Journal of Applied Volcanology

RESEARCH Open Access

Community preparedness for volcanic hazards at Mount Rainier, USA

Lauren J. Vinnell[1*], Emma E. Hudson-Doyle[1], David M. Johnston[1], Julia S. Becker[1], Lucy Kaiser[1], Michael K. Lindell[2], Ann Bostrom[2], Chris Gregg[3], Maximilian Dixon[4] and Brian Terbush[4]

Abstract

Lahars pose a significant risk to communities, particularly those living near snow-capped volcanoes. Flows of mud and debris, typically but not necessarily triggered by volcanic activity, can have huge impacts, such as those seen at Nevado Del Ruiz, Colombia, in 1985 which led to the loss of over 23,000 lives and destroyed an entire town. We surveyed communities around Mount Rainier, Washington, United States, where over 150,000 people are at risk from lahar impacts. We explored how factors including demographics, social effects such as perceptions of community preparedness, evacuation drills, and cognitive factors such as risk perception and self-efficacy relate to preparedness when living within or nearby a volcanic hazard zone. Key findings include: women have stronger intentions to prepare but see themselves as less prepared than men; those who neither live nor work in a lahar hazard zone were more likely to have an emergency kit and to see themselves as more prepared; those who will need help to evacuate see the risk as lower but feel less prepared; those who think their community and officials are more prepared feel more prepared themselves; and benefits of evacuation drills and testing evacuation routes including stronger intentions to evacuate using an encouraged method and higher self-efficacy. We make a number of recommendations based on these findings including the critical practice of regular evacuation drills and the importance of ongoing messaging that focuses on appropriate ways to evacuate as well as the careful recommendation for residents to identify alternative unofficial evacuation routes.

Keywords: Lahar, Volcano, Preparedness, Natural hazard, Hazard adjustment, USA

Introduction

Background

Understanding people's preparedness and intentions to prepare for natural hazard events is vital for building individual and community resilience. This is particularly important in regions that experience low frequency high consequence events, where preparedness for such events may have less prominence in people's day to day decision making. Lahars are such a hazard. They are one of the most hazardous phenomena associated with volcanoes (Smith & Fritz, 1989), being fast moving sediment-water flows that have long runouts and can cause major loss of human life and property (Jakob & Hungr, 2005). They are triggered by crater-lake outbreaks (Becker et al., 2017a), eruption-induced snow melting, debris avalanches, and rainfall-induced remobilization of sediment on upper volcanic flanks (Doyle et al., 2010). They caused an estimated 30,734 fatalities in the twentieth Century (Witham, 2005). Considerable effort has gone into developing modelling to predict the volume and paths of future lahars such as those which are expected in Colombia (Kunzler et al., 2012) and Italy (Tierz et al., 2017). This research typically considers lahar impacts on public safety among other factors, such as the efforts to mitigate lahar impacts from Ruapehu

*Correspondence: l.vinnell@massey.ac.nz
[1] Joint Centre for Disaster Research, Massey University, Wellington, New Zealand
Full list of author information is available at the end of the article

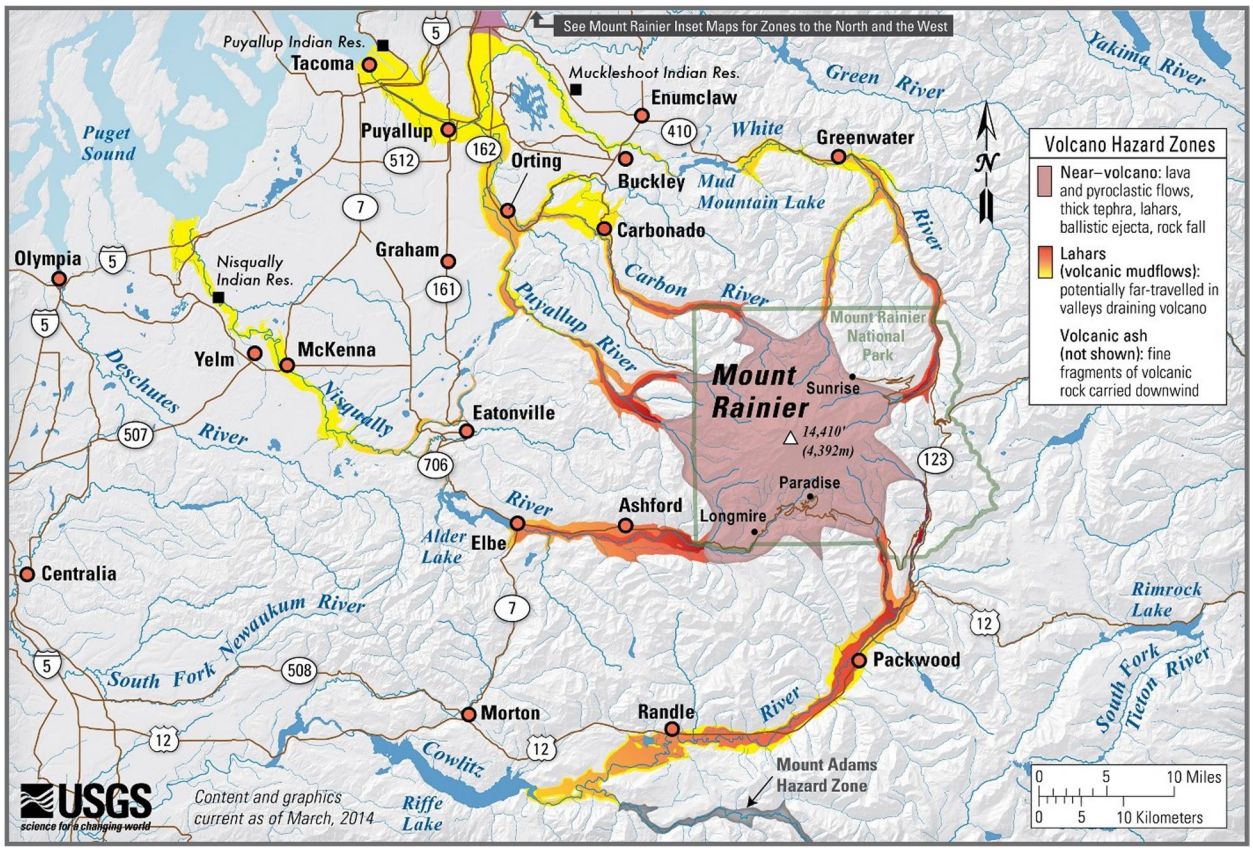

Fig. 1 Mount Rainier Hazard Map (based on the official hazard assessment: Hoblitt et al., 1998). Credit: U.S. Geological Survey, Department of the Interior/USGS, U.S. Geological Survey/Lisa Faust

volcano in Aotearoa, New Zealand (Keys, 2007). However, it is also important to explicitly consider the social elements of such disasters. Voigt (1996), in an analysis of the eruption of Nevado del Ruiz in Colombia which claimed over 20,000 lives in a single town, emphasizes the importance of identifying those at risk and using education, warning systems, and communication to prepare these communities. In this study we present the results of a survey identifying influences on community preparedness for lahars at Mount Rainier, Washington State, United States.

Mount Rainier is an active volcano in the Cascade range which runs 1100 km through parts of Western Canada and the US. This range, formed by the Cascadia subduction zone, includes over a dozen volcanoes and has produced significant events in recent history, including the 1980 eruption of Mount St. Helens which led to 57 deaths (Brantley & Myers, 2005). While Mount Rainier poses a number of typical volcanic hazards, this single volcano has a volume of snow and ice equivalent to all other volcanoes in the Cascade range combined. Lahars from this volcano which reach the Puget lowland occur every 500 to 1000 years (Fig. 1). At least 60 lahars have occurred in the last 10,000 years, including the Osceola Mudflow which covered approximately 550 km^2 (Hoblitt et al., 1998; see Fig. 2). There has also been at least 30 debris flows, which are not related to volcanic eruptions but occur as slope failures and therefore have few, if any, warning signs (Vallance et al., 2003). The Electron Mudflow 600 years ago left deposits up to 6 m thick at Orting, where over 8000 people now live. Since the last event, the Puget lowland has become densely populated placing more than 150,000 people in the hazard zone (Diefenbach, Wood, & Ewert, 2015). The history of lahars on Mount Rainier which were not triggered by volcanic eruption places particular importance on the development of, and education around, rapid evacuation infrastructure including sirens, evacuation routes, and drills. Communities near Mount Rainier also face other volcanic hazards, such as ashfall (see Fig. 3).

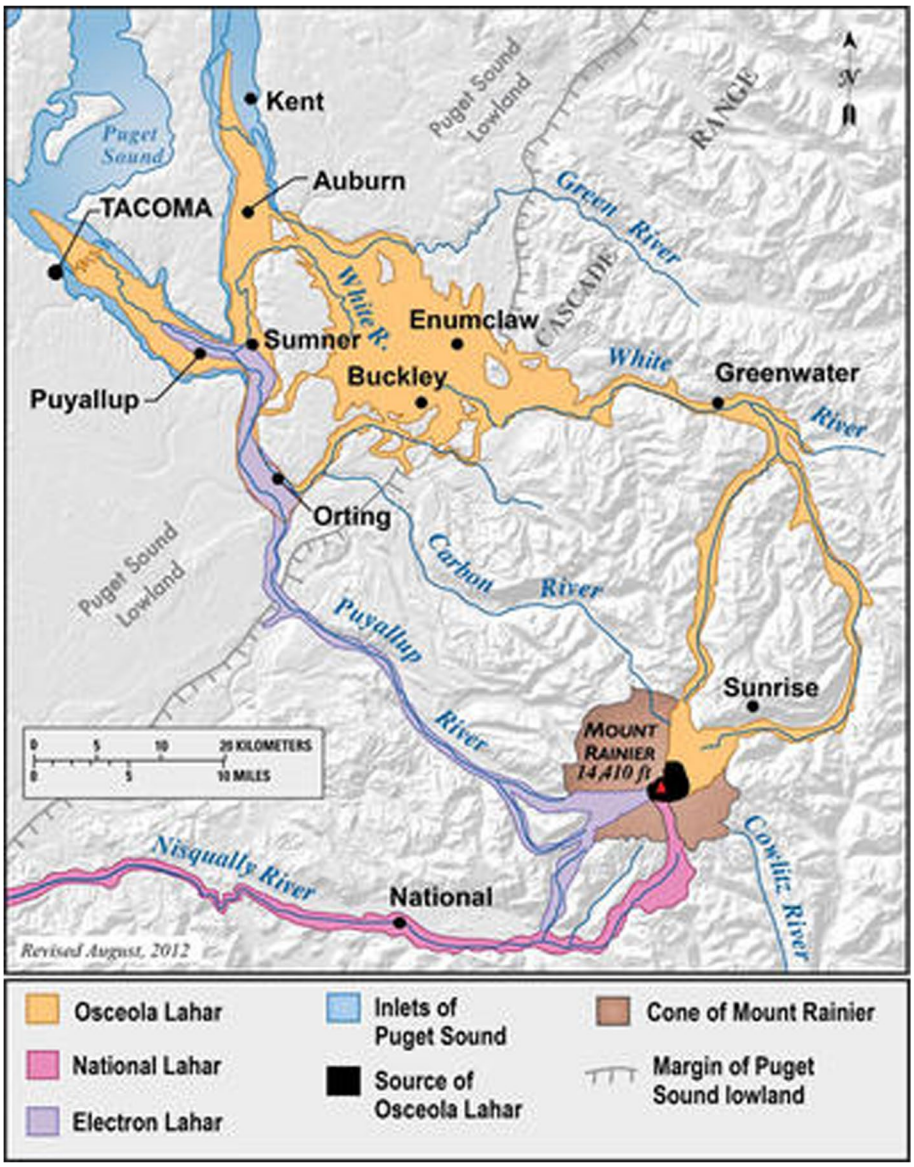

Fig. 2 Paths of previous major lahar and debris flow events at Mount Rainier. Credit: U.S. Geological Survey . Department of the Interior/USGS

In response to this hazard, a number of preparedness actions have been taken including: installing an automated lahar detection system which can trigger alerts (Allstadt et al., 2019); public education programs by groups such as emergency managers, the United States Geological Survey, and local educators (Davis et al. 2006; Johnston et al. 2001a,b; Johnston et al. 2005; Pierson et al., 2014; Cadag et al., 2017; Wei & Lindell 2017; Driedger et al., 2020); and the addition of evacuation drills to preparedness campaigns. Evacuation drills are a form of community education event that are important for preparedness, as not only do they help people understand routes and safe zones (Johnston et al., 2016; Doyle et al., 2020a), they also help build community relationships and increase resilience factors (Becker et al., 2017b).

Despite these efforts, preparedness for lahar hazards from Mount Rainier in the greater Orting/Puyallup area was low at a previous assessment 15 years ago (Davis et al., 2006). Only about half of survey participants had tested official evacuation routes (i.e., those promoted by local authorities such as emergency management), two-thirds did not have belongings stored ready to take with them should they need to evacuate, and most intended to

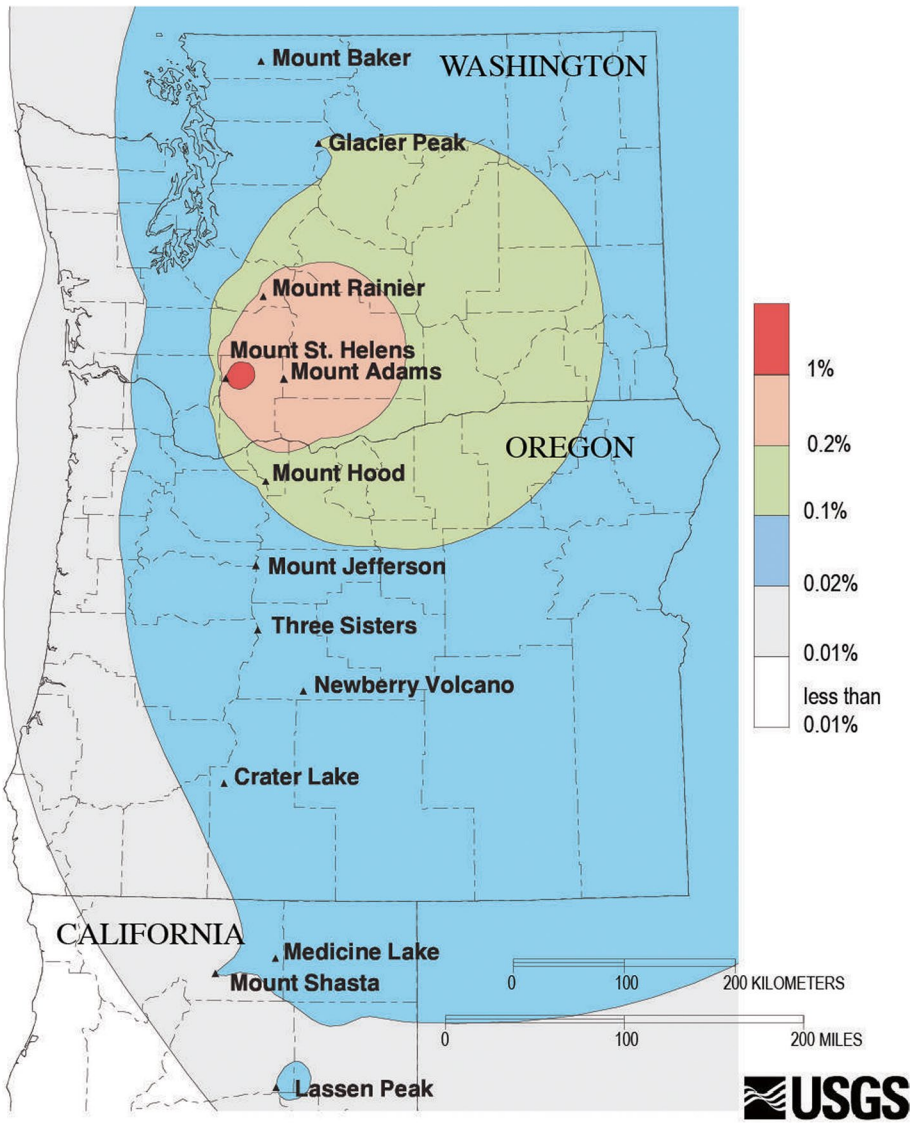

Fig. 3 Probability of 1+ centimetres of ashfall accumulation over a 1-year timeframe. Credit: U.S. Geological Survey. Department of the Interior/USGS. U.S. Geological Survey/Manny Nathensen

evacuate by car which can lead to traffic congestion and fatalities (Fraser et al., 2012). The current survey administers the same survey as used by Davis et al. (2006) to gain an understanding of current levels of lahar awareness and preparedness in the Mount Rainier area given continued education efforts and expansion of evacuation drills.

Further, Orting in particular has seen a proportionally large population growth (from approximately 5400 residents in 2006 to 8610 in 2019; United States Census Bureau, n.d.) which would likely impact the risk profile of the residents. Up-to-date information about attitudes and behaviour, particularly factors which appear to inhibit preparation or limit awareness, can be used by local emergency management to improve their public education and engagement activities. Although this study builds on that of Davis et al. (2006), the research is not longitudinal, so statistical comparison is unwise.

Natural hazard preparedness

The findings of lahar preparedness in the Mount Rainier area in 2006 reflect broader patterns of low natural hazard preparedness in other communities and contexts, despite ongoing efforts to educate and encourage preparation (Johnston et al., 2013; Lindell & Whitney, 2000; Paton, Smith, & Johnston, 2005; Peers et al., 2020). The most recent drills that were held before this research was

undertaken occurred on 10 May 2019 in Orting and 17 May 2019 in Puyallup. Participants in the drill, as has been the case with all lahar drills in the area for the last few decades, included school students, staff, and city employees, but not the general public; our assessment of community evacuation intentions and preparedness may therefore be biased away from drill participation, although with the exception of considerably older participants most will have at least participated in drills during their education. However, since the last assessment, education has continued to occur via both school and community outreach activities. For context, evacuation drills are run primarily within schools. At the sound of the lahar sirens, students leave the classroom, and proceed along a roughly 2.5 mile route to an established location, 30 ft in elevation above the valley floor at the County quarry. Students then return to their classrooms. School officials and volunteers from the community assist students along the walk, aiding them with directions, and traffic control (Z. Gibson, personal communication, May 24, 2021).

Given the continuing challenges in motivating public preparedness for lahars, we next review influences on hazard preparedness from a broad range of studies which informed the survey aims and method.

Many studies globally have aimed to understand preparedness for disasters and natural hazards generally (Becker, Paton, & Johnston, 2015), from an all-hazards perspective (Bourque, 2013; Paton, 2018), and for specific hazards such as earthquakes (Lindell & Perry, 2000; Solberg, Rossetto, & Joffe, 2010). Similar efforts have been made to understand preparedness for volcanic hazards specifically, including research in Indonesia (Sagala, Okada, & Paton, 2009), New Zealand (Paton, Smith, Daly, & Johnston, 2008), and the US (Peers et al., 2020; Perry & Lindell, 2008; Wei & Lindell, 2017), as well as work considering volcanic risks in a multi-hazard environment which also includes wildfire and earthquake potential (Peers et al., 2020; Perry & Lindell, 2008). The important factors identified in the context of volcanic risk overlap considerably with those identified in relation to other natural hazards (e.g., Becker et al., 2014; Lindell & Prater, 2000; Lindell & Whitney, 2000; Paton et al., 2005; Paton et al., 2010; Solberg, Rossetto, & Joffe, 2010). Individual-level factors include self-efficacy (the belief that the individual is capable of getting prepared), outcome expectancy (the belief that preparing will help), and hazard intrusiveness and affective responses (Wei & Lindell, 2017). Community-level factors such as collective-efficacy (the belief that a community or group is capable of action), social capital, community participation and empowerment, and trust in civic agencies have also been identified. The importance of specific factors can vary between contexts; for example, individual-level factors tend to be less important in collectivistic compared to individualistic countries (Sagala et al., 2009).

In the specific context of preparedness for lahars in the area of Mount Rainier, Wei and Lindell (2017) examined a range of demographic, location, and psychological variables relating to household adjustment. They found those who were more attached to their community demonstrated higher evacuation and emergency preparedness, although neither of these variables related to risk perception. Proximity to the crater was positively related with evacuation preparedness and community emergency preparedness, but not household preparedness or risk perception; proximity to a lahar hazard zone did not relate to any of the preparedness or psychological variables. It is possible that proximity to the crater leads to higher familiarity with the hazard than those who live in the hazard zone but are further from the crater; previous research has demonstrated that direct, but not vicarious, experience of volcanic hazards increase risk knowledge and perception (Paton, Johnston, Bebbington, Lai, & Houghton, 2001). Recent research in California found no effect of hazard exposure on preparedness, although hazard intrusiveness was positively related to information-seeking (Peers et al., 2020).

Further, this research found that risk perception was higher among female participants and those with lower incomes, and lower among those who identified as White, although these associations were small and there was no association with age, education, or length of time lived in the community. Interestingly, females reported lower household preparedness (perhaps due to their heightened risk perception raising the threshold for adequate preparedness), while those who were older and had lived in their community for longer reported higher preparedness. Sex and gender has been found in a number of other studies to relate to preparedness (e.g., Bateman, & Edwards, 2002; Becker, Paton, & Johnston, 2014; Becker, Paton, Johnston, & Ronan, 2012; Dooley, Catalano, Mishra, & Serxner, 1992; Doyle et al., 2020b; McIvor, Paton, & Johnston, 2009), but results can be inconsistent (Baker, 1991; Huang, Lindell, & Prater, 2016; Lindell, 2013; Lindell & Perry, 2000; Lindell & Prater, 2000). Corwin et al. (2017) identified self-efficacy and perceptions of responsibility to prepare as factors associated with volcanic hazard preparedness in Washington State, specifically Mount Baker and Glacier Peak communities.

Study aims

The need to ensure lahar hazard information is communicated, and communicated *well,* to at-risk communities has long been known (Pierson et al., 2014). To evaluate

impacts of current education strategies, and in particular target areas and potential improvements to future efforts, it is important to assess levels of risk awareness and preparedness among the public as well social and cognitive factors which could explain any concerning trends. To this end, a survey study in 2019 explored preparedness for lahars in Mount Rainier communities. The survey instrument built on a questionnaire used in a 2006 study (Davis et al. 2006) and was distributed to the same 850 households who participated in this previous research,[1] as well as being promoted to new participants via channels including social media and newsletters (see "Procedure" section below).

Research questions

Given the breadth of the study aims, a select number of specific research questions informed by the existing literature focused on demographic, social, and cognitive influences on behaviour.

RQ1: Are there demographic differences in intentions to prepare, perceived preparedness, and preparedness behaviour (creating a "disaster supply kit to take when a lahar warning is issued")?

- Demographics include age, sex, ethnicity, whether participants live and/or work in a lahar zone, and if they will need help to evacuate. Such variables do not demonstrate consistent effects across the literature, with examples of positive, negative, and non-significant findings (Becker et al., 2015; Bourque, 2013; Lindell & Perry, 2000; Solberg et al., 2010).

RQ2: Are there any social effects on intentions and preparedness?

- Social effects include perceptions of community preparedness and community attachment. Participating in community activities, feeling a sense of community, and believing that the community is capable of coping with hazard risks and impacts are related to preparedness (Becker et al., 2015). Social norms (i.e., perceptions of whether people in the community prepare for natural hazards) also typically relate to preparedness. Thus, people who think others like them will prepare, or have prepared, are more likely to prepare themselves (McIvor & Paton, 2007). However, these social norm effects can backfire if people believe that only a minority of others are prepared (Becker, Paton, Johnston, & Ronan, 2014).

RQ3: Are there any effects of practising evacuations on intentions, preparedness, or cognitions?

- This question examines both past participation in drills as well as past testing of official and unofficial evacuation routes (as defined by the participants; no specific information around what are official and unofficial routes was provided by the researchers. Testing refers to following evacuation routes for different reasons including as part of an official warning or as part of a training exercise). Following the Great East Japan Earthquake, those who had participated in tsunami drills were more likely to have evacuated than those who had not participated in such drills (Nakaya et al., 2018), while those who participate in earthquake drills are more likely to use protective actions (drop, cover, and hold) during actual earthquakes (Vinnell, Wallis, Becker, & Johnston, 2020).

RQ4: Are there any key cognitive factors associated with intentions and preparedness in this sample?

- The cognitive factors examined are risk perception, unrealistic optimism, and self-efficacy. Risk perception is typically seen as necessary for preparedness to occur but not a sufficient motivator on its own (Bourque, 2013). Unrealistic optimism is commonly held as a barrier to preparing for natural hazards such as earthquakes (Spittal, McClure, Siegert, & Walkey, 2005). This optimism represents an individual's belief that they are more prepared for a hazard event, and less likely to experience negative outcomes, than someone else like them despite being exposed to equal objective risk. Finally, self-efficacy, which refers to an individual's belief that they are capable of preparing in terms of factors such as time, effort, knowledge, and skill, is often demonstrated as positively related to preparation for natural hazards (Becker et al., 2015; Paton, Smith, & Johnston, 2005).

Method

Materials

Items in the questionnaire that required judgments from participants (such as how prepared they perceive themselves to be) mostly used Likert-type response scales. Several items had a limited range of responses (e.g., "Yes", "No", or "Don't know"), such as questions regarding whether participants live or work in lahar hazard zones and whether their communities have warning systems.

[1] The intention behind this decision was to compare data quasi-longitudinally. As only 10 participants indicated that they had also completed the 2006 survey, such comparisons were not possible.

Given the extent of the survey, not all questions which were asked are reported on here. As well as answering questions on behaviour, risk judgments, and biases, participants provided a range of demographic information including age, gender, ethnicity, and housing situation. This survey used that developed by Davis et al. (2006) in a collaboration between GNS Science in Aotearoa New Zealand and academics in the US (California and Hawaii). The full survey and raw data are available on the Open Science Framework here: https://osf.io/ckuvp/. Some key variables are described below.

Intentions to prepare were measured with four items, for which a mean score was calculated. The items asked how likely on a scale from 1 (Extremely unlikely) to 5 (Extremely likely) participants were to do the following in "the next month or so": "Become involved with a local group to discuss how to improve the response to a lahar", "Seek information on lahar risk", "Seek information about the lahar warning system in my community", and "Seek information about evacuation routes for my community". Perceived preparedness was also measured with a response on a 5-point scale from 1 (Not prepared at all) to 5 (Very prepared) to the question "How prepared do you think you are for a major lahar?"

Procedure

The survey data was collected via the online platform Qualtrics throughout June and July 2019. Participants were recruited via a range of methods and directed to the online survey. Methods included a postcard with a survey link printed on it (Fig. 4) posted to 850 households in the greater Orting/Puyallup area which were also invited to participate in the 2006 survey on which this one is based (Davis et al., 2006), distribution of postcards at the Orting and Puyallup farmers markets, distribution of postcards at Puyallup Library, and a range of social media pathways via the local and state Emergency Management agencies. Pierce County shared the survey link on their social media accounts (reaching 8000 people a day), sent out the survey in a newsletter and email, and helped with distributing it at Orting Farmers Market. Participants were therefore not deliberately recruited based on whether they lived or worked in lahar hazard zones. Given the somewhat counterintuitive findings around links between risk perception, preparedness, and proximity to hazards, it is useful to collect opinions from people who face different levels of objective risk. That is, the actual likelihood of lahar impacts and their severity, based on scientific assessment, can differ from people's subjective beliefs about how likely they are to be impacted, which can be influenced by a number of factors including personal experience and social representations of hazards (Boholm, 1998). Further, even if participants do not live or work in hazard zones, they are still likely to spend time in them, for example while commuting, shopping, or undertaking recreation, therefore understanding general community concern and awareness is still useful. While broader recruitment and online data collection have significant benefits for cost and time, it does limit the ability to target specific geographical areas beyond a town level. However, given the limited number of responses achieved using the same targeted approach as the 2006 survey, we believe the benefit of more, slightly less geographically-nuanced data, outweighs the downsides. Data collection began on June 7, 2019, approximately 1 month following lahar drills held in Orting (10 May) and Puyallup (17 May). The survey was closed on July 31, 2019. This study was evaluated by ethics peer review through Massey University and judged to be low risk, consistent with the procedure for ethical approval of studies using human subjects required by that University.

Participants

A total of 985 people followed the survey link. Of those, 830 proceeded to complete at least some of the survey. Table 1 provides the demographics of the study sample and the sampled populations.

There is considerable demographic variation within Pierce County, as can be seen in the differences between Orting and Puyallup. Our study sample appears somewhat skewed such that our participants more likely to be older, female, white, and to have a college degree. Such demographic skews are not uncommon in online surveys (Vinnell, 2020) but the following results should be considered in light of these differences.

Data analysis

Some items were reverse coded (i.e., scores on 1 to 7 scales were flipped so that scores of 1 were coded as 7, 2 as 6, 3 as 5, and vice versa) after data collection and before analysis such that higher scores reflect stronger and/or more positive results consistently across the survey. Mean scores for variables with multiple items were calculated when at least half of those items were answered. The small numbers across different ethnicity groups limit the reliability and power of statistical comparison, so analyses based on ethnicity are not reported. All analyses were completed using IBM's SPSS version 25. The results, discussed next, focus on demographic differences in intentions and behaviour, social effects on preparation, the role of evacuation drills, and cognitive predictors of preparedness.

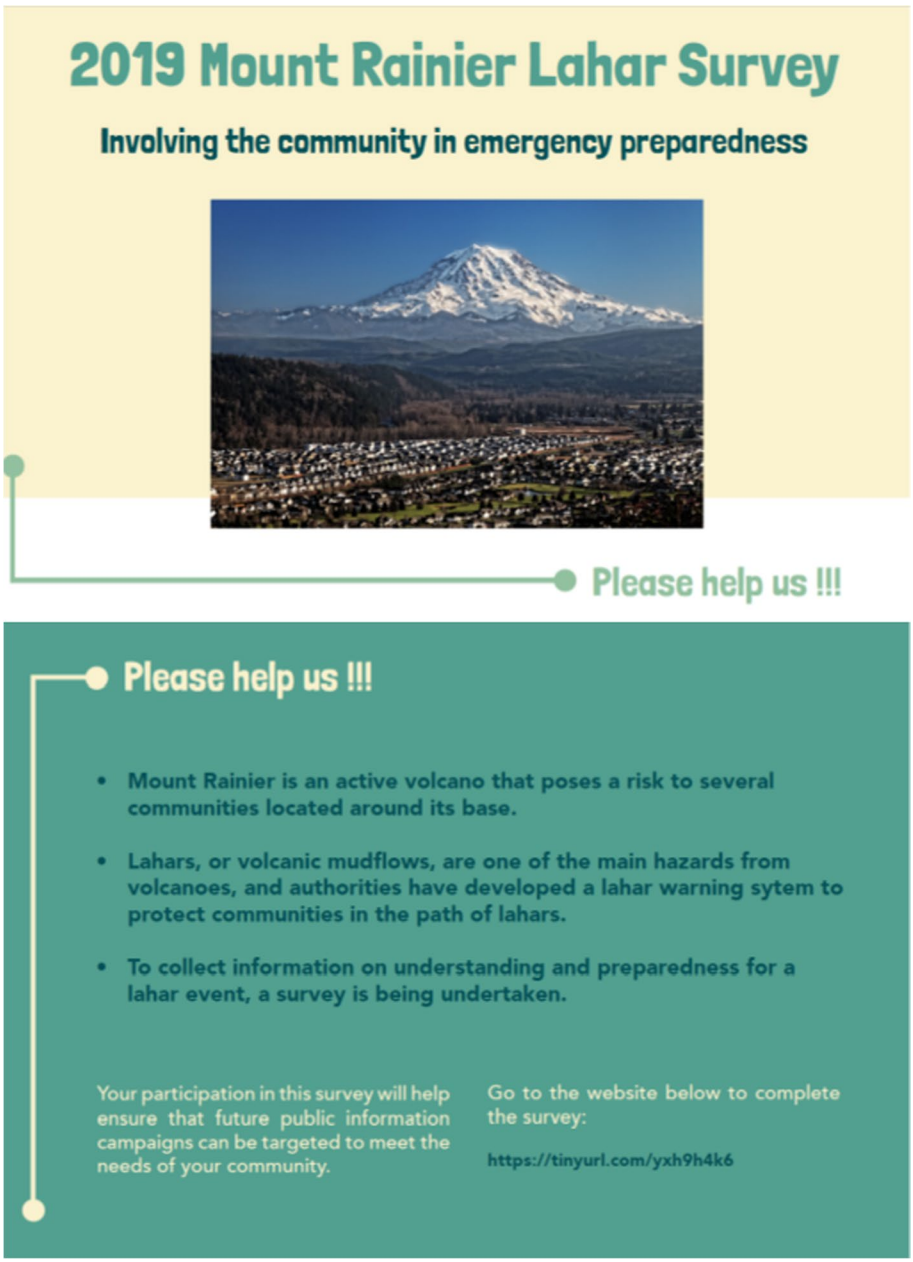

Fig. 4 Survey recruitment postcards. Image of Mount Rainier: Credit: U.S. Geological Survey. Department of the Interior/USGS. U.S. Geological Survey

Results and discussion

The introduction highlighted a number of factors that have previously been identified as influencing preparedness actions and intentions to prepare including: collective and self-efficacy, outcome expectancy, planning, community participation, empowerment, sense of community, place attachment, and demographics such as gender (Bateman & Edwards, 2002, Becker et al., 2015; Norris et al. 2008; Solberg et al., 2010; Wei & Lindell, 2017). Through this survey we aimed to explore the influence of demographic differences (RQ1), social effects (RQ2), evacuation drills (RQ3), and cognitive factors (RQ4). We present the findings and the possible explanations and implications of these findings with consideration of the wider literature for each of the research questions in turn.

Table 1 Study and population demographics

	Orting	Puyallup	Pierce County	Study sample[a]
Female	52.4	50.8	50.1	65.1
Age	35.2	40.2	36.1	45.0
White	80.4	77.7	65.7	87.9
Black	1.5	2.7	7.7	0.7
American Indian	1.9	0.8	1.8	1.9
Hispanic or Latino	8.4	7.7	11.4	3.7
Asian	0.9	5.3	7.1	1.3
Owner-occupied housing rate	76.9	52.3	62.1	79.2
College degree	18.1	27.5	27.2	76.9

Note. Demographic data for Orting, Puyallup, and Pierce County sourced from the United States Census Bureau. All values except for age are percentages

[a] In our study, we asked participants "Which of the following best reflects your ethnicity?" We appreciate that this question conflates race and ethnicity. As we had hoped to run quasi-longitudinal analyses, we chose to keep the wording from Davis et al. (2006) but are working to ensure less problematic phrasing in future research

Table 2 Means, standard deviations, and test statistics for demographic differences in intentions to prepare and perceived preparedness

		Intentions			Preparedness		
		M	*SD*	Means comparison	*M*	*SD*	Means comparison
Sex	Male	2.42	1.09	$t(531) = 5.22, p < .001, d = 0.45$	3.04	1.22	$t(530) = 3.34, p < .001, d = 0.29$
	Female	2.76	1.16		2.48	1.14	
Zone	Live	2.31	1.20	$F(3, 429) = 2.04, p = .11$	2.54	1.10	$F(3, 429) = 8.67, p < .001, \eta p^2 = .06$
	Work	2.73	1.10		2.79	1.15	
	Both	2.58	1.16		2.57	1.12	
	Neither	2.57	1.14		3.16	1.19	
Evacuation	Need help	3.19	1.24	$t(511) = 3.44, p < .001, d = 0.30$	2.20	1.25	$t(490) = 3.57, p < .001, d = 0.32$
	Don't need help	2.53	1.12		2.82	1.17	

Note. Cohen's *d* effect sizes can be interpreted as 0.15 = small, 0.36 = medium, and 0.65 = large (Lovakov & Agadullina, 2021)

Partial eta square (ηp^2) effect sizes can be interpreted as .01 = small, .06 = medium, and .14 = large

Table 3 Means, standard deviations, and test statistics for demographic differences in risk perception

		Likelihood			Threat		
		M	*SD*	Means comparison	*M*	*SD*	Means comparison
Sex	Male	2.86	0.85	$t(525) = 0.76, p = .45$	3.49	1.11	$t(535) = 2.06, p < .05, d = 1.14$
	Female	2.91	0.88		3.71	1.16	
Zone	Live	2.75	0.82	$F(3, 452) = 1.43, p = .23$	4.38	1.02	$F(3, 450) = 63.09, p < .001, \eta p^2 = 0.30$
	Work	2.9	0.84		3.28	0.91	
	Both	2.93	0.95		4.28	0.97	
	Neither	2.96	0.87		3.00	0.96	
Evacuation	Need help	3.33	0.86	$t(522) = 4.07, p < .001, d = 0.86$	4.10	1.10	$t(511) = 3.44, p = .001, d = 1.16$
	Don't need help	2.83	0.86		3.53	1.16	

RQ1: demographic differences in intentions and behaviour

Tables 2, 3, and 4 and Fig. 5 present descriptive and inferential statistics for the components of RQ1 exploring demographic differences considering sex, location in hazard zone, and need for help when evacuating. Tables 2 and 3 present mean comparisons for intentions to prepare, perceived personal preparedness, and risk perception. Table 4 presents the number of participants who

Table 4 *Ratio of participants who have prepared an evacuation kit and participated in evacuation drills split by demographic factors*

		Prepared a kit			Evacuation drill (last year)		
		Yes	No	Ratio comparisons	Yes	No	Ratio comparisons
Sex	Male	86	143	$X^2(1) = 2.07, p = .15$	16	168	$X^2(1) = 1.98, p = .37$
	Female	98	212		33	322	
Zone	Live	43	74	$X^2(3) = 10.20, p < .05, V = .15$	14	104	$X^2(3) = 3.30, p = .35$
	Work	34	37		8	63	
	Both	47	57		18	85	
	Neither	107	87		20	173	
Evacuation	Need help	24	38	$X^2(1) = 0.60, p = .44$	5	57	$X^2(1) = 8.35, p < .05, V = .12$
	Don't need help	211	270		56	425	

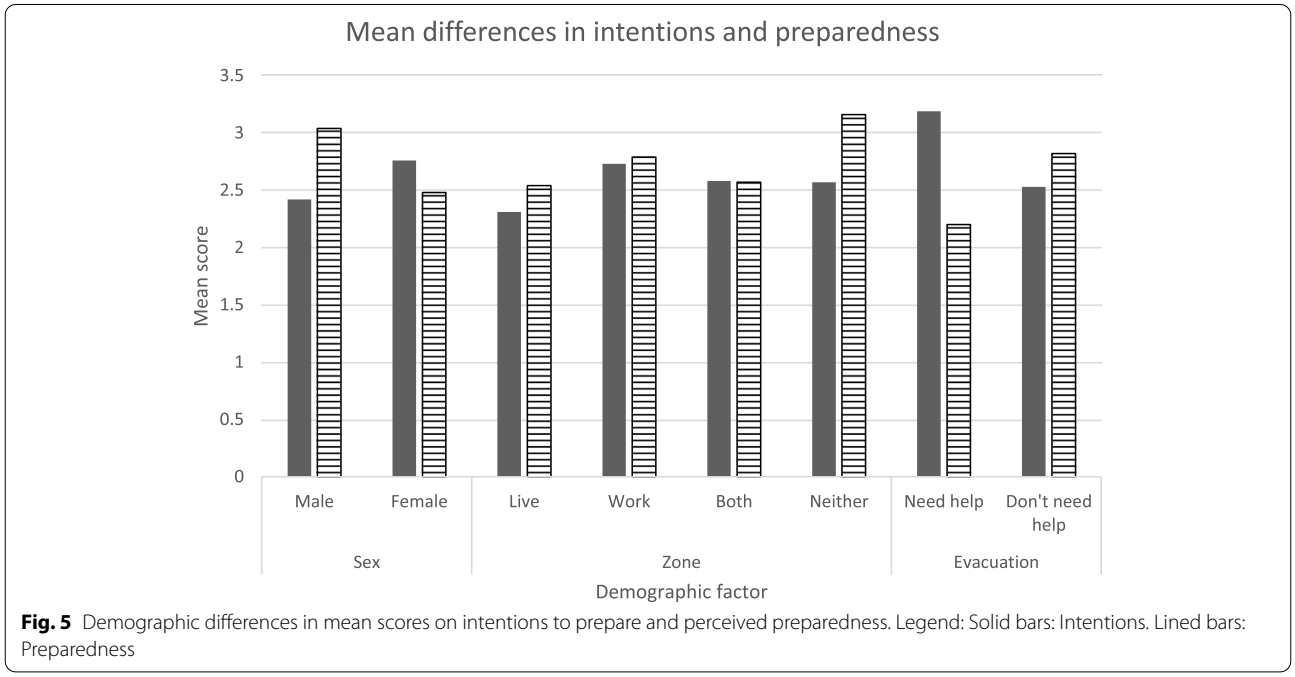

Fig. 5 Demographic differences in mean scores on intentions to prepare and perceived preparedness. Legend: Solid bars: Intentions. Lined bars: Preparedness

have prepared a "disaster supply kit to take when a lahar warning is issued".

Sex differences

Women showed significantly higher intentions to prepare than men but *lower* perceived preparedness, consistent with previous literature demonstrating gender differences. A similar proportion of men and women had prepared an emergency kit, suggesting that women need to take more actions before they feel prepared compared to men, consistent with past findings that women experience more anxiety, particularly trait-based (Mehta & Simpson-Housley, 1994), and perceive greater risk and negative impacts from natural hazards than do men (Doyle et al., 2020b; Finucane et al., 2000; Spittal et al., 2005; Vinnell, McClure, & Milfont, 2017). Other possible explanations for these findings include socially constructed gender differences in care giving roles influencing risk perception and action (Bateman & Edwards, 2002) and differences in implementation barriers or in perceptions of the hazard- or resource-related attributes of the available protective actions. The presence of lower risk perceptions amongst men for threat from lahars, but not likelihood of occurrence, aligns with the "white male effect" where a privileged demographic position and fewer negative life experiences result in lower levels of perceived risk and more positive outcome expectancies (Finucane, Slovic, Mertz, Flynn, & Satterfield, 2000; Olofsson & Rashid, 2011; Palmer 2003). This effect overlaps with various theories which suggest that socially

dominant groups tend to downplay risks that could jeopardize their position in society, such as a large-scale disaster (Feygina, Jost, & Goldsmith, 2010).

Location

The participants who felt the most prepared were those who neither live nor work in a lahar zone, which differs from the findings of Wei and Lindell (2017) where proximity to the lahar zone did not relate to household's general preparedness, although crater proximity was significantly related to evacuation preparedness. It is possible that living in a lahar zone heightens risk perceptions and feelings of vulnerability which means that the amount of action required to feel prepared is commensurately higher compared to those who do not live in a hazard zone. Consistent with this, those who live or live and work in a hazard zone saw the threat of lahars as higher than those who only work or neither live nor work in a hazard zone. It is also possible that some participants made conscious decisions not to live or work in a hazard zone and view this decision as a mitigation action; reducing exposure in this way is a key measure to reduce risk when the situation allows such a choice.

The majority of people who do not live or work in a hazard zone have prepared a kit, while the majority of people who live and/or work in a hazard zone *have not* prepared a kit, suggesting that there is an objective difference in preparedness; this could be due to fatalism among those who live or work in a hazard zone. Consistent with this suggestion, there was no difference in the proportion of people who had practised evacuation drills based on location in lahar hazard zones, although the small number of people who had participated in drills limits the power of this analysis.

Past research around earthquakes has demonstrated that informing people they live in a high hazard zone can induce fatalism (i.e., the belief that earthquakes are too destructive to prepare for; Crozier, McClure, Vercoe, & Wilson, 2006) although living in an area more exposed to climate change-related natural hazards does not affect concern unless those individuals also have personal experience (Lujala, Lein, & Rød, 2014). In contrast to our findings, research in the field of climate change consistently demonstrates that greater temporal, social, spatial, and psychological distance from impacts is linked to lower risk perception (Spence, Poortinga, & Pidgeon, 2011; Wang et al., 2019).

Vulnerability

Several, potentially conflicting, differences emerged between participants who will need help to evacuate and those who will not. First, those who will need help talked about lahars more but thought about them the same amount as those who will not need help. These findings might reflect a bias towards problem-focused coping; thinking about lahars would not necessarily help preparedness but talking about lahars might be one method by which people who will need help organise that help. This strategy of targeting preparation behaviour towards known problems has been demonstrated in relation to earthquake experience whereby people chose preparation actions which targeted the problems they had experienced during recent shaking (Doyle et al., 2018).

Secondly, those who will need help to evacuate had higher risk perception and saw themselves as less prepared and had higher intentions to prepare than those who will not need help. Previous research has demonstrated that people with physical disabilities do not perceive themselves as more vulnerable and do not prepare more (Rahimi & Azevedo, 1993). These findings might suggest that participants who will need help recognize personal vulnerability. However, those who need help are less likely to have practised an evacuation drill. Again, the small absolute numbers of both drill participation and those who will need help limits the power of the analysis. It is clearly important, though, to consider how different groups, with unique strengths and challenges, view both their own and their community's vulnerability and to ensure that evacuation drills consider different needs of participants.

RQ2: social effects on preparation

Social factors

Although the overall regression was significant, $F(4, 549) = 2.52$, $p < .05$, none of the factors of talking about lahars, perception of community preparedness, or attachment to community were significantly associated with intentions to prepare. The overall regression testing whether the social factors explained variance in perceptions of personal preparedness was also significant, $F(4, 549) = 17.88$, $p < .001$, $R^2 = .12$. Those who saw their community as more prepared ($\beta = .24$, $p < .001$) and those who were more attached to their community reported higher personal preparation ($\beta = .16$, $p < .01$). This difference in perceived preparedness could explain why intentions are lower among those who believe that their community does have a lahar warning system, as these participants perceive a higher level of existing preparedness and therefore, potentially, less need to prepare further. The overall regression for having an evacuation kit was non-significant.

Knowledge of warning system

Approximately half of participants (50.4%) answered "Yes" to the question "Does your community have a lahar warning system". Similar numbers answered "No" (22.6%)

Table 5 Mean differences in intentions to prepare and perceived preparedness varying by belief in existence of local warning systems

		Intentions		
		M	***SD***	**Means comparison**
Warning system	Yes	2.47	1.16	$F(2, 582) = 9.75$, $p < .001$, $\eta p^2 = .03$
	No	2.58	1.12	
	Don't know	2.97	1.08	
		Preparedness		
		M	***SD***	**Means comparison**
Warning system	Yes	3.04	1.22	$F(2, 584) = 7.48$, $p < .001$, $\eta p^2 = .03$
	No	2.48	1.14	
	Don't know	2.66	1.18	

and "Don't know" (27.1%).[2] Table 5 reports intentions to prepare for lahars and perceived personal preparedness split by whether participants believed their community has a warning system. There was no difference in the likelihood of having prepared a kit depending on belief in existence of local warning systems.

Participants who reported that they did not know if the community has a warning system had stronger intentions to prepare than those who reported that they knew there was one or did not know either way. Consistent with this finding, those who believe that their community does have a warning system felt more prepared themselves. This could reflect a number of influences. Firstly, this perception is "real" in that the fact of having a warning system will likely lead to better outcomes in an event, so that these participants are at a base level, all else being equal, objectively more prepared than those without a system. Secondly, participants might view preparedness as the responsibility of authorities and therefore base their feelings of personal preparedness on the actions undertaken by officials, such as installing a warning system. This latter possibility is supported by the finding that those who saw their community as more prepared and those who saw officials as more prepared reported higher personal preparation. This conflicts with some previous research (Becker et al., 2015; Flynn et al., 1999; Paton, Smith & Johnston, 2000) suggesting that people who view preparedness as the responsibility of authorities should be less prepared and other research (Arlikatti, Lindell & Prater, 2007; Lindell & Whitney, 2000) that reports no correlation between perceptions of authorities' protection responsibility and personal preparedness. As preparedness was self-defined it is not possible to conclude that the individuals in this study include both official and community preparedness as part of their self-evaluations of their feelings of personal preparedness but the findings suggest that this is happening at least to some extent. Finally, it is possible that these participants were influenced by social norms where the knowledge that others around them are prepared motivated them to prepare themselves (McIvor & Paton, 2007).

Community attachment (how much participants feel they belong in their community, believe their neighbours would help them in an emergency, and plan to say in their community) was positively associated with personal preparedness, consistent with the findings of Wei and Lindell (2017) in their investigation of lahar preparedness in the area of Mount Rainier; however, talking about lahars was only significantly related with preparing a kit and this effect was weak. Further, intentions to prepare, perceived personal preparedness, and likelihood of having prepared a kit did not differ between those participants who do not know if their child's school has an evacuation plan, know that they do, or know that they do not. Finally, participants' intentions to prepare did not correlate with their perceptions of the preparedness of local officials, although those who saw their local officials as more prepared also saw themselves as more prepared ($r = .21$, $p < .001$).

RQ3: effects of participation in evacuation drills

Table 6 and Fig. 6 present differences in intended mode of evacuation (foot, car, or bicycle) between those who have and those who have not participated in evacuation drill. Tables 7 and 8 present mean comparisons for variables of interest (intentions to prepare, perceived preparedness, self-efficacy, and risk perception) as well as kit preparation grouping participants based on whether they have tested evacuation routes and participated in drills (Fig. 7).

Those who had participated in an evacuation drill were more likely to intend to evacuate by foot and less likely to evacuate by car than those who had not participated in

[2] NB: We did not check whether participants were correct in their knowledge relating to their community having or not having a warning system

Table 6 Chi-square test results for participants' intended method for evacuation varying by participation in evacuation drills

	Participated		Not participated			
	Yes	No	Yes	No	χ^2	*V*
By car: drill in last year	78%	22%	59%	41%	12.49***	.14
By car: drill in last five years	79%	21%	66%	34%	9.49**	.12
By foot: drill in last year	47%	53%	29%	71%	6.57*	.10
By foot: drill in last five years	41%	59%	28%	72%	7.32**	.11
By bicycle: drill in last year	20%	80%	6%	94%	17.70***	.17
By bicycle: drill in last five years	8%	92%	7%	93%	.21 *ns*	N/A

Note. * = $p < .05$, ** = $p < .01$, *** = $p < .001$. Cramer's *V* effect sizes can be interpreted as .10 = small, .30 = medium, and .50 = large

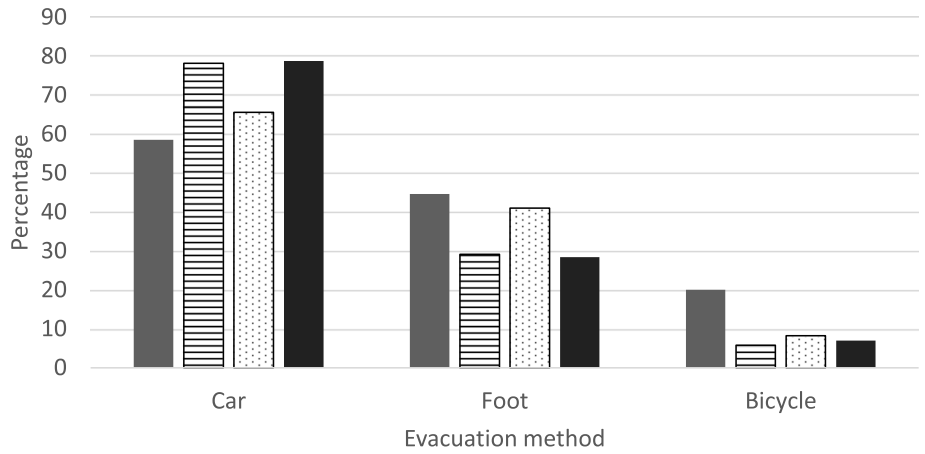

Fig. 6 Participants' intended method for evacuation, varying by participation in evacuation drills. Participants could intend to use multiple evacuation methods, hence the percentage totals above 100%. Legend: Grey bars: Last year: Have participated. Lined bars: Last year: Have not participated. Dotted bars: Last 5 years: Have participated. Black bars: Last 5 years: Have not participated

a drill. Intended car use was lower, and intended bicycle use higher, among those who had participated in a drill in the last year compared to the past 5 years; it is possible that this reflects the general increase in bicycle use in the US and availability of cycle paths in Pierce County specifically, such as the Foothills Rail Trail. Bicycle use in the US has increased slightly since 2006, up from approximately 40 million to nearly 48 million in 2018 (Statista, n.d.). Future work should test impacts of changes in messaging or frequency of drills and access to cycleways.

It is also important to note that evacuation drills were carried out in the area shortly before data collection so effects of participation may be stronger than if there had been a longer period of time between the last drill and data collection. Future work should examine for how long benefits of drills persist. While our data does not allow us to conclusively identify mechanisms for the differences we identified, previous evidence supports the effectiveness of active rather than passive education such as evacuation drills (Doyle et al., 2020a; Johnston et al., 2016) and earthquake drills (Vinnell et al., 2020). These types of community interventions are likely more effective as they require two-way engagement; that is, they involve active participation from the "recipient" beyond simply attending to and remembering information.

Contrary to expectations, unrealistic optimism did not differ based on either drill participation or type of evacuation route tested, suggesting that this common bias in hazard preparation is not a key concern in these communities. Those who participated in drills either in the last year or last 5 years saw themselves as more prepared, scored higher on self-efficacy, and were more likely than not to have prepared an evacuation kit. While risk perception largely did not differ based on drill participation, those who had practised both an official and unofficial route saw the threat of lahars as higher than those who had practised either or neither. People who had tested neither felt less prepared, while a majority of people had prepared a kit only among the groups who had tested an unofficial route.

Table 7 Differences in variables of interest depending on type of evacuation route tested

	Intentions		
Evacuation route tested	***M***	***SD***	**Means comparison**
Official	2.49	1.14	$F(3, 579) = 2.40, p = .067, \eta p^2 = .01$
Unofficial	2.68	1.06	
Both	2.58	1.19	
Neither	2.72	1.15	
	Preparedness		
	M	***SD***	**Means comparison**
Official	2.96	1.17	$F(3, 581) = 24.46, p < .001, \eta p^2 = .11$
Unofficial	3.08	1.07	
Both	3.15	1.13	
Neither	2.27	1.11	
	Self-efficacy		
	M	***SD***	**Means comparison**
Official	3.51	1.20	$F(3, 452) = 15.85, p < .001, \eta p^2 = .10$
Unofficial	4.08	.92	
Both	3.68	1.17	
Neither	2.94	1.36	
	Threat		
	M	***SD***	**Means comparison**
Official	3.70	1.14	$F(3, 507) = 7.99, p < .001, \eta p^2 = .05$
Unofficial	3.53	1.13	
Both	4.02	0.99	
Neither	3.38	1.21	
	Likelihood		
	M	***SD***	**Means comparison**
Official	2.71	0.84	$F(3, 519) = 2.90, p < .05, \eta p^2 = .02$
Unofficial	2.88	0.77	
Both	3.06	0.80	
Neither	2.90	0.93	
	Evacuation kit		
	Yes	**No**	**Ratio comparison**
Official	44	69	$X^2(3) = 31.86, p < .001, V = .24$
Unofficial	33	28	
Both	67	37	
Neither	88	171	

Self-efficacy was also higher among those who had tested an evacuation route than those who had not. This is consistent with previous evidence that participating in drills relates to key cognitive factors relating to preparedness and resilience (Becker et al., 2017b; Vinnell, 2020; Vinnell et al., 2020), as well as community bondedness, past information search, and crater proximity (Wei & Lindell, 2017). The cross-sectional nature of this study means we cannot conclude if people practice evacuation due to having higher self-efficacy or if the behaviour of practicing increases self-efficacy, so this should be the subject of future research. Conceptualizations of self-efficacy such as Bandura's (1989) reciprocal determinism suggests that causality likely works in both directions. Self-efficacy was slightly higher among those who had tested an unofficial route than those who had used an official route; this is logical given that identifying a route requires initiative and more independent action. It is possible that these participants are more self-motivated rather than externally motivated (i.e., requiring official guidance for evacuation routes). Evidence in this study for meaningful differences between these groups is conflicted. On the one hand, the only demographic differences between these groups were age and length of time in the state, community, and current residence, suggesting that this effect might be a result of having had more opportunity to explore their area and identify a route more suitable for their personal location and requirements as official routes are not tailored to individuals. On the other hand, the majority of participants who had tested an unofficial route had prepared a kit while the majority of participants who had tested only an official route, or neither, had *not* prepared a kit, suggesting that there is a difference in self-motivated preparedness.

RQ4: cognitive predictors of behaviour

Correlations between the explanatory variables (likelihood risk perception, threat risk perception, self-efficacy, and unrealistic optimism) and the outcome variables (intentions to prepare, perceived personal preparedness, and having prepared an emergency kit) are presented in Table 9. Table 10 presents the results of regression models.

Perception of risk was significantly associated with intentions to prepare, but only in regard to perceptions of the likelihood of lahars occurring, with those who saw lahars as more likely demonstrating stronger intentions to prepare; perceptions of the threat posed by lahars were not related to intentions. Those who saw a lahar as more likely were also more likely to have prepared a kit, suggesting that this facet of risk perception is important to consider and that there are benefits to considering perceptions of probability and outcomes separately.

Unexpectedly, neither unrealistic optimism nor self-efficacy were associated with intentions to prepare. However, self-efficacy was significantly and positively associated with both perceived preparedness and having prepared a kit, consistent with suggestions that self-efficacy has a direct effect on behaviour (instead of or as well as an indirect effect via intentions) proposed by behavioural models such as the Theory of Planned Behaviour (Ajzen, 1991).

Table 8 Differences in variables of interest depending on past drill participation

		Intentions		
	Drill participation	***M***	***SD***	**Means comparison**
Last year	Yes	2.65	1.33	$t(491) = 0.37, p = .71$
	No	2.59	1.13	
Last 5 years	Yes	2.73	1.27	$t(138.78) = 1.20, p = .23$
	No	2.56	1.12	
		Preparedness		
		M	***SD***	**Means comparison**
Last year	Yes	3.15	1.35	$t(490) = 2.59, p = .01, d = 1.18$
	No	2.70	1.16	
Last 5 years	Yes	3.03	1.17	$t(490) = 2.62, p < .01, d = 1.18$
	No	2.68	1.18	
		Self-efficacy		
		M	***SD***	**Means comparison**
Last year	Yes	3.89	1.11	$t(58.81) = 2.57, p < .05, d = 1.27$
	No	3.42	1.28	
Last 5 years	Yes	3.92	1.10	$t(133.39) = 3.85, p < .001, d = 1.26$
	No	3.37	1.14	
		Threat		
		M	***SD***	**Means comparison**
Last year	Yes	3.84	1.20	$t(511) = 1.71, p = .09$
	No	3.56	1.16	
Last 5 years	Yes	3.79	1.14	$t(510) = 1.99, p < .05, d = 1.17$
	No	3.54	1.17	
		Likelihood		
		M	***SD***	**Means comparison**
Last year	Yes	2.72	1.08	$t(66.09) = 1.23, p = .22$
	No	2.90	0.85	
Last 5 years	Yes	2.90	0.99	$t(141.18) = 0.26, p = .81$
	No	2.88	0.85	
		Evacuation kit		
		Yes	**No**	**Ratio comparison**
Last year	Yes	42	26	$X^2(1) = 12.21, p < .001, V = .14$
	No	237	360	
Last 5 years	Yes	70	54	$X^2(1) = 12.92, p < .001, V = .14$
	No	209	330	

General discussion

Implications

A significant implication of this research is the value of evacuation drills; anecdotal evidence demonstrates the importance of the public knowing how to respond to early warning systems for reducing injuries and fatalities from lahars (Worni et al., 2011). The evidence from this research suggests that drills should include messaging to encourage evacuation on foot or by bicycle and should be more frequent than every 5 years. Further work could explore if yearly drills are appropriate in terms of how often knowledge should be revisited without risking boredom or complacency and the potential for broader, community evacuation drills beyond the current focus on conducting these in schools. In line with this focus on drills, residents of lahar hazard zones could be encouraged and supported to practice evacuation routes on their own, as well as to identify additional unofficial evacuation routes that will reduce the demand on official evacuation routes during an emergency (Lindell, Murray-Tuite, Wolshon, & Baker, 2019b). Again, this requires a balance between allowing individuals to create evacuation routes which best suit their location and needs while ensuring they

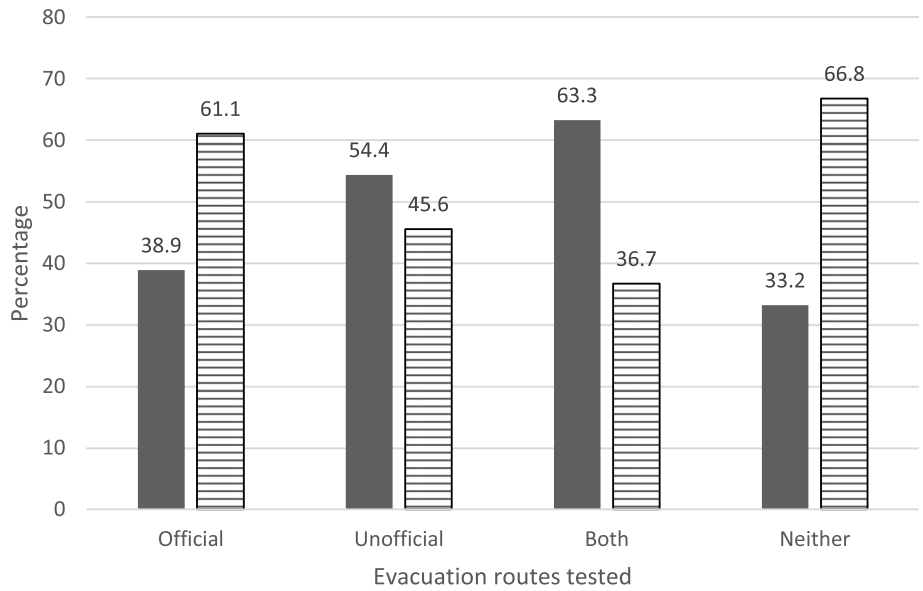

Fig. 7 Proportion of participants who have prepared an emergency kit, split by whether they had tested evacuation routes. Legend: Filled bars: Have kit. Lined bars: Don't have kit

Table 9 Correlation matrix of regression variables

	1	2	3	4	5	6	7
1. Risk perception (likelihood)	–	.21***	0.04	−.18***	.21***	.08	.12**
2. Risk perception (threat)		–	−.15**	−.41***	.12**	−.05	.00
3. Self-efficacy			–	.13**	−.07	.63***	.34***
4. Unrealistic optimism				–	−.10*	.03	.01
5. Intentions to prepare					–	−.02	.09*
6. Perceived personal preparedness						–	.54***
7. Emergency kit							–

Note. Point biserial correlations are reported for "emergency kit". * = $p < .05$, ** = $p < .01$, and *** = $p < .001$

are making educated decisions which will not put themselves or others in additional danger.

Relationships between feelings of personal preparedness and perceptions of community and official preparedness present mixed implications for public engagement. The results suggest that communicating increases or high levels of community and official preparedness might increase feelings of personal preparedness, which could help manage feelings of vulnerability and anxiety and ensure these perceptions motivate rather than demotivate (Becker et al., 2017b; Paton, Smith, & Johnston, 2005). However, the lack of association between perceptions of community and official preparedness and individuals' preparation intentions (in this study) and actual preparedness (in Wei & Lindell, 2017) suggest that such communication efforts might not be helpful for increasing actual individual preparation.

Previous studies have demonstrated the importance of individuals trusting official sources (Dhellemmes et al., 2021) and having good relationships with formal agencies (Paton et al., 2008). People who do not trust those communicating risk information (including scientists) and recommending or ordering evacuations (including emergency management and police) are less likely to prepare and evacuate. Trust is an important but complex concept; given we did not study this directly, the implications we can draw from our data are limited. However, our findings support suggestions from previous research around volcanic hazard risk that effective preparedness and mitigation requires complementary efforts between communities and groups tasked with improving outcomes after hazard events (Paton et al., 2008). It is important for scientists and those communicating science in particular to remember that people's perception of their

Table 10 Regression results for intentions to prepare, personal preparedness, and having prepared an evacuation kit

	Intentions to prepare			
Variables	**B**	**SE**	***β***	***p***
Risk perception (likelihood)	.261	.068	.196	.000
Risk perception (threat)	.016	.058	.016	.781
Self-efficacy	−.064	.047	−.077	.174
Unrealistic optimism	.011	.070	.009	.869
Model result	$F(4, 384) = 4.35, p < .01, R^2 = .04$			
	Personal preparedness			
	B	**SE**	***β***	***p***
Risk perception (likelihood)	.077	.060	.054	.196
Risk perception (threat)	.003	.050	.003	.953
Self-efficacy	.588	.041	.602	.000
Unrealistic optimism	−.080	.061	−.060	.191
Model results	$F(4, 384) = 53.41, p < .01, R^2 = .36$			
	Prepared a kit			
	B	**SE**	**Exp(B)**	***p***
Risk perception (likelihood)	.291	.129	1.338	.024
Risk perception (threat)	−.011	.108	0.989	.922
Self-efficacy	.540	.095	1.756	.000
Unrealistic optimism	.070	.129	1.073	.584
Model Result	$\chi^2(4) = 43.45, p < .001, R^2 = .14$[a]			

[a] This is a the Nagelkerke "pseudo R^2" statistic. Values range from 0 to 1 similar to an ordinary least squares R^2, but cannot be interpreted in exactly the same way.

risk can differ from their objective risk; risk perception is a complex process which takes into account factors such as personal experience which is not considered in determining objective risk (Paton et al., 2000). It is therefore likely not sufficient to only communicate objective indicators of risk, such as return periods, but instead practitioners should seek to understand how people in their area perceive that risk, taking into account specific local factors such as recent experiences.

From our study in particular, we can make several recommendations for those working to reduce lahar impacts, including scientists and emergency managers. The overarching implication of this study is that any public education or communication efforts should start with a scoping of reasons for preparation and evacuation intentions rather than building on assumptions around, for example, how people accurately perceive risk. Our data shows a clear distinction between the influence of the likelihood component of risk and the outcome component of risk, with only the former associating with intentions to prepare and having prepared a getaway kit. Those working to increase preparedness in Mount Rainier communities, therefore, might be better to focus on communicating how likely it is that a lahar could occur rather than focusing on potential impacts. It is possible that this direction of differences (i.e., likelihood over outcome) will differ in other locations and for other hazards, but this study demonstrates the importance of considering how people see both aspects of risk to ensure communications are designed to be as effective as possible.

A further recommendation which can be made from our findings is to ensure that communication and education is not solely aimed and targeted at the individual and individual factors. For example, findings that community attachment related to preparedness supports previous research showing the importance of cohesion within communities to increase hazard mitigation (Paton et al., 2008; Wei & Lindell, 2017). Emergency managers could instigate, continue, or increase initiatives aimed at encouraging preparedness or evacuation which take a community approach. Such initiatives include inviting the wider community to participate in school evacuation drills.

Limitations and future considerations

Participants to an extent self-defined preparedness, specifics of societal gender roles such as care-giving responsibilities were not measured, and minority ethnicities were not well-represented in this study. Further limitations with survey methods generally, particularly social desirability bias or researcher expectancy effects on responding might have occurred; we have no reason to expect that our participants would be particularly motivated to answer in line with either their perceptions of what their peers would answer or of what the researcher expects them to answer.

We did not collect precise location data for participants; differences in proximity to the volcano or lahar paths even within identified hazard zones might lead to different evacuation requirements in terms of how much time is available to take actions and make decisions. Further, we did not provide participants with a definition of an "official" evacuation route, in comparison to an unofficial route, so it is possible that they self-defined, and therefore reported on, these options in different ways. However, we do not feel that this would have a meaningful impact on the pattern of findings.

Similarly, we did not provide a detailed explanation of what should constitute an evacuation kit; future work could provide more information about what is considered an appropriate evacuation kit. However, what should be in a kit will vary somewhat depending on individual/family situations, so there are also benefits to not taking a strict approach to defining this action. For example, relating to the previous comment on precise location, what people will include in an evacuation kit likely depends on how long they would have to evacuate. For those closer to the volcano, they

will have to evacuate more quickly so might be able to take less with them than those further away who have more time. Further, having a kit is only one component of evacuation preparedness. Indeed, given the extent of efforts in the area including planning evacuation routes, running drills, and developing siren systems, some residents may not feel a need to prepare a kit. Although these efforts will reduce injuries and deaths by facilitating evacuation, people will still need supplies with them once they are out of harm's way.

This research presents one way to understand residents' awareness of and preparedness for lahar hazards around Mount Rainier. Our survey likely does not capture the complexity of the communities' experiences, including the important role of monitoring scientists and science communicators at the local and federal level. Where possible, future work should consider the situation more broadly, including current science and science communication efforts, as this will provide more nuanced information to improve public education efforts.

The main limitation of this study, which is inherent in many study designs, is the inability to definitively infer causal relationships from many of the correlations. For example, it is unclear whether the finding that those who have tested unofficial evacuation routes also scored higher on self-efficacy measures represents behaviour affecting belief, belief affecting behaviour, or the effect of a third variable that caused both the belief and the behaviour (Lindell, 2008). Cross-sectional designs are efficient in that they provide information about a sample for relatively little resource compared to other methods which allow for greater confidence in causal inference, such as longitudinal designs. This limitation does not necessarily undermine the usefulness of the current study but future research which aims to explore any of the findings in more depth ought to consider whether other, more intensive, methods are appropriate.

Thus, future research could focus on a number of core questions to further understand the influences on preparedness when living within or alongside hazard zones. These include conducting longitudinal surveys that are able to assess the direction of the causal links between, for example, practicing evacuation and self-efficacy. Further, inclusion of measures for affective responses which have not been thoroughly explored such as anxiety would increase our understanding of vulnerability and its role in preparedness, as well as to explore how it relates to gender, risk perception, and preparedness. Finally, including an assessment of care-responsibilities will extend our understanding of gender roles and disaster preparedness.

Conclusion

Lahars represent a significant volcanic hazard, particularly at snow-capped volcanoes where eruption-induced snow melting can cause significant loss of life, such as that seen at Nevado Del Ruiz in 1985 which led to over 23,000 fatalities and the destruction of Armero town in Colombia (Driedger et al., 2020). Such tragedies demonstrate not only the importance of effective monitoring and warning systems, but also the vital role that public education and training plays in preparedness and lahar evacuation route awareness. Through this survey at Mount Rainier, Washington, we have explored the role of demographics, social effects such as perceptions of community preparedness, evacuation drills, and cognitive factors such as risk perception and self-efficacy, on preparedness when living within, or alongside, a volcanic hazard zone. A key recommendation as part of school and community education is to continue and extend the critical practice of regular evacuation drills. This suggestion is consistent with evidence for the usefulness of active rather than passive education strategies such as drills to both teach and encourage preparedness and appropriate actions during a natural hazard event (Vinnell et al., 2020). Ongoing messaging should focus on the appropriate evacuation mode to ensure appropriate evacuation behaviours. Future work could also explore who should do this messaging and what it should contain. These recommendations likely apply to other hazard situations, such as warnings for tsunami (Buylova et al., 2020) and riverine floods (Lindell et al., 2019a), and we suggest future research to explore their applicability in these other hazard contexts.

Acknowledgements

We would like to thank those involved with sharing the survey as well as our participants.

Authors' contributions

Author LV designed and conducted the analyses and drafted the manuscript. Author EEHD assisted with the analyses and drafting the manuscript. Authors JB and DJ contributed to the study design, data collection, and drafting the manuscript. Authors LK, ML, AB, CG, MD, and BT contributed to the study design, data collection, and reviewing the manuscript.

Authors' information

N/A.

Funding

This project was supported by Washington State Emergency Management Division, Massey University and the National Science Challenges: Resilience to Nature's Challenges Kia manawaroa – Ngā Ākina o Te Ao Tūroa.

Availability of data and materials

The data and survey are available from the Open Science Framework here: https://osf.io/ckuvp/

Declarations

Competing interests

Author David Johnston is on the editorial board of the journal. The authors have no other competing interests to declare.

Author details
[1]Joint Centre for Disaster Research, Massey University, Wellington, New Zealand. [2]University of Washington, Seattle, WA, USA. [3]East Tennessee State University, Johnson, TN, USA. [4]Washington State Emergency Management Division, Camp Murray, WA, USA.

Received: 14 January 2021 Accepted: 2 October 2021
Published online: 09 December 2021

References

Ajzen I (1991) The Theory of Planned Behavior. Organ Behav Hum 50:179–211. https://doi.org/10.1016/0749-5978(91)90020-T
Allstadt KE, Farin M, Lockhart AB, McBride SK, Kean JW, Iverson RM, Logan M, Smith JB, Tsai VC, George DL (2019) Overcoming barriers to progress in seismic monitoring and characterization of debris flows and lahars. Proceedings of the 7th International Conference on Debris-Flow Hazards Mitigation, Golden, United States. 10–13 June 2019; p. 77–84
Arlikatti S, Lindell MK, Prater CS (2007) Perceived stakeholder role relationships and adoption of seismic hazard adjustments. Int J Mass Emerg Disasters 25:218–256
Baker E (1991) Hurricane evacuation behavior. Int J Mass Emerg Disasters 9(2):287–310
Bandura A (1989) Social cognitive theory. In: Vasta R (ed) Annals of child development. Vol. 6. Six theories of child development (pp. 1–60). JAI Press
Bateman JM, Edwards B (2002) Gender and evacuation: a closer look at why women are more likely to evacuate for hurricanes. Natural Hazards Review 3:107–117. https://doi.org/10.1061/(ASCE)1527-6988(2002)3:3(107)
Becker J, Paton D, Johnston D, Ronan K (2012) A model of household preparedness for earthquakes: how individuals make meaning of earthquake information and how this influences preparedness. Nat Hazards 64:107–137. https://doi.org/10.1007/s11069-012-0238-x
Becker J, Paton D, Johnston D, Ronan K (2014) Societal influences on earthquake information meaning-making and household preparedness. Int J Mass Emerg Disasters 32(2):317–352
Becker JS, Leonard GS, Potter SH, Coomer MA, Paton D, Wright KC, Johnston DM (2017a) Organisational response to the 2007 Ruapehu crater Lake dam-break lahar in New Zealand: use of communication in creating an effective response, In observing the volcano world (pp. 253–269). Springer, Cham
Becker JS, Paton D, Johnston DM (2015) Communication of risk: a community resilience perspective. GNS Science Report 2015(66):30 p
Becker JS, Paton D, Johnston DM, Ronan KR, McClure J (2017b) The role of prior experience in informing and motivating earthquake preparedness. International Journal of Disaster Risk Reduction 22:179–193. https://doi.org/10.1016/j.ijdrr.2017.03.006
Boholm A (1998) Comparative studies of risk perception: a review of twenty years of research. Journal of Risk Research 1(2):135–163. https://doi.org/10.1080/136698798377231
Bourque L (2013) Household preparedness and mitigation. Int J Mass Emerg Disasters 31(3):360–372
Brantley SR, Myers B (2005) Mount St. Helens – From the 1980 Eruption to 2000. United States Geological Survey. https://pubs.usgs.gov/fs/2000/fs036-00/fs036-00.pdf
Buylova A, Chen C, Cramer LA, Wang H, Cox DT (2020) Household risk perceptions and evacuation intentions in earthquake and tsunami in a Cascadia Subduction zone. International Journal of Disaster Risk Reduction 44:101442
Cadag JR, Driedger C, Garcia C, Duncan M, Gaillard JC, Lindsay J, Haynes K (2017) Fostering participation of local actors in volcanic disaster risk reduction, In observing the volcano world (pp. 481–497). Springer, Cham
Corwin KA, Brand BD, Hubbard ML, Johnston DM (2017) Household preparedness motivation in lahar hazard zones: assessing the adoption of preparedness behaviors among laypeople and response professionals in communities downstream from mount Baker and glacier peak (USA) volcanoes. J Appl Volcanol 6(3):1–19. https://doi.org/10.1186/s13617-017-0055-8
Crozier M, McClure J, Vercoe J, Wilson M (2006) The effects of hazard zone information on judgements about earthquake damage. Area 38(2):143–152. https://doi.org/10.1111/j.1475-4762.2006.00686.x
Davis M, Johnston D, Becker J, Leonard G, Coomer M, Gregg C (2006) Risk perceptions and preparedness: Mt Rainier 2006 community assessment tabulated results. GNS Science Report 2006(17):43 p
Dhellemmes A, Leonard GS, Johnston DM, Vinnell LJ, Becker JS, Fraser SA, Paton D (2021) Tsunami awareness and preparedness in Aotearoa New Zealand: the evolution of community understanding. Int J Disaster Risk Reduct 102576. https://doi.org/10.1016/j.ijdrr.2021.102576
Diefenbach AK, Wood NJ, Ewert JW (2015) Variations in community exposure to lahar hazards from multiple volcanoes in Washington state (USA). J Appl Volcanol 4(4):1–14 https://doi.org/10.1186/s13617-015-0024-z
Dooley D, Catalano R, Mishra S, Serxner S (1992) Earthquake preparedness: predictors in a community survey. J Appl Soc Psychol 22:451–470 https://doi.org/10.1111/j.1559-1816.1992.tb00984.x
Doyle EE, Hogg AJ, Mader HM, Sparks RSJ (2010) A two-layer model for the evolution and propagation of dense and dilute regions of pyroclastic currents. J Volcanol Geotherm Res 190:365–378. https://doi.org/10.1016/j.jvolgeores.2009.12.004
Doyle EEH, Lambie E, Orchiston C, Becker JS, McLaren L, Johnston D, Leonard G (2020a) Citizen science as a catalyst for community resilience building: a two-phase tsunami case study. Australas J Disaster Trauma Stud 24:23–49
Doyle EEH, McClure J, Potter SH, Becker JS, Johnston DM, Lindell MK, Johal S, Fraser SA, Coomer MA (2018) Motivations to prepare after the 2013 Cook Strait earthquake, N.Z. International Journal of Disaster Risk Reduction 31:637–649 https://doi.org/10.1016/j.ijdrr.2018.07.008
Doyle EEH, McClure J, Potter SH, Lindell MK, Becker JS, Fraser SA, Johnston DM (2020b) Interpretations of aftershock advice and probabilities after the 2013 Cook Strait earthquake, Aotearoa New Zealand. Int J Disaster Risk Reduct 101653. https://doi.org/10.1016/j.ijdrr.2020.101653
Driedger C, Calvache M, Cortés GP, Ewert J, Montoya J, Lockhart A, Allen R, Banks D, Beason S, Bocanegra HT, Burkhart F, Bustad K, Gallego JA, Gibson Z, Giraldo FR, Gutierrez C, Quintero JI, Rodríguez E, Schelling J, Scott M (2020a) Leveraging lessons learned to prevent future disasters—insights from the 2013 Colombia-US binational exchange. J Appl Volcanol 9(3):1–21 https://doi.org/10.1186/s13617-019-0090-8
Feygina I, Jost JT, Goldsmith RE (2010) System justification, the denial of global warming, and the possibility of "system-sanctioned" change. Personal Soc Psychol Bull 36(3):326–338
Finucane ML, Slovic P, Mertz CK, Flynn J, Satterfield TA (2000) Gender, race and perceived risk: the 'white male' effect. Health Risk Soc 2(2):159–172
Flynn J, Slovic P, Mertz CK, Carlisle C (1999) Public support for earthquake risk mitigation in Portland, Oregon. Risk Anal 19(2):205–216
Fraser S, Leonard GS, Matsuo I, Murakami H (2012) Tsunami evacuation: Lessons from the Great east Japan earthquake and tsunami of March 11th 2011. GNS Science Report 2012(17):89 p
Hoblitt, R. P., Walder, J. S., Driedger, C. L., Scott, K. M., Pringle, P. T., & Vallance, J. W. (1998). Volcano hazards from Mount Rainier, Washington, revised 1998. United States Geological Survey
Huang SK, Lindell MK, Prater CS (2016) Who leaves and who stays? A review and statistical meta-analysis of hurricane evacuation studies. Environ Behav 48(8):991–1029 https://doi.org/10.1177/0013916515578485
Jakob M, Hungr O (2005) Debris flow hazards and related phenomena. Springer
Johnston D, Becker J, McClure J, Paton D, McBride S, Wright K, Leonard G, Hughes M (2013) Community understanding of, and preparedness for, earthquake and tsunami risk in Wellington, New Zealand. In: Joffe H, Rossetto T, Adams J (eds) Cities at risk. Springer, pp 131–148
Johnston D, Driedger C, Houghton B, Ronan K, Paton D (2001a) Children's risk perceptions and preparedness: a hazard education assessment in four communities around Mount Rainier, USA – preliminary results. GNS Science Report 2001(02):29 p
Johnston D, Ronan K, Becker J, Gregg C, Davis M (2005) Children's risk perceptions and preparedness: Mt Rainier 2005 hazard education assessment tabulated results. GNS Science Report 2005(029):33 p
Johnston D, Tarrant R, Tipler K, Lambie E, Crawford M, Johnson V, Becker Ronan K (2016) Towards tsunami-safer schools in the Wellington region of New Zealand: Evaluating drills and awareness programs. Aust J Emergency Management 31(3):59–66

Johnston DM, Paton D, Driedger C, Houghton B, Ronan K (2001b) Student perceptions of hazards at four schools near Mount Rainier, Washington, USA. Journal of the American Society of Professional Emergency Planners 8:41–51
Keys HJR (2007) Lahars of Ruapehu volcano, New Zealand: risk mitigation. Ann Glaciol 45:155–162 https://doi.org/10.3189/172756407782282390
Kunzler M, Huggel C, Ramirez JM (2012) A risk analysis for floods and lahars: case study in the cordillera central of Colombia. Nat Hazards 64:767–796 https://doi.org/10.1007/s11069-012-0271-9
Lindell MK (2008) Cross-sectional research. In: Salkind N (ed) Encyclopedia of Educational Psychology. Sage, Thousand Oaks CA, pp 206–213
Lindell MK (2013) North American cities at risk: household responses to environmental hazards. In: Rossetto T, Joffe H, Adams J (eds) Cities at risk: living with perils in the 21st century (pp. 109–130). Springer
Lindell MK, Arlikatti S, Huang S-K (2019a) Immediate behavioral response to the June 17, 2013 flash floods in Uttarakhand, North India. International Journal of Disaster Risk Reduction 34:129–146 https://doi.org/10.1016/j.ijdrr.2018.11.011
Lindell MK, Murray-Tuite P, Wolshon B, Baker EJ (2019b) Large-scale evacuation: the analysis, modeling, and management of emergency relocation from hazardous areas. Routledge, New York
Lindell MK, Perry RW (2000) Household adjustment to earthquake hazard: a review of research. Environ Behav 32(4):590–630 https://doi.org/10.1177/00139160021972621
Lindell MK, Prater CS (2000) Household adoption of seismic hazard adjustments: a comparison of residents in two states. Int J Mass Emerg Disasters 18:317–338
Lindell MK, Whitney DJ (2000) Correlates of seismic hazard adjustment adoption. Risk Anal 20:13–25 https://doi.org/10.1111/0272-4332.00002
Lovakov A, Agadullina ER (2021) Empirically derived guidelines for effect size interpretation in social psychology. Eur J Soc Psychol 21 p https://doi.org/10.1002/ejsp.2752
Lujala P, Lein H, Rød JK (2014) Climate change, natural hazards, and risk perception: the role of proximity and personal experience. The International Journal of Justice and Sustainability 20(4):489–509. https://doi.org/10.1080/13549839.2014.887666
McIvor D, Paton D (2007) Preparing for natural hazards: normative and attitudinal influences. Disaster Prev Manag 16:79–88 https://doi.org/10.1108/09653560710729839
McIvor D, Paton D, Johnston DM (2009) Modelling community preparation for natural hazards: understanding hazard cognitions. J Pac Rim Psychol 3(2):39–46 https://doi.org/10.1375/prp.3.2.39
Mehta MD, Simpson-Housley P (1994) Trait anxiety and perception of a potential nuclear power plant disaster. Psychol Rep 74:291–295 https://doi.org/10.2466/pr0.1994.74.1.291
Nakaya N, Nemoto H, Yi C, Sato A, Shingu K, Shoji T, Sato S, Tsuchiya N, Nakamura T, Narita A, Kogure M, Sugawara Y, Yu Z, Gunawansa N, Kuriyama S, Murao O, Sato T, Imamura F, Tsuji I et al (2018) Effect of tsunami drill experience on evacuation behavior after the onset of the great East Japan earthquake. Int J Disaster Risk Reduction 28:206–213 https://doi.org/10.1016/j.ijdrr.2018.02.037
Norris FH, Stevens SP, Pfefferbaum B, Wyche KF, Pfefferbaum RL (2008) Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. Am J Community Psychol 41:127–150
Olofsson A, Rashid S (2011) The white (male) effect and risk perception: can equality make a difference? Risk Anal 31(6):1016–1032 https://doi.org/10.1111/j.1539-6924.2010.01566.x
Palmer CGS (2003) Risk perception: another look at the "white male" effect. Health Risk Soc 5(1):71–83 https://doi.org/10.1080/1369857031000066014
Paton D (2018) Disaster risk reduction: psychological perspectives on preparedness. Aust J Psychol 2018:1–15 https://doi.org/10.1111/ajpy.12237
Paton D, Johnston DM, Bebbington MSS, Lai C-D, Houghton BF (2001) Direct and vicarious experience of volcanic hazards: implications for risk perception and adjustment adoption. Aust J Emergency Management 15(4):58–63
Paton D, Sagala S, Okada N, Jang L-J, Burgelt P, Gregg CE (2010) Making sense of natural hazard mitigation: personal, social and cultural influences. Environmental Hazards 9:183–196. https://doi.org/10.3763/ehaz.2010.0039
Paton D, Smith L, Daly M, Johnston D (2008) Risk perception and volcanic hazard mitigation: individual and social perspectives. J Volcanol Geotherm Res 172:179–188
Paton D, Smith L, Johnston D (2005) When good intentions turn bad: promoting natural hazard preparedness. Aust J Emergency Management 20:25–30
Paton D, Smith LM, Johnston D (2000) Volcanic hazards: risk perception and preparedness. N Z J Psychol 29:84–88
Peers JB, Lindell MK, Gregg CE, Reeves AK, Joyner AT, Johnston DM (2020) Multi-hazard perceptions at Long Valley caldera, California. USA Int J Disaster Risk Reduction Online first. https://doi.org/10.1016/j.ijdrr.2020.101955
Perry RW, Lindell MK (2008) Volcanic risk perception and adjustment in a multi-hazard environment. J Volcanol Geotherm Res 172:170–178
Pierson TC, Wood N, Driedger C (2014) Reducing risk from lahar hazards—concepts, case studies, and roles for scientists. J Appl Volcanol 3(16):25 https://doi.org/10.1186/s13617-014-0016-4
Rahimi M, Azevedo G (1993) Building content hazards and behaviour of mobility-restricted residents. In: Bolton PA (ed) The Loma Prieta, California, earthquake of October 17, 1989 – public response (pp. B51-B62) United States Government Printing Office
Sagala S, Okada N, Paton D (2009) Predictors of intention to prepare for volcanic risk in Mt. Merapi, Indonesia. J Pac Rim Psychol 3:47–54
Smith GA, Fritz WJ (1989) Volcanic influences on sedimentation. Geology 17:375–376
Solberg, C., Rossetto, T., & Joffe, H. (2010). The social psychology of seismic hazard adjustment: re-evaluating the international literature. Natural hazards and earth system sciences. 10, 1663-1677. https://doi.org/10.5194/nhess-10-1663-2010, 2010
Spence A, Poortinga W, Pidgeon N (2011) The psychological distance of climate change. Risk Anal 32(6):957–972 https://doi.org/10.1111/j.1539-6924.2011.01695.x
Spittal MJ, McClure J, Siegert RJ, Walkey FH (2005) Optimistic bias in relation to preparedness for earthquakes. Australas J Disaster Trauma Stud 2005(1) Retrieved from www.massey.ac.nz/~trauma/issues/2005-1/spittal.htm
Statista. (n.d.). Number of participants in bicycling in the United States from 2006 to 2018 (in millions). Statista. https://www.statista.com/statistics/191204/participants-in-bicycling-in-the-us-since-2006/
Tierz P, Woodhouse MJ, Phillips JC, Sandri L, Selva J, Marzoochi W, Odbert HM (2017) A framework for probabilistic multi-hazard assessment of rain-triggered lahars using Bayesian belief networks. Front Earth Sci 5:1–23 https://doi.org/10.3389/feart.2017.00073
United States Census Bureau. (n.d.). Quick Facts Orting city, Washington. https://www.census.gov/quickfacts/fact/table/ortingcitywashington/RHI725219
Vallance JW, Cuncino ML, Schilling SP (2003) Debris-flow hazards caused by hydrologic events at Mount Rainier. United States Geological Survey, Washington
Vinnell, L. J. (2020). Why do people prepare for natural hazards? An application of the theory of planned behaviour to household preparation [doctoral thesis, Victoria University of Wellington]. ResearchArchive. http://hdl.handle.net/10063/9157
Vinnell LJ, McClure J, Milfont TL (2017) Do framing messages increase support for earthquake legislation? Disaster Prev Manag 26:28–40. https://doi.org/10.1108/DPM-06-2016-0127
Vinnell LJ, Wallis A, Becker JS, Johnston DM (2020) Evaluating the ShakeOut drill in Aotearoa/New Zealand: effects on knowledge, attitudes, and behaviour. Int J Disaster Risk Reduction 48:1–9 https://doi.org/10.1016/j.ijdrr.2020.101721
Voigt B (1996) The management of volcano emergencies. In Monitoring and mitigation of volcano hazards Springer. https://doi.org/10.1007/978-3-642-80087-0_22
Wang S, Hurlstone MJ, Leviston Z, Walker I, Lawrence C (2019) Climate change from a distance: an analysis of construal level and psychological distance from climate change. Front Psychol 10:1–22 https://doi.org/10.3389/fpsyg.2019.00230
Wei HL, Lindell MK (2017) Washington households' expected responses to lahar threat from Mt. Rainier International Journal of Disaster Risk Reduction 22:77–94 https://doi.org/10.1016/j.ijdrr.2016.10.014
Witham C (2005) Volcanic disasters and incidents – a new database. J Volcanol Geotherm Res 148:191–233
Worni R, Huggel C, Stoffel M, Pulgarin B (2011) Challenges of modelling current very large lahars at Nevado del Huila volcano, Colombia. Bull Volcanol 74(2):309–324 https://doi.org/10.1007/s00445-011-0522-8

Publisher's Note