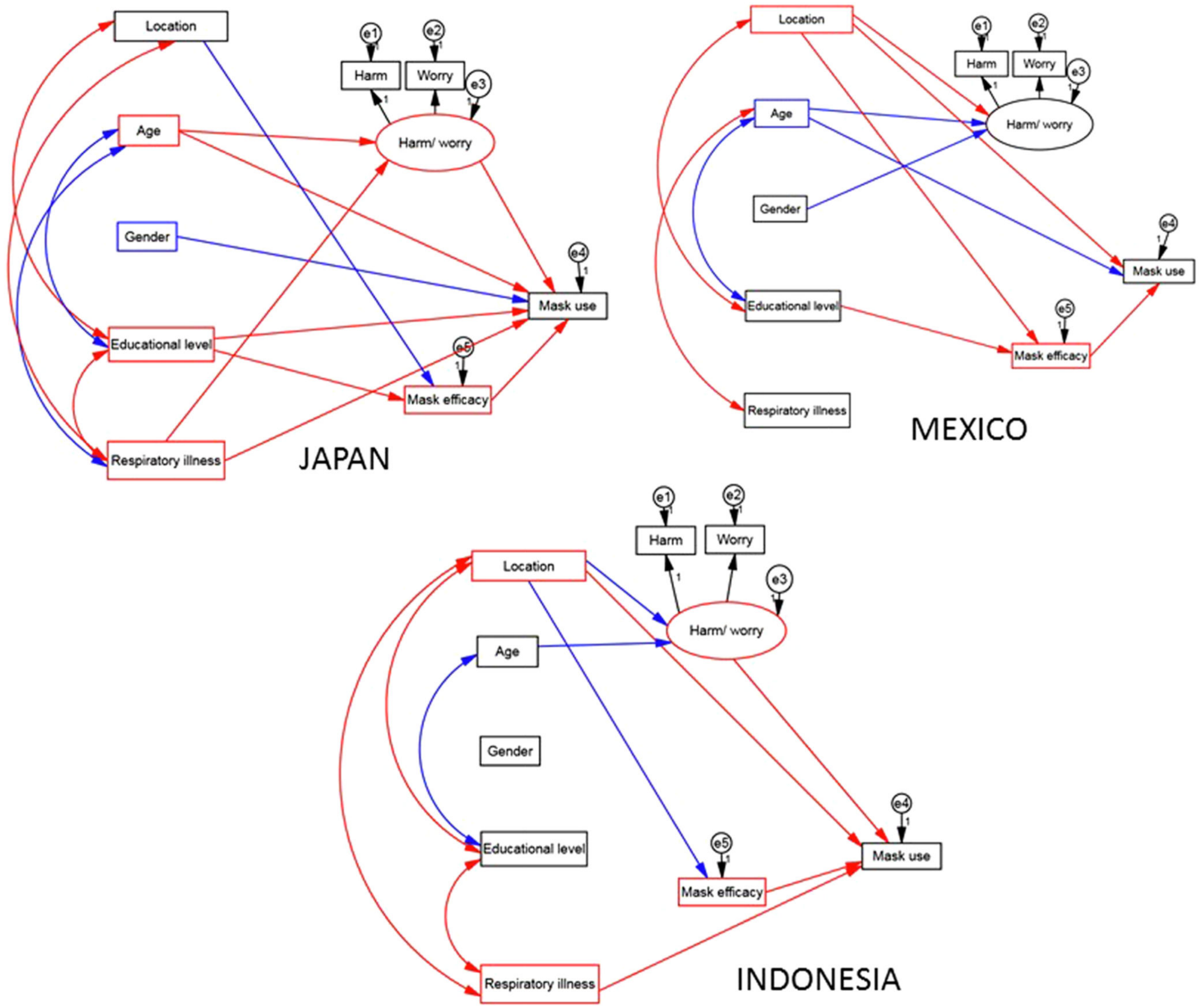

Fig. 3.

Structural Equation Models for each country. Significant covariances between the exogenous variables and path coefficients are denoted in red (positive coefficient) or blue (negative coefficient). Significant total effects are denoted by a red (positive coefficient) or blue (negative coefficient) border surrounding the variable. For example, in the Mexican sample, the border surrounding 'location' is red, which indicates that the total effect of location on mask use is positive (i.e., people living in the urban location used masks more frequently than people living in the rural location). In contrast, the border surrounding 'age' is blue, which indicates that the total effect of age on mask use is negative (i.e., older people used masks less frequently than younger people).

Table 1
Demographic characteristics of respondents.

	Japan (N = 749)		Mexico (N = 654)		Indonesia (N = 600)	
	N (%)	Census	N (%)	Census	N (%)	Census
Urban	431 (57.5%)		320 (48.9%)		300 (50.0%)	
Rural	318 (42.5%)		334 (51.1%)		300 (50.0%)	
Age group						
13-39 years	218 (29.1%)	36.0%	357 (54.6%)	57.5%	305 (50.8%)	54.0%
40-59 years	223 (29.8%)	25.0%	160 (24.5%)	23.5%	179 (29.8%)	32.5%
60+ years	308 (41.1%)	39.0%	137 (20.9%)	19.0%	116 (19.3%)	13.5%
Gender						
Male	325 (43.4%)	46.5%	307 (46.9%)	47.5%	294 (49.0%)	49.0%
Female	424 (56.6%)	53.5%	347 (53.1%)	52.5%	306 (51.0%)	51.0%
Education (highest level)						
No formal education	12 (1.6%)	34.3%[a]	127 (19.4%)	71.9%[a]	30 (5.0%)	48.5%[a]
Primary/Junior high	84 (11.2%)		274 (41.9%)		261 (43.5%)	
High school	310 (41.4%)	65.7%[b]	83 (12.7%)	28.1%[b]	217 (36.2%)	51.5%[b]
College / graduate	300 (40.1%)		170 (26.0%)		92 (15.3%)	
Missing	45 (5.7%)		–		–	
Occupational status						
Full-time paid work	210 (28.0%)		146 (22.3%)		182 (30.3%)	
Part-time paid work	141 (18.8%)		42 (6.4%)		29 (4.8%)	
Self-employed	56 (7.5%)		198 (30.3%)		96 (16.0%)	
Looking after family	14 (1.9%)		94 (1.1%)		101 (16.8%)	
In training/education	32 (4.3%)		72 (14.4%)		141 (23.5%)	
Retired	33 (4.4%)		32 (4.9%)		29 (4.8%)	
Not working	206 (27.5%)		58 (8.9%)		21 (3.5%)	
Other	18 (2.4%)		0 (0%)		1 (0.15%)	
Missing	34 (4.5%)		5 (0.8%)		-	
Respiratory health problem						
One or more	177 (23.6%)		95 (14.5%)		97 (16.2%)	
Asthma	48 (6.4%)		22 (3.4%)		43 (7.2%)	
Bronchitis	23 (3.1%)		20 (3.1%)		6 (1.0%)	
COPD	3 (0.4%)		5 (0.8%)		1 (0.15%)	
Lung cancer	1 (0.15%)		2 (0.3%)		0 (0%)	
Cystic fibrosis	0 (0%)		1 (0.15%)		0 (0%)	
Tuberculosis	0 (0%)		1 (0.15%)		1 (0.15%)	
Allergic rhinitis	142 (19.0%)		47 (7.2%)		23 (3.8%)	
Other[c]	4 (0.5%)		19 (2.9%)		32 (5.3%)	
When they last noticed ash in the air						
Last 24 hours	23 (3.1%)		35 (5.4%)		0 (0%)	

	Japan (N = 749)		Mexico (N = 654)		Indonesia (N = 600)	
	N (%)	Census	N (%)	Census	N (%)	Census
Few days ago	51 (6.8%)		211 (32.3%)		1 (0.15%)	
About a week ago	34 (4.5%)		103 (15.7%)		1 (0.15%)	
About a month ago	103 (13.8%)		264 (40.4%)		1 (1.3%)	
Few months ago	430 (57.4%)		36 (5.5%)		8 (1.3%)	
About a year ago	53 (7.1%)		2 (0.5%)		27 (4.5%)	
More than year ago	55 (7.3%)		3 (0.5%)		562 (93.7%)	

Notes:

[a]This census % refers to the combined percentages for No formal education and Primary/ Junior high

[b]This census % refers to the combined percentages for High school and College/ graduate

[c]Other types of respiratory health problems included dust allergy, shortness of breath, sinusitis, nose irritation, pneumonia, colds, flu, sore throat and persistent cough.

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Table 2

Actions taken during heavy ashfall.

		Country contrasts[1]			Covariates (Odds-ratios)			
	Pooled	Japan	Mexico	Indonesia	Age	Gender (1 = male)	Education level	Respiratory illness (1 = yes)
Windows/ doors closed	96.1%	96.9%[ac]	93.3%[b]	98.2%[c]	0.81	0.39***	1.29	1.59
Clean house	90.3%	84.8%[a]	90.8%[b]	96.5%[c]	1.20	0.51***	1.30**	0.91
Limit time outdoors	84.6%	85.2%[a][2]	77.2%[b][2]	91.8%[c]	0.89	0.49***	1.57***	1.27
Wet/ clean ash outdoors	80.3%	75.2%[a]	73.7%[ab]	94.0%[c]	1.48***	0.82	1.19*,[3]	1.06
Wear facemask	75.0%	67.6%[a][2]	61.8%[b][2]	98.8%[c]	1.00	0.74**	1.50***	1.91***
Wear a hat	67.5%	75.3%[a]	50.6%[b]	76.2%[ac]	1.42***	1.42**	0.69***	0.91
Handkerchief over mouth/nose	56.3%	72.5%[a]	51.8%[b]	41.0%[c]	0.77***	0.73**	1.19**	1.10
Hand over mouth/nose	54.3%	71.6%[a]	49.8%[b]	37.8%[c]	0.67***	0.83	1.03	1.22
Use an umbrella/ parasol	46.4%	65.0%[a]	15.7%[b]	56.5%[c]	0.89	0.39***	1.31***	0.99
Scarf/ bandana over mouth/nose	35.4%	25.2%[a]	39.8%[b]	43.3%[b]	0.69***,[4]	0.89	0.89*	1.25
Shawl/veil over face	24.8%	23.6%[a]	18.2%[b]	33.3%[c]	0.98	0.34***	0.87*	1.36*
Other[5]	5.7%	0.8%	5.4%	12.2%	–	–	–	–

Notes:

* $p < .05$.

** $p < .01$.

*** $p < .001$.

[1] For countries with a different superscript letter the difference is significant ($p < .05$). For countries with the same superscript letter the difference is not significant ($p < .05$).

[2] The difference between these countries was not significant at step 2 when the covariates were included in the model.

[3] Although this covariate is significant, the assumption of linearity between the independent variable (education level) and dependent variable (wet/ clean ash outdoors) does not hold. Analysis of educational level as a categorical rather than ordinal variable showed that those educated to high school or graduate level were significantly more likely to undertake this action than those with no formal education (ORs 2.28 ** 1.91 **), but that there was no difference between those with high school and graduate qualifications (OR 1.20).

[4] Although this covariate is significant, the assumption of linearity between the independent variable (age) and dependent variable (wear a scarf/ bandana over the mouth/nose) does not hold. Analysis of age as a categorical variable showed that those aged 40–59 or 60+ years were less likely to undertake this action than those aged 13–39 years (ORs 0.57 *** 0.50 ***), but that there was no difference between those aged 40–59 and 60+ (OR 1.14).

[5] Other types of actions taken to avoid breathing in the ash included shutting car windows, not going out, wearing a cap (as opposed to a hat), or putting a cloth in the mouth, or sweatshirt over the face.

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Table 3

Frequency of use of different types of facemask.

	Japan			Mexico			Indonesia		
	Always	**Sometimes/ often**	**Never**	**Always**	**Sometimes/ often**	**Never**	**Always**	**Sometimes/ often**	**Never**
Surgical mask	19.4%	44.8%	35.8%	25.4%	34.1%	40.5%	58.8%	39.3%	1.8%
Fashion mask	1.1%	4.3%	94.7%	0.2%	2.9%	96.9%	2.5%	13.3%	84.2%
Scooter mask	0.3%	1.5%	98.3%	0.5%	0.8%	98.8%	6.7%	12.5%	80.8%
Hard cup mask	0.7%	4.9%	94.4%	3.4%	5.5%	91.1%	0.5%	6.5%	93.0%
High-efficiency mask	0.7%	3.9%	95.5%	0.6%	1.8%	97.6%	1.2%	3.3%	95.5%

Table 4

Country contrasts in mask use frequency, beliefs about mask efficacy and perceptions of harm and worry.

	Country contrast[1]			Covariates (Odds-ratios)			
	Japan	**Mexico**	**Indonesia**	**Age**	**Gender (1 = male)**	**Education level**	**Respiratory Illness (1 = yes)**
Mask use frequency[2]							
Never (0)	32.4%	38.1%	1.2%				
Sometimes/ often (0.5)	47.3%	34.9%	37.2%				
Always (1)	20.3%	27.1%	61.7%	–	–	–	–
Mean (SD)	0.44[a] (0.36)	0.45[a] (0.40)	0.80[b] (0.26)	1.02	0.68***	1.48***	1.58**
Mask efficacy[2]							
Not at all effective (0)	3.7%	7.2%	0.5%				
A little effective (1)	32.7%	16.4%	1.5%				
Quite effective (2)	44.5%	27.8%	19.0%				
Very effective (3)	17.2%	45.9%	79.0%	–	–	–	–
Mean (SD)	1.77[a] (0.78)	2.16[b] (0.96)	2.74[c] (0.49)	1.11	1.06	1.24***	1.04
Perceived harm							
No harm (0)	10.8%	6.1%	1.2%				
A little harmful (1)	50.3%	13.6%	3.3%				
Quite harmful (2)	21.1%	30.1%	23.0%				
Very harmful (3)	13.6%	48.8%	72.5%				
Can’t say	4.10%	1.40%	0	–	–	–	–
Mean (SD)	1.39[a] (0.87)	2.23[b] (0.60)	2.67[c] (0.91)	0.91	1.21***,[3]	1.34*,[4]	
Perceived worry							
Not at all (0)	11.1%	13.3%	2.58%				
A little worried (1)	53.0%	23.5%	4.5%				
Quite worried (2)	19.4%	31.8%	28.2%				
Very worried (3)	13.5%	30.7%	65.5%				
Can’t say	3.1%	0.6%	0.15%	–	–	–	–
Mean (SD)	1.32[a] (0.86)	1.80[b] (0.66)	2.58[c] (1.02)	1.04	0.86	1.12*,[5]	1.49**,[6]

Notes:

* $p < .05$.

** $p < .01$.

*** $p < .001$.

[1] For countries with a different superscript letter the difference is significant ($p < .05$) at step 1 and step 2.

[2] The mask use frequency and efficacy ratings shown in this table refer to the ratings respondents gave to the type of mask that they said they used most often.

[3] This coefficient was not significant when the dependent variable was dichotomised 0 = 0,1,2 1 = 3.

[4] This coefficient was only significant when the dependent variable was dichotomised 0 = 0,1 1 = 2,3.

[5] This coefficient was only significant when the dependent variable was dichotomised 0 = 0, 1 = 1,2,3.

[6] This coefficient was only significant when the dependent variable was dichotomised 0 = 0,1, 1 = 2,3.

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Table 5

Estimated total, indirect and direct effects from the structural equation models (b coefficients).

	Japan				Mexico				Indonesia			
	Total effect	**Indirect effect (harm/ worry)**	**Indirect effect (mask efficacy)**	**Direct effect**	**Total effect**	**Indirect effect (harm/ worry)**	**Indirect effect (mask efficacy)**	**Direct effect**	**Total effect**	**Indirect effect (harm/ worry)**	**Indirect effect (mask efficacy)**	**Direct effect**
Harm/worry[1]	0.157**	–	–	–	0.026	–	–	–	0.039*	–	–	–
Mask efficacy	0.056**	–	–	–	0.172**	–	–	–	0.089**	–	–	–
Location (1 = urban)	− 0.030	− 0.006	− 0.009**	− 0.015	0.164*	0.006	0.038*	0.121*	0.047*	− 0.005	− 0.024**	0.075*
Age	0.056**	0.024**	0.0005	0.032*	− 0.061**	− 0.006	0.010	− 0.065**	− 0.013	− 0.003	− 0.008	− 0.011
Gender (1 = male)	− 0.131**	− 0.003	0.003	− 0.131**	− 0.005	− 0.004	0.022	− 0.023	− 0.039	0.001	− 0.003	− 0.038
Education level	0.056**	0.010	0.007**	0.039**	0.036[4]	0.001	0.022**	0.013	0.026	0.002	− 0.0006	0.024
Respiratory illness (1 = yes)	0.144**	0.038**	0.005	0.102**	0.019	0.004	0.016	0.005	0.071*	0.002	− 0.0005	0.069*
Model fit[2] (full model)	RMSEA = 0.098, p(RMSEA > 0.05) = 0.248				RMSEA = 0.026, p(RMSEA > 0.05) = 0.873				RMSEA = 0.042, p(RMSEA > 0.05) = 0.618			
Model fit[2] (reduced model[3])	RMSEA = 0.039, p(RMSEA > 0.05) = 0.807				RMSEA = 0.024, p(RMSEA > 0.05) = 0.973				RMSEA = 0.034, p(RMSEA > 0.05) = 0.890			

Note:

* 95% chance that credible interval does not contain zero.

** 99% chance that credible interval does not contain zero.

[1] Unobserved (latent, unmeasured) variable constructed from the observed (measured) variables ‘harm’ and ‘worry’.

[2] MacCallum, Browne and Sugawara [45] have used 0.01, 0.05, and 0.08 to indicate excellent, good, and mediocre fit, respectively. Others suggest 0.06 as the cutoff for poor-fitting models [46].

[3] The reduced model retained only paths that were significant.

[4] If location or age were removed from the model, the total effect of education level on mask use was significant ($b \geq 0.060$).

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Table 6

Reasons given by respondents who said they had not worn a facemask to protect themselves from breathing in volcanic ash.

	Japan (N = 243)	Mexico (N = 249)	Indonesia (N = 4)
Breathing ash doesn't bother me	24.7%	27.7%	25.0%
Breathing ash doesn't worry me	18.5%	15.7%	25.0%
Don't think I need to wear a mask	18.5%	38.3%	50.0%
Don't think masks are effective	5.3%	11.6%	25.0%
Never considering wearing a mask	46.1%	31.3%	50.0%
Don't have a mask	20.5%	57.3%	0
Masks are expensive	1.2%	12.4%	0
Don't know where to get a mask from	0	24.1%	0
Masks not easily available	0.8%	15.3%	0
Wearing a mask is difficult	4.1%	6.0%	0
Inconvenient to carry a mask around	33.7%	15.3%	0
Wearing a mask is uncomfortable	24.7%	42.6%	0
Wearing a mask would make me too hot	23.5%	18.9%	0
Wearing a mask would affect my breathing	41.2%	16.9%	0
Wearing a mask creates humidity/ moisture	10.7%	13.7%	50.0%
Wearing a mask is embarrassing	4.1%	13.7%	0
Wearing and mask is unfashionable	3.7%	4.8%	0
Noone else/few people wear a mask	10.7%	34.9%	25.0%
Other[a]	4.1%	7.6%	50.0%

Note: Respondents could select more than one reason.

[a]Other reasons for not wearing a mask included the fact that they had not been provided with a mask, they use other things (like a handkerchief), glasses get fogged up wearing a mask, don't like wearing a mask, don't go out much, or stay in until the ashfall ends.