TRANSLATING RISK INFORMATION INTO PROTECTIVE ACTION–

EXAMINING HOUSEHOLD RESPONSE TO INFORMATION ABOUT

EARTHQUAKE HAZARDS AND RISK

by

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A dissertation

submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy in Geosciences

Boise State University

August 2021

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

of the dissertation submitted by

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Dissertation Title:	Translating Risk Information into Protective Action – Examining Household Response to Information about Earthquake Hazards and Risk
Date of Final Oral Examination:	19 May 2021

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DEDICATION

To my parents,

who have shown me unwavering love and support
throughout my academic and life journey.

Grateful is an understatement.

ACKNOWLEDGMENTS

As the African proverb goes, “it takes a village to raise a child.” In this case, the “child” is a Ph.D. dissertation. As such, I have countless people to thank for helping me accomplish this goal.

Thank you to my advisor and friend, Dr. Brittany Brand. If you had not called me up so many years ago now and proposed this amazing project, I never would have ventured down this path. Your passion and commitment to the work you do inspires me to be more and to jump into unknown, but worthy, territory. Your encouragement, support, and feedback helped me grow as both a scientist and a person.

Thank you to my co-advisor Dr. Mike Lindell, whose name I read many times doing literature reviews during my masters, but whom I never thought I would be advised by. I am consistently amazed by the depth of your knowledge and your ability to recall names, theories, and statistical equations. I also appreciate the kindness, humor, and wisdom you provided over our countless zoom calls. I feel very grateful to have worked with and learned from you.

Thank you to my committee members, Eric Lindquist and Jen Pierce, who provided feedback, advice, and food for thought throughout my time at Boise State. Your varied perspectives and encouragement made this work better.

Thank you to my friends. I could not have done any of this without our coffee walks, workout sessions, weekends spent in the woods, climbing trips, craft nights, potlucks, and discussions over beers. Special thanks go to: Emma McCully, Claire

Harrigan, Darin Schwartz, Mayara Cizina, Buchanan Kerswell, Aaron Marshall, Nick Pollack, Anna Roser, Lauren Hunt, Sarah Halperin, Clinton Colwell, Alice Opalka, Katie Griffith, and Hannah Gallagher. Thanks for being such a wonderful support system. You are truly the best. Also – shoutout to all the troopers who helped me stuff 9,000+ envelopes without complaint and to Beyoncé whose tracks helped me get through some tough writing and life days. Many thanks.

And finally, thank you to my parents, Susan MacPherson Krutsky and Jonathan Krutsky. You raised me to be curious and ask questions. You also instilled in me the confidence to try things that feel unknown. Without these qualities I would not be where I am today. Through the ups and downs of these past four years, you have always been there helping me to work through things, but also stepping back to let me handle them when you knew I could. I am so proud to be your kid. Soon you will get to see the super long hyphenated name you chose for me become a little bit longer with a "Dr." in front of it. I love and thank you.

ABSTRACT

Natural hazards have been a part of the landscape since its existence, but they are becoming more devastating as they intersect with growing populations and as climate change increases their frequency and intensity. As these changes occur, the need to understand how to reduce disaster impacts becomes paramount. Despite growing concern and increasing costs of disasters over the past decade, household preparedness, which is at the foundation of disaster readiness, has seen little to no improvement. Using two research experiments, we adopt the Protective Action Decision Model (PADM; Lindell & Perry, 2004; 2012) as a framework to investigate what motivates households to prepare and examine how effective risk communication strategies are at increasing awareness and preparedness. Here we find information seeking behavior to be the strongest influence not only on preparedness, but other PADM factors as well, such as intentions to prepare, feelings (positive and negative) about earthquake threat, knowledge of protective recommendations, and risk perception. Additionally, in our Portland, Oregon case study, we find significant gaps exist in terms of public understanding of earthquake hazards (liquefaction), and what to do during an earthquake. We also find that the majority of residents do not know their risk zone and have difficulty interpreting and using hazard maps. This research expands our understanding of the factors that influence household preparedness and highlights specific areas for improvement. Because hazards are a natural part of living on this planet, it is important that we consider the inherent risks and develop strategies to become more resilient.

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LIST OF ABBREVIATIONS

CBF	Color Blind Friendly
CREW	Cascadia Region Earthquake Workgroup
CSZ	Cascadia Subduction Zone
DHS	Department of Homeland Security
DOGAMI	Oregon Department of Geology and Mineral Industries
ETS	Educational Testing Service
EV	Expectancy Value
FAO	Food and Agriculture Organization
FEMA	Federal Emergency Management Agency
FP	False Positive
GHI	GeoHazards International
HM1	Hazard Map 1
HM2	Hazard Map 2
IFRC	International Federation of Red Cross and Red Crescent Societies
JP	Japan
LAX	Los Angeles Metropolitan Region
M	Mean
MANOVA	Multivariate Analysis of Variance
MMI	Modified Mercalli Intensity
NOAA	National Oceanic and Atmospheric Administration

NZ	New Zealand
OLS	Ordinary Least Squares
OR	Oregon
PADM	Protective Action Decision Model
PAR	Protective Action Recommendation
PBEM	Portland Bureau of Emergency Management
PDX	Portland Metropolitan Region
PMT	Protective Motivation Theory
PSA	Philadelphia Spatial Abilities Scale
PVA	Philadelphia Verbal Abilities Scale
RDPO	Regional Disaster Preparedness Organization
RH	Research Hypothesis
RISP	Risk Information Seeking Processing Model
RQ	Research Question
SBSOD	Santa Barbara Sense of Directions Scale
SEA	Seattle Metropolitan Region
SD	Standard Deviation
TV	Television
USGS	United States Geological Survey

CHAPTER ONE: INTRODUCTION

Natural hazard events are evidence that the earth is alive; shifting faults generate earthquakes, rapid snowmelt creates flooding, subsurface and surface processes lead to landslides, magma rising within the earth triggers volcanic eruptions, and so on. Whether these hazard events become disasters depends upon how they intersect with the economic, social, and political conditions in which they occur (Wisner et al., 2003). Over the past 40 years the number of billion-dollar disasters in the United States has steadily risen (Figure 1.1). This trend will likely continue as population growth and climate change increase the frequency, intensity, and impact of future hazard events (United Nations, 2015). It is therefore critical to consider how communities can better anticipate and prepare for events before they happen. Historically funds spent following a disaster

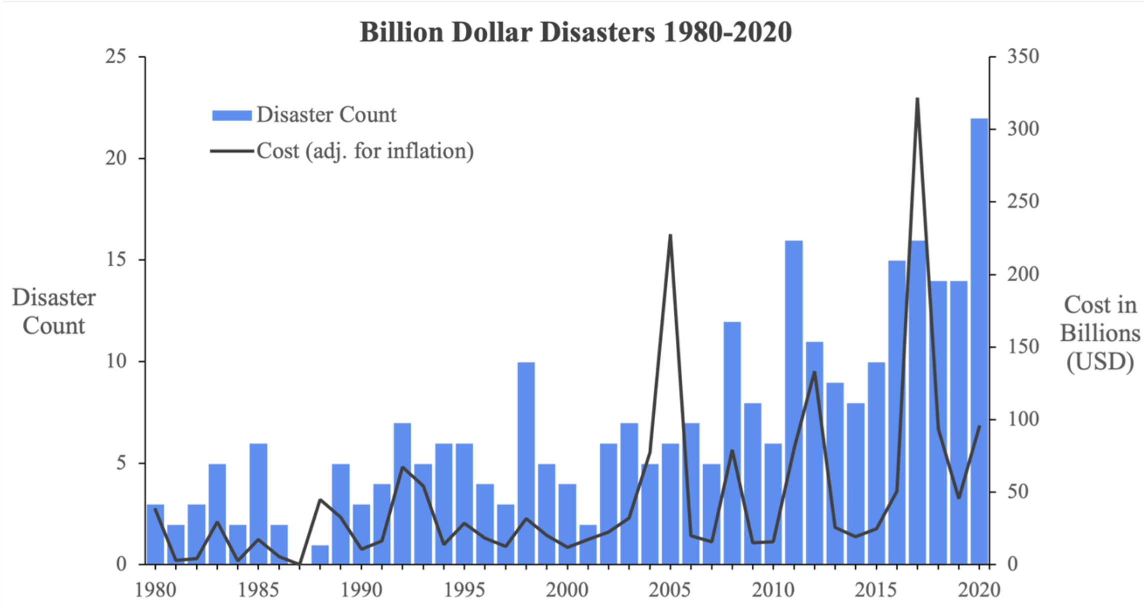

Figure 1.1. Billion-dollar disasters in the United States over the last 40 years (modified from NOAA, 2021).

on response and recovery have far exceeded funds spent beforehand on mitigation and preparedness (Birkland, 2006, p. 112). This practice has created a disaster spending model in the U.S. that is "unsustainable" (Stauffer et al., 2020). However, maximizing mitigation while minimizing total disaster costs is possible (Figure 1.2). Indeed, analysis shows that each dollar spent on mitigation saves between four and six dollars on response and recovery (Godschalk et al., 2009; Porter et al., 2017). Necessarily, these cost benefit estimates require the effective use of mitigation and preparedness resources at all levels, from the individual to the national government.

National and global agencies advocate for the development of cultures of 'preparedness' and 'prevention' to reduce disaster impacts (FEMA, 2019; United Nations, 2015). Their visions include creating communities where people understand their risks, have the resources to prepare and mitigate them, and fare better when hazard events inevitably occur. Though national and local governments in the U.S. have expanded systems and capabilities to prepare for and respond to disasters, motivating

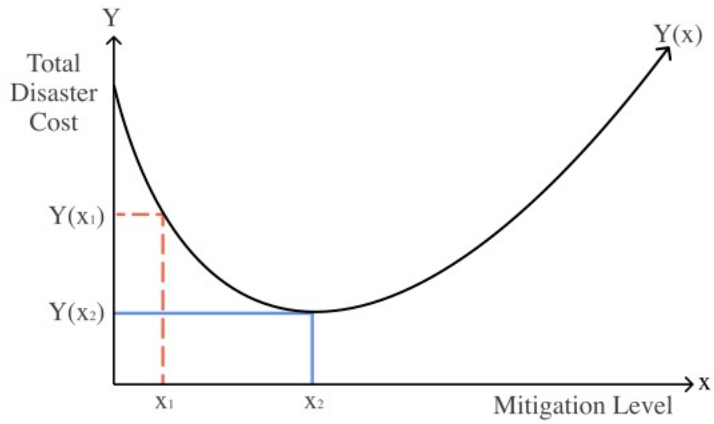

Figure 1.2 Total disaster cost is the sum of mitigation cost and cost of expected losses. It is a function of mitigation level. A mitigation level of x_2 minimizes the total cost. It is possible that x_1 and $Y(x_1)$ more closely resembles the U.S.'s current mitigation level and spending, respectively (modified from Stein & Stein, 2013).

household preparedness remains challenging. Results from the recent National Household Survey show that compared to 2013, individual preparedness has only increased a small amount from 49 to 51 percent, although intentions to prepare increased significantly from 9 to 26 percent (FEMA, 2020). Another national survey produced similar results finding household concern about hazards being much higher than preparedness levels (HealthCare Ready, 2020). These findings prompt study of what factors influence people to move from contemplation to action and what styles of risk communication can facilitate individual preparedness.

More than ever before, information about natural hazards risk and preparedness is available, but whether it is accessible or motivating to general audiences is less understood. There are webpages and news articles about hazards and risks (e.g., FEMA, 2021; Schulz, 2015), interactive hazard maps (e.g., de Moel et al., 2009), educational videos (e.g., *PrepTalks,* 2019), podcasts (Natural Hazards Center, n.d.), phone apps (e.g., Haimes et al., 2015), and even board games (e.g., Tsai et al., 2015) designed to provide hazard and risk information to broad audiences. However, the copious amount of information about hazards and risk does not appear to increase community preparedness as shown from FEMA's recent study (2020). It is therefore important to examine the following questions:

- What is inhibiting the translation of risk information into household preparedness?
- What factors are most influential at motivating people to prepare?
- How can these motivating factors be leveraged to develop better strategies?

As we better understand how information translates into preparedness action, researchers and emergency managers can develop more effective approaches that target household preparedness.

The expansion of disaster research on household preparedness has also led to the development of theoretical models. These models provide frameworks that help researchers assess individual variables and their relationships to one another. Prominent theoretical models of protective action include the Protective Motivation Theory (PMT; Rogers, 1975, 1983), the Risk Information Processing Model (RISP; Griffin et al., 1999), and the Protective Action Decision Model (PADM; 2004, 2012) among others (for discussion, see Lindell & Perry, 2004). Each of these models have distinct differences that make them useful for a variety of applications. The PMT and RISP models were developed in the context of health risks and associated protective responses, whereas the PADM was developed specifically in the context of natural hazard threats.

Lindell and Perry developed the PADM (2004, 2012) to explain the stages involved in personal decision-making related to preparing for or responding to environmental hazard threats (Figure 1.3). To do so, Lindell and Perry synthesized existing theories and research related to social influence, persuasion, attitude-behavior influences, information seeking, cognitive and behavioral processes, and protective action. The PADM is valuable for use in disaster research because it can be applied to a variety of hazards and to protective actions taken when a threat is imminent and during the time between hazards, "the continuing hazards phase."

The PADM comprises five main sections including (1) environmental/individual inputs, (2) pre-decisional processes, (3) core perceptions, (4) protective action decision-making, and (5) behavioral response. A feedback loop also ties the model outputs to inputs suggesting that this process may repeat or change as new inputs enter an individual's environment. Importantly, Lindell and Perry note that flow through the model is not necessarily linear and that internal feedbacks are also possible.

Since the PADM's development, researchers have tested variable relationships and applied them in different locations and to a variety of hazards. Some have focused on protective response to imminent threats such as evacuation behavior (e.g., Folk et al., 2019; Strahan et al., 2019) and intended response to earthquake shaking (e.g., Arlikatti et al., 2019), whereas others have focused on the "continuing hazards phase" to look at which factors influence hazard adjustment adoption (e.g., Heath et al., 2018; Lindell et al., 2009). These studies confirm that certain aspects of the model, such as core perceptions, play an integral, though complex, role in hazard adjustment adoption. Other aspects, such as information seeking behavior, appear to be important (Mileti & Darlington, 1997; Mileti & Fitzpatrick, 1992), but have not been as well studied. Lindell and Perry founded the PADM on the results of previous studies and theories (2004) and have since updated it to reflect new discoveries (Lindell & Perry, 2012). Continued examination of the less studied or conflicting aspects of the model is needed to assess and refine it. This testing is especially needed in time when the flow of risk information and how people engage with it is changing and may be influencing perceptions and actions.

Although disaster research has made significant gains in understanding the motivators of household preparedness, gaps remain. The complex nature of individual decision-making makes additional study in different political and cultural settings necessary (Solberg et al., 2010). Researchers (Lindell, 2013b; Solberg et al., 2010) also note that a general limitation in the field is the variety of ways in which constructs are measured. For example, *risk perception* can be construed in a variety of ways from someone's expectations about the likelihood of a specific hazard event happening to the perceived personal consequences of that event. Similarly, *disaster preparedness*, can also be estimated in many ways with no agreed upon definition or measure (Kirschenbaum, 2005). This lack of measure consistency makes it difficult to systematically compare these factors across studies and therefore limits the generalizability of future conclusions. Recycling previously used measures is one alternative for future research (Lindell, 2013b). With the many factors found to influence household preparedness, additional research is needed to uncover which are most influential and under which conditions.

The aims of this dissertation research are to (1) better understand how effective current risk communication strategies are at both educating general audiences and motivating preparedness, and (2) use on the PADM to contextualize and assess the relationships between psychological and environmental factors that influence how people understand and act on natural hazard threat information. In this research, I place specific emphasis on seismic hazards and information seeking behavior as it has less study than many of the other PADM constructs despite it being found to be strongly correlated with preparedness (Mileti & Darlington, 1997). Additionally, I address the calls for measure consistency in the following chapters by using existing constructs where possible.

This dissertation comprises three chapters written in a journal manuscript format. Chapter 2 examines how effective interactive multi-hazard maps are at helping students comprehend risk and whether updating a specific map with mapping and risk communication best practices will increase risk comprehension (MacPherson-Krutsky et.

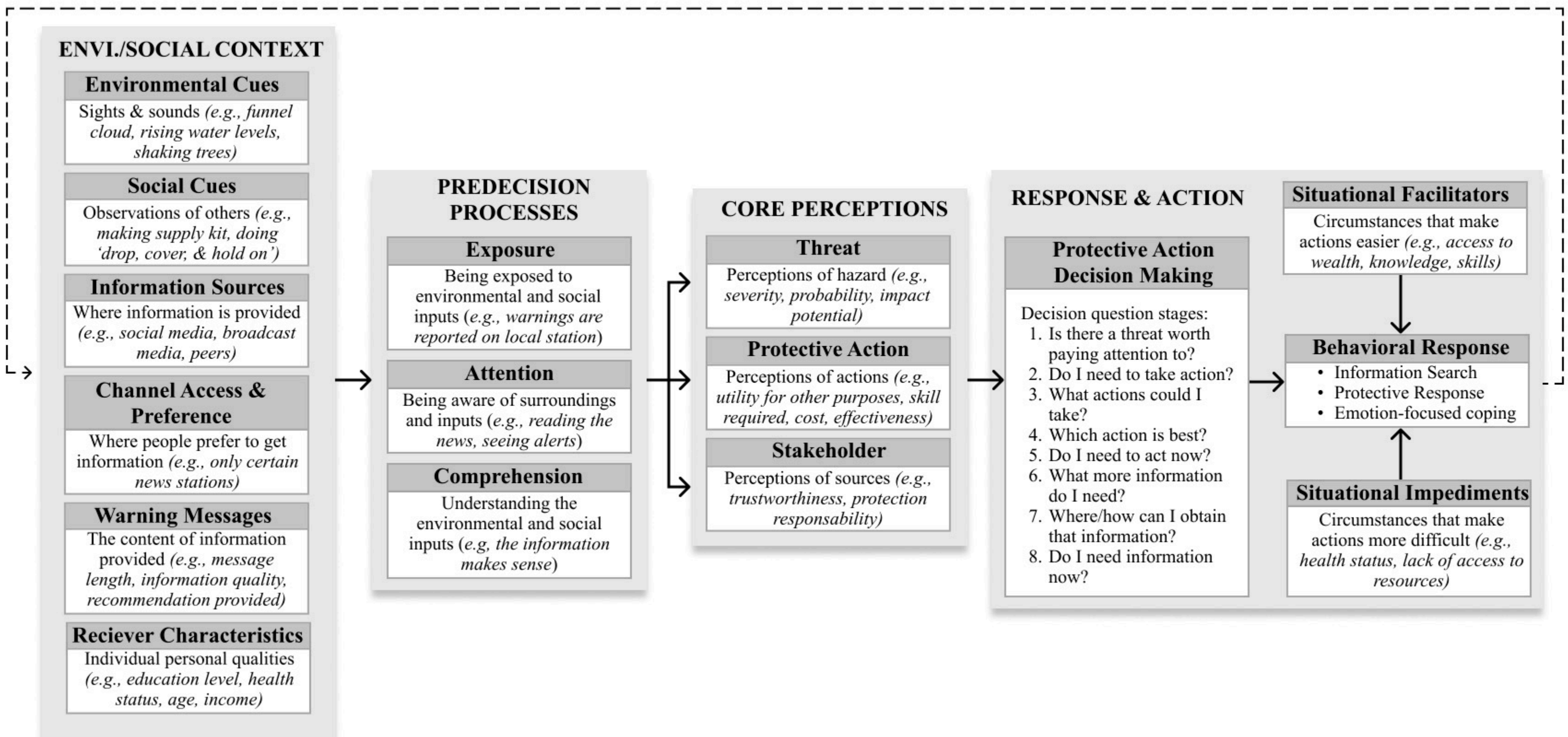

Figure 1.3. Protective Action Decision Model including descriptions of key factors and examples in italics (Modified from Lindell and Perry, 2012).

al., 2020). Chapter 3 tests a hypothesized model of household hazard adjustment based on components of the PADM and refines it based on subsequent results. Chapter 4 investigates how effective risk communication efforts have been in at increasing understanding of earthquake risk and how to prepare in the Portland metropolitan region (PDX) and compares it to other places along the Cascadia Subduction Zone. For a list of term definitions that may be helpful as you read this dissertation, refer to Table 1.1.

Table 1.1 Helpful definitions

Term and definition (in the context of this dissertation)	Source
Natural Hazard: “Naturally occurring physical phenomena caused either by rapid or slow onset events which can be geophysical (e.g., earthquakes), hydrological (e.g., floods), climatological (e.g., wildfires), meteorological (e.g., cyclones) or biological (e.g., disease epidemics).”	IFRC, 2021
Risk: “The potential loss of societally important assets caused by hazards”	Ludwig et al., 2018
Risk perception: A measure of expected consequences (e.g., the probability of an event occurring, damage to property, deaths and injuries, disruption to life) from an individual to community/city/regional level.	Lindell and Perry, 2000
Protective actions: A broad term that describes actions taken to promote health and safety. With respect to natural hazards, these can be taken in the time between or during hazard events. For example, installing cabinet latches and doing ‘drop, cover, and hold on’ during an earthquake are both considered protective actions.	Lindell and Perry 2000
Long-term hazard adjustments: “Actions taken between hazard events that intentionally or unintentionally reduce risk”	Lindell et al., 1997
Mitigation: Resources or actions that “provide passive protection” at the time of hazard impact (e.g., seismic retrofitting)	Lindell and Perry, 2000
Preparedness: Activities completed before an event that “support active response” at the time of hazard impact (e.g., having water stored)	Lindell and Perry, 2000
PADM: The Protective Action Decision Model is a multistage model that identifies and organizes variables that influence individual decision-making in response to environmental hazard threats	Lindell and Perry, 2012
Information seeking: A voluntarily process of searching for information from specific sources to reach informational goals and making decisions about which messages to pay attention to	Dunwoody and Griffin, 2014
Affect - Emotional reaction, subtle or obvious feelings. (e.g., positive = happy, energetic, optimistic and negative = fear, depressed, nervous)	Finucane et al., 2000

CHAPTER TWO: DOES UPDATING NATURAL HAZARD MAPS TO REFLECT BEST PRACTICES INCREASE VIEWER COMPREHENSION OF RISK?[1]

Abstract

In this study, we examine whether updating an interactive hazard map using recommendations from the literature improves user map comprehension. Analyses of experimental data collected from 75 university students revealed that map comprehension scores were not significantly better for those who viewed a "best practices" map compared to those who viewed an existing version. This may be because the existing map was itself better than most other interactive maps. Additionally, we found map comprehension levels to have significant positive relationships with objective tests, but not self-reported measures of spatial ability. Moreover, self-reported spatial ability had statistically significant, but only moderately strong, correlations with objective tests. These results indicate that spatial ability should be measured objectively rather than through self-reported methods in research on map comprehension. Further research is needed to examine the cognitive processes involved in hazard map comprehension, especially using a broader range of map characteristics and population segments with more diverse cognitive abilities.

Introduction

Government agencies use hazard maps, in-print and online, to communicate environmental hazard risks. In many cases, maps made for use by experts such as geologists, engineers, land use planners, and emergency managers are shared with the public. However, these groups have diverse levels of hazard knowledge and cognitive abilities, which can produce confusion when maps contain technical or unnecessary information. As such, a one-size fits all approach to creating and disseminating maps for the purpose of communicating environmental hazards and risk is potentially problematic (Dransch et al., 2010; Nave et al., 2010).

Despite their widespread use, few studies assess the usability of hazard maps, and even fewer studies have identified map characteristics that are essential for people to accurately assess their risks. Thus, research is needed to (1) determine how maps currently published on hazard management websites compare to the best available map display practices, as outlined in summaries such as Dodge et al. (2011), and (2) determine if people's map comprehension is a function of stable individual characteristics such as spatial, verbal, and numeric abilities.

Some progress toward addressing the issue of map usability can be drawn from the broader research literature on people's interpretations of maps—and even more broadly on visuospatial displays. However, most map studies examine people's map learning and memory and do not assess real-time inferences viewers draw from maps while they view them (Taylor, 2005). The lack of research on how people use and interpret hazard maps in real-time is an important limitation because that is typically how people use them.

The purpose of our study is to explore whether updating an interactive hazard map using best practices helps improve people's comprehension of risk. We also consider how individual differences in cognitive ability affect map comprehension. The results of our research inform strategies to better communicate environmental risks to the diverse audiences who can use map information to prepare for natural hazard events. With $2.6 billion spent annually on preparedness in the United States (DHS, 2019), it is imperative that maps used to communicate environmental hazard risks are effective.

Literature Review

In the following section, we summarize research evaluating hazard maps, and then turn to a discussion of map types, cognitive processes in map comprehension, mapping best practices, and determinants of map comprehension.

Hazard Map Studies

The Lindell (2018) review of research on warnings of imminent hazards found a much more extensive literature on verbal elements of warnings than on graphic displays or numeric information. However, literature that assesses people's interpretations of hazard maps is increasing, especially for earthquakes (Crozier et al., 2006), wildfires (e.g., Cao et al., 2016, 2017; Cheong et al., 2016), volcanoes (e.g., Haynes et al., 2007; Nave et al., 2010; Thompson et al., 2015), floods (e.g., Bell and Tobin, 2007; de Moel et al., 2009; Hagemeier-Klose and Wagner, 2009; Maidl and Buchecker, 2015; van Kerkvoorde et al., 2018), tornadoes (e.g., Ash et al., 2014; Casteel and Downing, 2015; Jon et al., 2018, 2019; Sherman-Morris and Brown, 2012), and hurricanes (S. Arlikatti et al., 2006; Cox et al., 2013; B. F. Liu et al., 2017; L. Liu et al., 2019; Meyer et al., 2013; Padilla et al., 2015; H.C. Wu et al., 2015a, 2015b; Ha. C. Wu et al., 2014; Zhang et al., 2004).

These publications explore a variety of dependent variables such as viewer perceptions of risk, risk area accuracy, preferences for map features, misconceptions about visualizations, and effects of user characteristics on performance. These studies concluded that risk area residents are better able to locate and orient themselves using aerial photographs and 3D maps with clearly labeled landmarks than with conventional contour maps (Cao et al., 2016; Dransch et al., 2010; Haynes et al., 2007; Nave et al., 2010) and that isarithmic maps produce better understanding than gradational shaded or binned maps. However, color coding scheme and probability coding (numerical vs. verbal) also influence participants' judgments, at least among geoscientists and emergency managers (Thompson et al., 2015). Furthermore, confusion can occur when aspects of the map are poorly defined, such as having too many or too few features, or have a confusing map legend (S. Arlikatti et al., 2006; Zhang et al., 2004). In addition, people draw important inferences about risk information that is not explicitly provided (Crozier et al., 2006).

Overall, the hazard map studies listed above signify the importance of assessing people's perceptions of map characteristics such as perceived relevance and ease of understanding, as well as accuracy of interpretation.

Map Types

To better understand the broader literature, it is important to recognize that spatial displays, of which maps are a specific type, can be classified as iconic, relational, or hybrid (Hegarty, 2011). An iconic display represents spatial objects. An example of an iconic display is a road map because it represents the network of roads and the locations of landmarks in a geographical area. A relational display, such as a graph, represents nonspatial variables such as average rainfall in each month of the year or the correlation between education and income. A hybrid display combines an iconic display (e.g., a base map) with a relational display to provide a spatial representation of nonspatial categories or quantities, as when temperature ranges are represented by map contours (Allen et al., 2006). Thus, hazard maps are hybrid displays.

Cognitive Processes in Map Comprehension

Accurate interpretation of a spatial display requires viewers to— (1) see the display clearly, (2) pay attention to relevant features, (3) develop a cognitive map, and (4) make inferences from their cognitive map to produce judgements, decisions, and actions (Hegarty, 2011). The ability to see the display clearly is affected by factors such as visual element size and the degree of clutter in a display. Attention is influenced by "bottom-up" processes, in which visually salient features such as bright colors capture viewers' attention. It is also influenced by "top-down" processes in which viewers' expectations direct their attention to specific display elements. These expectations are generated by schemas, also known as mental models, which are generic belief structures about entities, their attributes, and the interrelationships among those attributes (Endsley & Jones, 2012). People can have schemas of varying comprehensiveness about maps in general and, in particular, about the specific map content being displayed. Accordingly, people can range in knowledge from novice to expert in each of these domains. Another important contributor to the encoding process is the viewer's spatial ability which, following Colom et al. (2002), can be defined as the ability to generate, retain, retrieve, and transform visual images. Map inferences are determined by a viewer's goals, which can be self-generated (e.g., a desire to find the most direct route from one location to another) or externally imposed (e.g., an experimenter-assigned task to reproduce the map).

Most map research assesses the quality of the cognitive maps derived from physical maps or, to a lesser degree, from navigation through the environment. For example, many studies reviewed by Taylor (2005) presented viewers with a map, asked them to study it, withdrew the map, and asked them to perform some task indicating the degree to which they learned the map's elements and their relationships (e.g., recall of landmarks, distances among points).

Only a few studies on map comprehension examine the basic elements of map reading skills (Aksoy, 2013; Albert et al., 2016; Milson & Alibrandi, 2008; Muir, 1985). Specifically, these are (1) *symbol recognition:* accurate interpretation of map symbols, (2) *direction finding*: the determination of geographical directions among landmarks using a map compass, and (3) *scale use:* determination of actual geographical distances among landmarks using a map scale. In addition, more sophisticated maps, such as topographical maps require (4) *contour utilization*: the determination of quantities such as elevations from the location of points within contours.

<u>Mapping Best Practices.</u>

Maps can facilitate or impede viewers' map comprehension, depending upon the degree to which they are consistent with viewers' cognitive processes (Haynes et al., 2007; Kosslyn, 1989; Thompson et al., 2015). The impediments to map comprehension identified in the hazard map literature are consistent with a broader summary of the research literature on visual displays, which concludes that viewers' graph interpretations are a function of seven broad factors (Shah et al., 2005). These factors include *data complexity* (e.g., the number of variables and categories within each variable), *data display characteristics* (e.g., the discriminability of graphical features—object positions, lengths/areas, colors, dimensionality), *viewer tasks* (e.g., retrieve point values, compare values, infer relationships), *viewer prior content knowledge* (expert vs. novice), *viewer prior knowledge of display conventions* (expert vs. novice), *visuospatial abilities*, and *working memory*.

Best practices for visual elements

Researchers have made a number of recommendations to increase map comprehension, such as best base map choice, most important map elements to display, appropriate symbols and labels, and clear hierarchical structure. For example, feature selection eliminates inessential map elements; visual salience draws viewers' eyes to the most important features (Brewer, 2005; Kunz & Hurni, 2011). There is also research that investigates the use of shape, size, and color of map symbols. In particular, shape ranges from abstract to iconic, with comprehension being fastest and most accurate for iconic symbols that do not need a legend (Taylor, 2005). Larger elements are easier to see and more readily attract attention but can obscure other elements by cluttering the map if they are too large. Recommendations on color choice are outlined below.

Visual salience is often accomplished using color. There are five main recommendations for color choice. First, adapt color schemes to the type of data displayed, such as sequential schemes for data with increasing values (e.g. earthquake shaking intensities), diverging schemes for data whose values are above or below a critical value (e.g. temperatures above or below freezing), and qualitative schemes for nominal data (e.g. forest, lakes, and deserts are green, blue, and yellow, respectively) (Thompson et al., 2015; Kunz & Hurni, 2011; Harrower & Brewer, 2003). Second, use seven or fewer color classes when displaying data because a greater number produces difficulty matching legend items with data layers (Thompson et al., 2015). Third, use color-blind friendly (CBF) colors schemes since 7-10 percent of the male population is red-green color-blind (Harrower & Brewer, 2003; Cao et al., 2016; Thompson et al., 2015). Fourth, use real-life color to represent data when possible, such as blue for flooding and red for lava (Hagemeier-Klose & Wagner, 2009; Kunz and Hurni, 2011; Brewer, 2005). Finally, ensure that the colors in the legend match the colors on the map because transparency options and base map imagery can obscure or change map colors (Brewer, 2005).

Best practices for content elements

Research on content choice has produced five recommendations. We use the term 'content' to refer to verbal or numeric information provided on or next to a hazard map. First, content must be current and accurate (Nave et al., 2010). If hyperlinks are broken, data are old, or information is no longer valid, map users may lose trust in the map and disregard the information—thus impeding personal preparedness (Dransch et al., 2010; Lindell & Perry, 2012). Second, incorporate engaging auxiliary information to personalize the hazards (Dransch et al., 2010; Cao et al., 2016; Crozier et al., 2006; Maidl & Buchecker, 2015). Auxiliary information could include local photographs of past events, personal stories, infographics, and protection measures. Another way to personalize interactive maps specifically is to include a search by address function and the ability to zoom to locations of interest (Cao et al., 2017; Dransch et al., 2010; Bell & Tobin, 2007). Third, avoid specialized terms that many people are likely to misunderstand, such as 100-year flood, peak ground acceleration, and debris flow (Bell & Tobin, 2007; Hagemeier-Klose & Wagner, 2009). Fourth, use easily understandable terminology to explain what each data layer and colored zone represents (Brewer, 2005). If this is done properly, users do not need to seek more information to understand the map. Fifth, avoid or clearly explain verbal labels for quantitative variables such as probabilities. Terms such as “low”, “medium”, or “high” are confusing because there is substantial variation in the numerical values that people assign to these labels (Lindell et al., 2016; Thompson et al., 2015). This problem can be minimized by providing probabilistic information in multiple formats, supplementing verbal labels with probability percentages (e.g. 30% probability), natural frequencies (e.g. 3 in 10), or graphics such as risk ladders (Keller, 2011), pictographs (Kreuzmair et al., 2016), or shaded displays (Thompson et al., 2015). Since people vary in their ability to process probabilistic information, presenting more than one descriptor type allows a wider audience to understand the data.

An evaluation rubric for hazard maps

To develop the rubric, we conducted a literature review focused on effective map design, hazard maps as risk communication tools, and risk communication best practices. The review encompassed literature on both static and interactive maps, though most focused on static maps since fewer interactive map studies exist. The recommendations naturally separated into two categories, visual and content aspects of map design. Many of the recommendations were repeated in the literature so we consolidated them to create the “high performance” criteria of the evaluation rubric. We defined moderate and poor performance criteria from there.

The resulting rubric has two sections with nine visual and nine content elements. For each element a map can score from one (poor performance) to three (high performance) points. A map's total score is the points scored divided by the points possible. For example, a map that scores moderate on all items would have 36 points out of 54 possible for a total score of 0.67. The rubric can be used for multi-hazard or single-hazard maps and online or paper maps. Some rubric elements may not apply to every map. For example, visual rubric Element 6, "colors match hazard color," would not apply for an earthquake hazard map. In this case, the points for Element 6 would not be included in the total points possible. Table 2.1 summarizes the recommendations from the previous two sections for nine visual and nine content elements in the 'high performance' column of the hazard map evaluation rubric.

Determinants of Map Comprehension

Cognitive abilities

Although some scholars suggest more complex models (e.g., Carroll, 1993), McGee (1979) propose that spatial abilities can be defined primarily by two factors, spatial visualization and spatial orientation. Spatial visualization is the ability to manipulate or transform the image of spatial patterns into other arrangements (Ekstrom et al., 1976, p. 173). Spatial orientation is "the ability to perceive spatial patterns or to maintain orientation with respect to objects in space" (Ekstrom et al., 1976, p. 149). In addition, a third spatial ability that seems particularly relevant to map comprehension is spatial scanning, which refers to "speed in exploring visually a wide or complicated spatial field" (Ekstrom et al., 1976, p. 155).

Multiple studies find that individuals who have higher levels of spatial ability are better at interpreting and applying map information (Aksoy, 2013; Hegarty et al., 2010; Ooms et al., 2015; Postigo & Pozo, 2004). The types of spatial abilities that predict

Table 2.1 Visual and Content Elements for the Hazard Map Evaluation Rubric

Recommendations
Visual 1. Aerial imagery base map used (or pops up as first map). 2. Landmarks clearly visible to help viewers orient/locate themselves. 3. Important map components are present and well-positioned on page 4. Visual hierarchy is achieved through appropriate colors, symbols, font size, line width, and other symbolization techniques. Most important map elements are emphasized. Base map is complimentary and does not distract from primary message. 5. Appropriate color schemes used on all data—sequential for increasing values (intensities) diverging schemes for values above/below critical value (temperature - freezing), and qualitative for nominal data (trees, water, desert are green, blue, yellow, respectively) 6. If applicable, colors match hazard color 7. Fewer than 5 color classes used (7 or fewer is ideal) 8. Legend colors are matched exactly with those on map 9. Color-blind friendly schemes are used
Content 1. Auxiliary information is present along with mapped data 2. Risk messaging is included and positively framed 3. Maps are personalized/customizable 4. Information appears to be accurate and up-to date and is presented in clear and concise manner 5. Protection measures are included along with risk 6. Jargon/specialized terms are not used in map or descriptions 7. Legend items are clearly explained 8. If data are probabilistic, both percent and natural frequency are used and likelihood term is not used to describe the data 9. Qualitative (low-med-high) terms are not used

performance on spatial tasks depend on the scale of the representation. Specifically, spatial abilities at small (object) and large (environmental) scales are distinct even though they are positively correlated (Hegarty et al., 2006). Environmental-scale tasks require a distinction between survey knowledge and route knowledge. Survey knowledge involves an allocentric perspective of map elements and their relationships (i.e., aerial view), whereas route knowledge involves an egocentric perspective (i.e., street view) that is defined by the sequence of steps required to move from one location to another (Bosco et al., 2004). Moreover, relevant spatial abilities also depend on the type of spatial task. For example, in studies of map utilization, the map is continuously present (e.g., Allen et al., 2006). By contrast, studies of map learning require the recall and reproduction of map elements (e.g., Bosco et al., 2004; Thorndyke and Stasz, 1980).

Although there does not seem to be any research on this topic, it is also possible that map comprehension and spatial ability scores are affected by a user's level of verbal ability. Map comprehension tests and spatial ability tests require that test takers read or listen to verbal instructions about how to perform the task. As a result, complex instructions could depress scores on map comprehension or spatial tests for those with lower levels of verbal ability. If verbal ability is a significant predictor of map comprehension or spatial abilities, word choice becomes critical when designing experiments to test these factors.

Previous studies use a variety of instruments to measure cognitive abilities. These instruments separate into objective and self-reported abilities. Examples of objective cognitive tests include those developed by the Educational Testing Service (Ekstrom et al., 1976) and Vandenberg and Kuse (1978) that ask participants to perform various timed tasks. Each test measures a distinct cognitive ability. Instruments that measure self-reported or perceived abilities include the Santa Barbara Sense of Direction Scale (SBSOD, a measure of environmental-scale spatial ability), the Philadelphia Spatial Ability Scale (PSA, a measure of object-scale spatial ability), and the Philadelphia Verbal Ability Scale (PVA, a measure of verbal ability) (Hegarty et al., 2010). Since their development, both objective and self-reported styles of measurement have been used to investigate cognitive abilities (Kastens, 2010; Mayer & Massa, 2003; Nazareth et al., 2019; Oppenheimer et al., 2015; Weisberg et al., 2014). Self-reported ability measures are much simpler to implement, but more research is needed to determine how well they correlate with objectively measured cognitive abilities.

Metacognition

One neglected research question is whether those who have greater levels of map comprehension are able to assess their performance and conclude that the task is easy, an assessment known as *metacognition* (McCormick, 2003). Although one might presume that metacognitive accuracy is a given—those who struggle to comprehend a map would be aware of the task's difficulty for them—this is not necessarily the case. There is ample support for precisely the opposite finding, the Dunning-Kruger effect, in which less competent people are oblivious to their own ignorance (Dunning, 2011).

Research Hypotheses and Research Questions

The research reviewed in the previous sections leads to four research hypotheses (RHs) and two research questions (RQs) that address the relationships of map comprehension, spatial abilities, and other cognitive abilities.

RQ1. Can map comprehension be meaningfully divided into a Basic Map Skill scale and an Advanced Map Skill scale?

RH1. Map comprehension scores of participants viewing a "best practices" hazard map will be significantly higher than those viewing an existing hazard map.

RH2. Objective spatial ability scores and self-report spatial ability scores will have significant positive correlations with each other but nonsignificant correlations with verbal ability.

RH3. SBSOD scores will have significant positive correlations with PSA scores but will have distinctly different correlations with other variables.

RH4a-b. Map comprehension scores will have significant positive correlations with (a) objective and (b) self-report spatial ability scores.

RQ2. Are map comprehension scores positively correlated with metacognitive awareness of performance?

Research Design

Procedure

To test these research hypotheses and research questions, we randomly assigned participants to a two group between-subjects experimental design in which half of the participants viewed the conventional map and the other half viewed the best practice map (Picture 2.1). Participants in both groups began by taking three timed objective tests of spatial abilities. After completing the spatial tests, participants logged on to the hazard map and answered a questionnaire. The questionnaire comprised a map comprehension quiz, three self-report spatial ability scales, a self-report verbal ability scale, and demographic questions. A total of 75 Boise State University students in introductory level courses participated in exchange for extra-credit toward their course grade. The protocol was approved by the Boise State University Institutional Review Board.

Picture 2.1 After completing the timed spatial tests, students view HM1 (student on left) and HM2 (student on right) and fill out the map comprehension questionnaire.

Hazard Map Development

Participants assigned to the existing map were directed to the *Oregon HazVu: Statewide Geohazards Viewer* (DOGAMI, 2018, see: www.oregongeology.org/hazvu/), referred to below as

Hazard Map 1 (HM1; Figure 2.1). We selected this viewer as it is currently in use, displays multiple hazards, and has procurable data layers.

We constructed the best practices hazard map by first developing a rubric consisting of best practices in hazard mapping and science communication from the literature described above (Table 2.1; see Table A.1 for full rubric). We then applied the rubric to HM1 to identify areas of improvement that were then implemented to produce the "best practices" hazard map (HM2; bit.ly/dataview2) using ArcGIS Story Map software (Figure 2.2). Finally, all hazard data in HM1 were imported to populate HM2. In addition to updating data colors and map legend terminology, HM2 also included a side-panel with auxiliary information, historical photos, definitions, and further explanation of legend items to help put the data in context. In all, HM2 involved

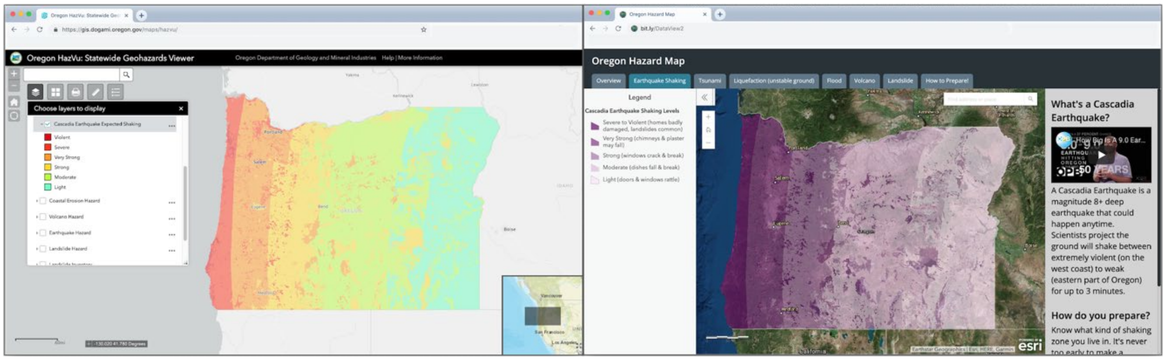

Figure 2.1 Two screen captures show HM1 (left) and HM2 (right) with the earthquake shaking layer displayed. Note differences in color scheme, legend items, and auxiliary information added to HM2.

21 changes to HM1(Table A.2). There were 15 specific changes in the visual criteria involving 7 of the 9 rubric items. In addition, there were 6 specific changes in the content criteria involving 6 of the 9 rubric items, with some addressing more than 1 rubric item.

Map Comprehension, Spatial Ability, and Demographic Items

The map comprehension scale comprised 13 questions in two categories covering the basic elements of map reading as well as more advanced skill in map interpretation (Table 2.2). Specifically, two items addressed participants' compass utilization, two items measured scale utilization, two items measured participants' ability to use the compass and scale in combination, two items measured legend utilization, and five items measured risk interpretation. The mean over the six items addressing compass utilization, scale utilization, and compass and scale in combination yielded a scale of Basic Map Skill. The mean over the seven items measuring legend utilization and risk interpretation yielded a scale of Advanced Map Skill. The internal consistency reliabilities for these two scales were $\alpha = .54$ and $.52$, respectively.

The three objective measures of spatial ability were selected from a series of cognitive tests published by Educational Testing Service—ETS (Ekstrom et al., 1976). The Paper Folding test measured visualization, the Cube Comparison test measured spatial orientation, and the Map Planning test measured spatial scanning. The Paper Folding test requires people to select which of five options represents how a sheet of paper that has been folded and then hole-punched looks when it is unfolded. The Cube Comparison test requires people to determine if two cubes showing three faces with various designs, numbers, or letters visible on each face are different cubes or are the same cube that has been rotated to present different faces. The Map Planning test assesses people's ability to find the shortest route between two points in a stylized street grid that is partially obstructed by roadblocks. All three tests required the participants to answer as many questions as possible within 3 minutes and were hand-scored using the total number of correct responses for each test. The estimated reliabilities of these tests range .75-.92 for Paper Folding, .77-.89 for Cube Comparison, and .75-.94 for Map Planning (Ekstrom et al., 1976).

The three self-report spatial ability measures are the SBSOD and PSA (Hegarty et al., 2002, 2010), as well as the Allocentric View scale (Table A.3). The SBSOD and PSA scales contain questions describing the respondent's ability to perform a variety of tasks that require environmental- and object-scale spatial skills, respectively. For the SBSOD and PSA, participants responded to each item using a five-point Likert scales (*Strongly Agree* to *Strongly Disagree*) to indicate the degree to which it applied to them. These two spatial scales were supplemented by a newly developed Allocentric View scale that contains self-report items that are more directly related to map interpretation. That is, the items in this scale supplement the predominantly egocentric view items in the SBSOD. For the Allocentric View scale, participants responded to each item using a five-point scale (*Not at all to Very Great Extent*) to indicate its relevance to them.

Table 2.2 Map Comprehension Questions

Knowledge Category *Question Focus*	Specific question asked
Compass Utilization *Cardinal Directions: North, East, South, & West*	• Which of the following four cities is directly South of Portland? • From Salem, OR, which direction would you have to travel to reach Dallas City, OR?
Scale Utilization *Distances*	• How far is Salem (in Marion County) from Eugene (in Lane County) as the crow flies? • Which two cities below are approximately 10 miles apart (as the crow flies)?
Compass & Scale Utilization *Direction & Distance*	• If you travel about 10 miles East of Portland which town will you be in? • Which direction and distance would you have to travel from Bend to Eugene as the crow flies?
Legend Utilization *Hazard information shown in the legend & on the map*	• Which of the following cities could experience a tsunami? • Eugene is expected to experience which level of shaking from a Cascadia earthquake? • If you live at 701 Claggett St NE, Keizer, OR 97303 (at the corner of 7th Ave NE & Claggett St NE), which of the following hazards are likely to impact you? (choose as many as applicable)
Risk Interpretation *Hazards & risk information associated with specific locations*	• If you are the owner of The Bank of America Financial Building (1001 SW 5th Ave, Portland, OR 97204 at the corner of 5th Ave. and SW Main St.), should you anticipate that flooding could impact your business in the next 100 years? • If you are moving to Oregon and Mount Jefferson volcano is erupting, which of the following cities would be the most risky to live in? • If your grandma lives at 3438 SE Chestnut St, Newport, OR 97366 (at the corner of SE 35th and SE Chestnut St.) and the Cascadia earthquake happens, which of the following is her home likely to experience? • Rank locations Cloverdale, Pacific City, and Beaver from highest (Hi) to lowest (Lo) risk of being damaged from a tsunami.

Participants also completed the PVA self-report measure of verbal ability using a five-point Likert scales (*Strongly Agree to Strongly Disagree*) to indicate the degree to which each statement applied to them. Finally, they completed a Metacognition scale, which comprised a four items self-assessment of their performance on the map comprehension task. Participants used a five-point Likert scale (*Strongly Agree to Strongly Disagree*) to indicate the degree to which each statement applied to them.

After factor analysis and scale analysis, the SBSOD score was computed from the mean of all items except Item 9 (α = .89), the PSA score was computed from the mean of Items 5-13 (α = .86), the PVA score was computed using the mean of Items 1, 2, 6, and 7 (α = .64), and the Allocentric View score was computed using the mean of all five items in that scale (α = .77). The Metacognition score was computed using the mean of all four items in that scale (α = .77). Variable labels are shown in Table 2.3.

Results

<u>Mean Comparisons</u>

The tests associated with RQ1—*Can map comprehension be meaningfully divided into a Basic Map Skill scale and an Advanced Map Skill scale?*— showed that scores on Basic Map Skill (Mean, M = .81) are significantly higher (t_{71} = 2.14, p < .05) than those on Advanced Map Skill (M = .74) and, as indicated in Table 2.4, the two scales have a significant Pearson correlation (r = .23) and a nonsignificant Spearman correlation with each other (r = .20). The small magnitude of both correlations suggests that map comprehension can be meaningfully divided into two relatively distinct skills.

Table 2.3 Variable Descriptions

Measure	Name	Type (range of values)
Dependent Variables		
Basic Map Skill*	BasicSkill	Mean of values Q1-6
Advanced Map Skill*	AdvancedSkill	Mean of values Q7-13
Independent Variables		
Map Type	MapType	HM1 (0), HM2 (1)
ETS Cube Comparison Test	CubeCompare	Score (max possible = 42)
ETS Map Planning Test	MapPlanning	Score (max possible = 40)
ETS Paper Folding Test	PaperFold	Score (max possible =20)
SBSOD Scale	SOD	Mean of items except 9* (1-5)
PSA Scale	PSA	Mean of items 5-13* (1-5)
PVA Scale	PVA	Mean of items 1, 2, 6, & 7* (1-5)
Metacognition	Metacog	Mean of items* (1-5)
Allocentric View	AlloView	Mean of items* (1-5)

*(high value=high perceived ability)

Correlation Analyses

To test the relationships between variables, we computed both Pearson and Spearman correlations (Table 2.4). We included Spearman correlations since the individual items cannot be assumed to be strictly interval or ratio level measures. However, discrepancies between statistically significant Pearson and Spearman Correlations are between .01 and .06. Upon testing the 95 percent confidence intervals for each discrepancy, we found these differences to be nonsignificant ($p > 0.05$). As such, the following results reference the Pearson correlation values.

Table 2.4 **Mean (M), standard deviations (SD), & Pearson (lower left) and Spearman (upper right) correlations (r_{ij}) among variables.**

			Map Comp			ETS tests			Self-report scales				
			1	2	3	4	5	6	7	8	9	10	11
	M	SD	Basic	Adv.	Type	Cube	Map	Paper	SBSOD	PSA	PVA	Meta	Allo
1 BasicSkill	.81	.21	--	.20	-.28*	.15	.27*	.09	.04	.09	.02	.13	.21
2 AdvancedSkill	.74	.29	.23*	--	.01	.13	.26*	.34**	-.04	-.05	.24*	.28*	.20
3 MapType	.49	.50	-.27*	.00	--	-.16	-.26*	.08	-.09	-.16	-.03	-.17	-.25*
4 CubeCompare	24.04	8.06	.17	.17	-.17	--	.58**	.46**	.25*	.24*	-.19	.27*	.25*
5 MapPlanning	22.59	8.02	.28*	.32**	-.24*	.55**	--	.49**	.28*	.43**	.11	.37**	.37**
6 PaperFold	12.35	3.69	.08	.29*	.07	.48**	.44**	--	.20	.43**	.16	.22	.32**
7 SBSOD	3.20	.89	.07	-.08	-.11	.21	.26*	.19	--	.46**	-.02	.33**	.49**
8 PSA	3.18	.91	.08	-.09	-.17	.25*	.41**	.38**	.52**	--	.23	.39**	.55**
9 PVA	2.90	.87	.01	.22	-.04	-.15	.19	.15	.07	.26*	--	-.02	.11
10 Metacog	3.61	.98	.21	.26*	-.18	.26*	.38**	.18	.32**	.38**	.01	--	.37**
11 AlloView	2.80	1.03	.21	.23	-.24*	.26*	.36**	.31**	.53**	.58**	.17	.37**	--

* $p < .05$, ** $p < .01$ (2-tailed)

Contrary to RH1—*Map comprehension scores of participants viewing a "best practices" hazard map will be significantly higher than those viewing an existing hazard map*—Table 2.4 shows that Map Type is significantly correlated only with Basic Skills and, unexpectedly, that correlation is negative (*r* = -.27). That is, participants who viewed HM2 tended to have lower Basic Map Skill scores than those who viewed HM1. Moreover, Map Type also has significant negative correlations with ETS Map Planning (*r* = -.24) and Allocentric View (*r* = -.24).

Mostly consistent with RH2—*Objective spatial ability scores and self-report spatial ability scores will have significant positive correlations with each other but nonsignificant correlations with verbal ability*—the three ETS spatial ability tests have significant positive correlations with each other (average correlation, $\bar{r}$ = .49) and all three have significant positive correlations with PSA ($\bar{r}$ = .35), and Allocentric View ($\bar{r}$ = .31). However, Map Planning has the highest correlations with these two variables (*r* = .41 and .36, respectively) and also with SBSOD (*r* = .26). Neither Cube Comparisons nor Paper Folding is significantly correlated with SBSOD. Although not hypothesized, the ETS Cube Comparisons and Map Planning tests have significant positive correlations with Metacognition ($\bar{r}$ = .32). Contrary to the hypothesis, PVA score has significant positive correlation with PSA (*r* = .26).

Partially consistent with RH3—*SBSOD scores will have significant positive correlations with PSA scores but will have distinctly different correlations with other variables*—SBSOD and PSA have a significant positive correlation (*r* = .52). Unexpectedly, however, they have similar positive correlations with Allocentric View ($\bar{r}$ = .56) and Metacognition ($\bar{r}$ = .35) The only notable difference in their patterns of correlations is that PSA is more strongly correlated with PVA (*r* = .25 vs. .07), but neither of these correlations is statistically significant.

Partially consistent with RH4—*Map comprehension scores will have significant positive correlations with objective spatial ability scores*—both Basic Map Skill (*r* = .28) and Advanced Map Skill (*r* = .32) have significant positive correlations with Map Planning. However, only Advanced Map Skill has a significant positive correlation with Paper Folding (*r* = .29) and neither map comprehension scale has a significant correlation with Cube Comparison.

Contrary to RH5—*Map comprehension scores will have significant positive correlations with self-report spatial ability scores*—the correlations of both map comprehension scales with all self-report spatial ability scales are nonsignificant.

The tests associated with RQ2—*Are map comprehension scores positively correlated with metacognitive awareness of performance?*—show that Metacognition has a significant positive correlation with Advanced Skills (*r* = .26) but not Basic Skill (*r* = .21), although the difference between these two correlations is not statistically significant. Although not hypothesized, Metacognition and Allocentric View have significant positive correlations with each other (*r* = .37).

<u>Ordinary Least Squares (OLS) Regression Analyses</u>

To further test the results from RH1 and RH4, Map Type and Map Planning were entered as potential predictors of Basic Map Skill and Advanced Map Skill. Table 2.5a shows the results of the analyses for the prediction of Basic Map Skill. The left-hand panel of table shows that, after entering Map Type at the first step, Map Planning failed to enter after that. Conversely, the right-hand panel shows that, after entering Map

Planning at the first step, Map Type, failed to enter after that. Table 2.5b shows the results of the analyses for the prediction of Advanced Map Skill. Map Type failed to enter at the first step (not shown) but as shown in the left panel, Map Planning did enter in the second step while Map Type remained nonsignificant. Conversely, the right-hand panel shows that, after entering Map Planning at the first step, Map Type, failed to enter after that.

To further test RH2, the self-report measures were entered as potential predictors of ETS scores. Table 6 shows that only PSA scores significantly predicted Paper Folding test scores (Adj R^2 = .10 in the left-hand panel) and Map Planning test scores (Adj R^2 = .14 in the right-hand panel), but not Cube Comparison scores (Adj R^2 = .04 in the center panel). SBSOD scores did not significantly predict any of the ETS scores.

The validity of OLS regression analyses depends upon four assumptions—(1) linearity of the relationships between the independent and dependent variables, (2) independence of errors, (3) homoscedasticity (constant error variance), and (4) normal distribution of errors. Tests following the procedures in Ott and Longnecker (2010, Chapter 13) were conducted for the data used in the regression analyses above and revealed that Assumption 1 is supported by scatterplots of map comprehension against each of the independent variables, which revealed no indication of curvilinearity. Moreover, Assumption 2 is reasonable because the data are cross-sectional so there is no serial autocorrelation. Finally, Assumption 3 is supported by residual plots showing approximately constant dispersion across all values of the independent variables, and Assumption 4 is supported by linearity in the *p-p* plots of the standardized residuals.

Table 2.5a Regression of Basic Map Skill Scores onto Map Type and Map Planning Scores

	Map Type Entered First					Map Planning Entered First				
	b^{*}	SE(b)	β	t	Sig.	b	SE(b)	β	t	Sig.
Constant	.87	.033		26.48	.00	.64	.074		8.59	.00
Map Type	-.11	.047	-.27	-2.40	.02					
Map Planning						.01	.003	.28	2.48	.02
	Adj R^2 = .06, $F_{1,73}$ = 5.78, p = .02					Adj R^2 = .07, $F_{1,73}$ = 6.15, p = .02				

Note. b^{*} denotes the unstandardized regression coefficient; *SE(b)* denotes the standard error of the regression coefficient; β denotes standardized regression coefficient.

Table 2.5b Regression of Advanced Map Skill Scores onto Map Type and Map Planning Scores

	Map Type Entered First					Map Planning Entered First				
	b^{*}	SE(b)	β	t	Sig.	b	SE(b)	β	t	Sig.
Constant	.44	.111		3.94	.00	.47	.097		4.89	.00
Map Type	.04	.067	.08	0.66	.51					
Map Planning	.01	.004	.34	2.94	.01	.01	.004	.32	2.87	.01
	Adj R^2 = .08, $F_{1,73}$ = 8.62, p = .01					Adj R^2 = .09, $F_{1,73}$ = 8.24, p = .01				

Note. b^{*} denotes the unstandardized regression coefficient; *SE(b)* denotes the standard error of the regression coefficient; β denotes standardized regression coefficient.

Discussion

RQ1: Can Map Comprehension Be Meaningfully Divided into a Basic Map Skill Scale and an Advanced Map Skill Scale?

The ability to interpret a hazard map is an important skill because many people need these hybrid visuospatial displays to determine whether they are in a hazard zone and, thus, need to take action to protect themselves from hazard impact. Basic and advanced map skills both require a degree of knowledge of mapping conventions and visuospatial skills. However, the results from the analyses of RQ1—*Can map comprehension be meaningfully divided into a basic Map Skill scale and an advanced*

Map Skill scale?—suggest that these two types of map skills are somewhat distinct because there were significantly higher scores on basic skill than on advanced skill and the two scales were not significantly correlated. More generally, the fact that scores on Basic Map Skill (M = .81) were substantially less than perfect poses a challenge for developers of hazard maps because it means that people make errors when using the two most fundamental elements of these displays—the compass and scale. Further research is needed to determine if this lack of basic map skill can be replicated in samples that are more representative of the broader population. However, it seems likely that map comprehension scores will be even lower in a general population sample than in a university student sample that has been selected specifically for its higher level of cognitive ability. If so, research will also be needed to identify the specific impediments to successful compass and scale utilization, and either develop training methods to improve basic skill or create displays that overcome these impediments.

RH1: Map Comprehension Scores of Participants Viewing a "Best Practices" Hazard Map Will Be Significantly Higher Than Those Viewing an Existing Hazard Map.

The lack of support for RH1 is quite surprising because Map Type not only had nonsignificant correlation and regression coefficients with Advanced Map Skill, it had a significant *negative* correlation with Basic Map Skill. A possible methodological explanation for the nonsignificant correlation and regression coefficients with Advanced Map Skill is that this variable has only modest reliability (α = .52), which would attenuate its correlation with other variables (Nunnally & Bernstein, 1994). However, this explanation is contradicted by the finding that Advanced Map Skill had significant correlations with other variables, so this scale seems to be measuring a meaningful construct even though its reliability is lower than is desirable. In any event, the map comprehension scales need further development to increase their psychometric quality.

An alternative explanation for the nonsignificant difference between map types is that there was essentially no meaningful difference between the two map types with respect to their demands for Advanced Map Skill. One variation of this explanation is that the changes made in transforming HM1 to HM2 were an inadequate operationalization of "best practices". Although this possibility cannot be ruled out definitively, it seems unlikely because—as noted above—the production of HM2 involved an extensive set of changes. A second variation of this explanation is that HM1, the existing map, was already quite good at meeting the participants' information needs with respect to advanced map skill, so the improvements implemented in HM2 had a minimal psychological impact on the participants. This explanation is consistent with the finding that HM1 already met many of the best practices. Thus, to better address this issue, further research should examine people's ability to process the information from hazard maps that encompass a wider range of quality with respect to the rubric elements in Table 2.1.

The explanation for the negative correlation of Map Type with Basic Map Skill involves the software used to create HM2, which was based on uploaded and formatted data and content in ArcGIS Story Maps. Story Maps software has many options but also has feature display limitations. For example, this software sets the map legend to pop-up *only when clicked*. As the first author watched people navigate HM2, it was apparent that many of them failed to click on the legend, which makes accurate interpretation almost impossible. By contrast, HM1 had a legend always visible. In addition, Story Maps also makes the scale bar a specific color independent of the base-map. Consistent with recommendations from previous studies, HM2 included an aerial image base map and the scale bar was dark grey. This made seeing the scale bar a bit challenging. By contrast, HM1 had a more visible scale bar and included measurement tools that could be used to measure distances precisely. Since the map comprehension test included questions about distance, this would also have contributed to slightly higher scores for HM1 viewers on Basic Map Skill.

RH2: Objective Spatial Ability Scores and Self-Report Spatial Ability Scores Will Have Significant Positive Correlations With Each Other But Nonsignificant Correlations With Verbal Ability.

The partial support for RH2 is consistent with previous research. Specifically, the PSA has moderately high correlations with Map Planning (r = .39) and Cube Comparisons (r = .36), and a noticeably lower, but still significant, correlation with Paper Folding (r = .23). By contrast the SBSOD had noticeably lower correlations with the three ETS tests (r = .26, .19, and .21, respectively). These results support the contention that the SBSOD and PSA, though highly correlated (r = .51), are indeed measuring somewhat different constructs (Hegarty et al., 2006).

Moreover, consistent with RH2, there are nonsignificant correlations of Paper Folding (r = -.04), Cube Comparisons (r = .14), Map Planning (r = -.14), and SBSOD (r = .06) with PVA. However, contrary to this hypothesis, PVA has a significant positive correlation with PSA (r = .25). It is not obvious why this is the case because all three of the ETS spatial ability tests and the SBSOD have instructions that are at about the same level of verbal complexity as those for the PSA. Thus, further research is needed to determine if this finding can be replicated and, if so, explained.

As a practical matter, the poor predictability of the ETS tests from the SBSOD and PSA, as shown in Table 2.6, is unfortunate because the ETS tests are timed and, therefore, must be administered in a carefully controlled setting such as a laboratory. By contrast, the SBSOD and PSA are untimed and can be administered in an uncontrolled setting such as a mail or Internet survey. In turn, this restriction in ETS test administration limits the types of population segments that can be tested using these scales. Consequently, further studies of the effects of spatial abilities on map comprehension should administer the ETS tests in controlled settings.

RH3: SBSOD Scores Will Have Significant Positive Correlations With PSA Scores But Will Have Distinctly Different Correlations With Other Variables.

Regarding RH3, the high correlation of the SBSOD and PSA is consistent with the Hegarty et al. (2006) conclusion that these two scales measure related but distinct types of spatial ability—the SBSOD measures spatial ability at the environmental scale (e.g., wayfinding) and the PSA measures spatial ability at the object scale (e.g., object manipulation). The support for this conclusion is particularly noticeable in the factor loadings in Appendix C. Moreover, the only significant correlation of the SBSOD with an ETS test is with the Map Planning test—the only one of these tests that assesses a skill approximating wayfinding at the object scale. Nonetheless, it is difficult to explain, given the assumption that the PSA measures object-scale spatial ability, that this scale's highest

Table 2.6 Regression of ETS Scores onto Self-Report Spatial Scale Scores

	Paper Folding					Cube Comparison					Map Planning				
	b^*	SE(b)	β	t	Sig.	b^*	SE(b)	β	t	Sig.	b^*	SE(b)	β	t	Sig.
Const.	7.52	1.73		4.35	.00	15.58	3.91		3.99	.00	10.18	3.69		2.76	.01
SBSOD	.06	.53	.02	.12	.90	1.15	1.20	.13	.96	.34	.67	1.13	.07	.59	.56
PSA	1.45	.53	.35	2.72	.01	1.50	1.21	.17	1.24	.22	3.23	1.14	.36	2.83	.01
	Adj R^2 = .10, $F_{2,72}$ = 5.25, p = .01					Adj R^2 = .04, $F_{2,72}$ = 2.49, p = .09					Adj R^2 = .14, $F_{2,72}$ = 6.82, p = .002				

Note. b^* denotes the unstandardized regression coefficient; *SE(b)* denotes the standard error of the regression coefficient; β denotes standardized regression coefficient.

correlation with an ETS test is also with the Map Planning test. The most logical explanation is that performance on the Map Planning test draws upon spatial ability at both the object and environmental scales. The present study extends this finding by showing that the PSA scale and Map Planning test have similar patterns of correlations with Allocentric View, and Metacognition, all of which have significant positive correlations with each other. However, the present results provide no support for the contention that the SBSOD and PSA have distinctly different correlations with other variables.

RH4a-b: Map Comprehension Scores Will Have Significant Positive Correlations With (a) Objective and (b) Self-Report Spatial Abilities Scores.

Partially consistent with RH4a, Map Planning was significantly correlated with Basic Map Skill (r = .27) and Advanced Map Skill (r = .32). In addition, Paper Folding was significantly correlated with Advanced Map Skill. (r = .29) but not Basic Map Skill (r = .08). However, Cube Comparison was not significantly correlated with either measure of map comprehension. These results suggest that the Map Planning test provides the most direct measure of the cognitive skills required for map comprehension.

Contrary to RH4b, neither the SBSOD nor the PSA was significantly correlated with Basic Map Skill (r = .07 and .08, respectively) or Advanced Map Skill (r = -.08 and -.08, respectively). Indeed, even the Allocentric View scale, which was constructed to be a self-report scale of map comprehension, lacked statistically significant correlations with the two map comprehension measures. The Allocentric View scale does not appear to have suffered from variance restriction (SD = 1.03 is approximately 20% of the scale range) or attenuation due to unreliability (α = .77), but there is some room for improvement in this scale and, as noted earlier, substantial room for improvement in the psychometric quality of the map comprehension scales.

RQ2: Do Participants Have a Metacognitive Awareness of Their Performance on Map Skills?

The results regarding metacognitive awareness showed that participants' assessments of their performance is significantly correlated with Advanced Map Skill. That is, those who were better at this task were able to assess their performance and conclude that the task was easier. This metacognitive accuracy is the opposite of the Dunning-Kruger effect, in which less competent people are oblivious to their own ignorance (Dunning, 2011). This finding suggests feedback from the task itself provided poor performers with an assessment of the quality of their performance. In turn, this suggests that map users who are experiencing difficulty are likely to recognize their need to use general Help tabs if these are readily accessible. Indeed, the lower performance associated with the absence of a continuously visible map legend in HM2 suggests that context-dependent help features would be a particularly useful addition to hazard maps.

Study Limitations & Opportunities for Future Work

The first study limitation is the sample; students are a subset of the general population that can be assumed to have higher levels of verbal and numeric abilities because they are explicitly selected for admission on the basis of these cognitive abilities. However, it is less clear whether they have higher levels of spatial ability because universities do not use this cognitive ability as an explicit selection criterion. If university students do indeed have generally higher levels of spatial ability, then the absence of those who score low on this ability would produce a reduced variance and, in turn, attenuate the estimates of the correlation in the general population (Nunnally & Bernstein, 1994). Thus, it is possible that use of a student sample underestimates the magnitude of the correlations found in this study. To overcome this sampling bias, future map comprehension studies should aim to recruit participants with a broader range of ages and abilities to be more representative of the population using these maps. With a more representative sample, we would expect larger correlations between variables. In practice, people may view hazard maps with a family member or friend, so future research could also include testing map comprehension in pairs or groups. Group discussion has been shown to improve reading comprehension (Fall et al., 2000) and may also improve map comprehension.

A second issue associated with this sample is that the students were not residents of the mapped area. This lack of familiarity with the area might have depressed map comprehension scores, especially for those with low spatial ability. To address this issue, future research on map comprehension should be conducted using samples of people who live in the mapped area.

A second study limitation arises from the type of map studied. Specifically, interactive hazard maps are fairly new, so this study is one of few investigating how people view and interpret dynamic map information. One consequence of the scarcity of prior studies on dynamic maps is that many of the recommendations used to update HM1 were made primarily for plan-form maps. It may be that people interpret maps differently when they are online versus in-print and that recommendations for one type do not apply well to the other. Thus, one future research objective should be to determine if providing the same hazard information on a plan-form and interactive map leads to comparable user comprehension levels.

A related issue is that, with the increasing use of interactive hazard maps, more research is needed on both single- and multi-hazard maps. Better understanding of how people navigate and use map features, how long they spend on the maps, and what kind of information they absorb are topics on which more research is needed. Assessment of the cognitive processes and cognitive abilities involved in map comprehension could also be expanded. More studies are needed to further identify which abilities predict map comprehension and how they are recruited in processing hazard maps (Padilla et al., 2017).

The third limitation concerns whether the regression models are specified correctly. The available literature on map comprehension indicates that many, if not most, of the relevant variables have been included in the model, but the models in Tables 2.5 and 2.6 only account for ~4-14% of the variation in the dependent variables. This means either that the variables included need to be measured more reliably or that there are omitted variables that were not included in the analysis. The estimated reliabilities for SBSOD ($\alpha = .89$) and PSA ($\alpha = .86$) are quite satisfactory, but those for Basic Map Skill ($\alpha = .54$), Advanced Map Skill ($\alpha = .52$), and PVA ($\alpha = .64$) have ample room for improvement. With regard to omitted variables, it is possible that adding measures of numeric ability would improve the prediction of map comprehension. Further study is needed to test these variables and to identify additional predictors of map comprehension.

Conclusions

This study provides a practical test of whether hazard map design and content recommendations are necessary to improve user comprehension of risk. We found that a "best practices" interactive map provided no improvement over an original interactive map. This may be because the original interactive map scored higher on the rubric than many other interactive maps. Consequently, although HM1 might be as effective as the "best practices" map (HM2), other hazard maps may need to be improved to reach the same degree of comprehension. Thus, government agencies should design their interactive hazard maps for the public by addressing the rubric elements in Table 2.1.

As expected, objectively measured spatial ability is an important determinant of peoples' ability to interpret map information. Specifically, spatial scanning, as measured by the ETS Map Planning test, was a somewhat better predictor of both measures of map comprehension than was spatial orientation (Paper Folding) or spatial visualization (Cube Comparison). Unexpectedly, however, self-reported spatial ability does not significantly predict map comprehension and poorly predicts objectively measured spatial ability.

Many of the studies referenced above use individual perceptions of map objects and information to develop map recommendations. Our results suggest that more quantitative metrics may be better. Nonetheless, the regression analyses accounted for only a small portion of the variation in map comprehension. More research is needed to better assess the degree to which different factors contribute to high map comprehension levels.

CHAPTER THREE: RESIDENTS' INFORMATION SEEKING BEHAVIOR AND PROTECTIVE ACTION FOR EARTHQUAKE HAZARDS IN THE PORTLAND OREGON METROPOLITAN AREA

Abstract

This study tests a proposed model of household seismic hazard adjustment using questionnaire responses of roughly 400 households living in the Portland, OR metro region. The proposed model includes components of the Protective Action Decision Model (PADM) with specific emphasis on assessing the role information seeking behavior plays in influencing past preparedness behavior, intentions to seek information, and intentions to take protective action. Consistent with previous research, we find information seeking behavior to have the strongest influence on preparedness. We found that risk perception, affective response, and intent to prepare are also important for protective action decision-making. We also investigate the influence seismic risk zone residency has on people's perceptions of earthquake risk. We find weak ties between risk zone residency and earthquake risk perception, though this may be because our sample has little experience with earthquakes and the majority are located in the same earthquake risk zones. Importantly, longitudinal studies are needed to determine whether information seeking and intentions to prepare eventually result in household protective action.

Introduction

As populations grow into hazard zones and the impacts of a changing climate are felt around the globe, the need to understand how to reduce disaster impacts becomes paramount. The responsibility for taking action to reduce disaster risk spans all levels of involvement, from the individual citizen through national governments (Aerts et al., 2018; Kuhlicke et al., 2020; Lindell, 2020a). Preparedness at the household level is at the foundation of disaster readiness, yet the majority of households remain underprepared (Ablah et al., 2009; Bourque et al., 2012). Additionally, attempts by the Federal Emergency Management Agency (FEMA) over the last decade to increase household preparedness have shown "little to no sign of improvement" (FEMA, 2019). Thus, the need to better understand what motivates household preparedness and mitigation actions has never been more relevant.

Over the past fifty years, disaster researchers focused on identifying to what degree certain factors influence households' strategies for coping with hazards, also referred to as *hazard adjustments* (Burton et al., 1993); despite this effort variability and gaps in knowledge remain. A collection of review papers summarizing past research on household hazard adjustment adoption helps to clarify how measures were assessed and characterize which ones appear to consistently correlate with household preparedness for floods (Andráško, 2021; Bamberg et al., 2017; Bubeck et al., 2012; Poussin et al., 2014) earthquakes (Lindell & Perry, 2000; Solberg et al., 2010), and other hazards (Lindell, 2013a). These summary papers suggest that a major impediment to the scientific understanding of hazard adjustment adoption is the variety of ways in which relevant variables, such as risk perception and preparedness, are measured, thus making comparisons across studies difficult. To remedy this issue, they recommend that future studies replicate existing measures across different locations and over time. In addition, these authors advise using theoretical frameworks to organize and understand variable relationships with respect to protective action decision-making. In doing so, existing theoretical frameworks can be tested and refined to uncover the main drivers of household hazard adjustment adoption.

One such theoretical framework is the Protective Action Decision Model (PADM), which synthesizes research on risk communication, disaster sociology, persuasion, and attitude-behavior relationships. This framework identifies the context needed to test how well-known variables such as hazard experience and risk perception impact peoples' decision to prepare for and respond to hazard threats. The PADM was proposed by Lindell and Perry (1992) and later revised (2004; 2012) to reflect available research findings and address unresolved issues. Since then, components of the PADM have been either well tested and supported (e.g., the relationship between female gender and risk perception), tested with mixed findings (e.g., the relationship between hazard experience and protective action adoption), or acknowledged to be unexamined (for additional examples, see Lindell, 2018). One significant limitation of PADM studies to date is the relative neglect of research on information seeking at times other than imminent threats, also called the 'continuing hazard phase' (Lindell & Perry, 2012). Thus, more study is needed to confirm or challenge the PADM's propositions regarding the role of information seeking in pre-disaster preparedness.

Another limitation in household preparedness research is that very few studies, other than FEMA's broad surveys of household emergency preparedness, re-examine the same constructs years later or in different locations (FEMA, 2018). Unfortunately, this restricts our understanding of whether the predictors of household preparedness persist or change over both space and time, and ultimately reduces the ability of this research to be practically applied to increase household preparedness.

To address the research gaps outlined above, this paper aims to test components of the PADM and their influence on seismic hazard adjustment adoption, investigate the influence of information-seeking behavior on seismic preparedness, and use previously implemented measures of preparedness and risk perception. The results of these efforts will provide a better understanding of how to effectively motivate preparedness at the household level.

Background

This study investigates PADM components that include information seeking behavior, threat/risk perception, risk zone residency, and demographic characteristics to understand their influences on household hazard adjustment adoption. The following sections summarize the research on these variables and existing knowledge gaps.

Earthquake Hazard Adjustments

Following Burton et al. (1993), Lindell and Perry (2000) defined hazard adjustments as protective actions that intentionally or unintentionally reduce risk from extreme events in the natural environment. That is, hazard adjustment adoption is equivalent to what many flood risk reduction researchers call ‘preparedness’ (Andráško, 2021, Bamberg et al., 2017; Bubeck et al., 2012; Poussin et al., 2014). To be consistent with FEMA’s typology of disaster phases, Lindell and Perry (2000, see also Lindell et al., 2006) further categorized household hazard adjustments as comprising hazard mitigation (e.g., strapping heavy objects down), emergency preparedness (e.g., gathering emergency supplies), and recovery preparedness (e.g., purchasing hazard insurance). They defined *hazard mitigation* as resources or actions that provide passive protection when a hazard occurs, whereas *emergency preparedness* supports active response at the time of hazard impact. Practically, the more hazard adjustments a household implements, the more prepared they are likely to be when a hazard occurs.

To address the need for re-examination of important research findings over time, we incorporate measures of preparedness, risk perception, and earthquake experience from those measured by the Lindell and Prater's (2000) Six Cities study. This study assessed sixteen hazard adjustments and found that earthquake experience and hazard intrusiveness (frequency of thought and discussion about the hazard), along with age and marital status, played a significant role in residents' seismic preparedness. These findings have not been tested for other Pacific Northwest regions, such as the Portland area, where the history of earthquakes is similar to that of the Seattle area at the time of Lindell and Prater's survey.

Earthquake Information Seeking

The concept of information seeking is a key component of many models that investigate decision making and behavior change in response to risk, such as the Risk Information Seeking and Processing (RISP; Griffin et al., 1999), Planned Risk Information Seeking Model (PRISM; Kahlor, 2010), and PADM (Lindell & Perry, 2012). Irrespective of the type of risk, which can include health or hazard, information seeking is a process that individuals go through when they perceive a risk but lack enough information to make a decision about whether or how to respond. Research suggests people remain in this "milling" (Michele M. Wood et al., 2018) phase until they feel they have enough information to move forward with a protective action, although they may return to this phase when circumstances change (Lindell & Perry, 2012).

Models suggest that information seeking behavior depends upon a combination of variables that include, but are not restricted to, *individuals' characteristics* (e.g., hazard experience, hazard knowledge, risk perception, affective responses, personal values, attitudes toward information seeking, perceived information insufficiency, information seeking subjective norms, information seeking control, and demographic characteristics), *perceived ability to collect information*, and *perceptions of information source and channel characteristics*. In addition, information search is influenced by the relative importance of people's concern about accuracy vs. consistency with existing beliefs (Hart et al., 2009). The search for accurate information is more important when people are uncertain about a threat than when they are uncertain about the efficacy of protective actions (Goodall & Reed, 2013; Howell & Shepperd, 2012).

Though significant research exists on earthquake hazard adjustment adoption more generally, very little exists on earthquake information seeking other than findings that show it being strongly correlated with preparedness (Mileti & Darlington, 1997; Mileti & Fitzpatrick, 1992). In the PADM, information seeking is one of the three behavioral responses along with protective response and emotion-focused coping. By better understanding the connection between information seeking behavior and seismic hazard adjustment adoption, a goal of our study, risk communication and education materials can be better tailored to meet community needs.

<u>Earthquake Risk Perception</u>

Across studies, risk perception appears to play an important, though complicated, role in hazard adjustment adoption. Consistent with findings from flood studies, seismic risk perception is frequently correlated with hazard adjustment adoption, but some studies fail to find this relationship (Lindell, 2013a; Lindell & Perry, 2000; Solberg et al., 2010). A number of reasons can explain the inconsistent findings.

First, studies differ in their measures of risk perception making comparisons difficult (Kirschenbaum, 2005). For example, Peers et al. (2021) recently noted that some researchers define risk perception in terms of dread and unknown risk (Slovic, 1987), while many others use an expectancy value (EV) model. EV formulations, which date at least to Withey (1962), define risk perception by the perceived probability and consequences of an event (for a review of EV models, see Kruglanski & Stroebe, 2005). EV models of risk perception have been operationalized in Protection Motivation Theory by severity and vulnerability (Rogers, 1975) and in the PADM by the probability of consequences such as death, injury, property damage, and disruption to daily activities within a defined period of time (Lindell & Perry, 1992).

Second, an individual's risk perception can change over the course of the two stages of the hazard adjustment adoption process (Bubeck et al., 2012; Weinstein & Nicolich, 1993). Stage one occurs between when someone becomes aware of a hazard and when they adopt one or more hazard adjustments, whereas stage two happens after they adopt hazard adjustments. Specifically, having an elevated risk perception in the first stage of the process may motivate increased preparedness which, in turn, would then lower risk perception in the second stage. Cross-sectional surveys that only ask which hazard adjustments respondents have adopted without also asking which adjustments they intend to adopt may find nonsignificant correlations of risk perception with hazard adjustment adoption if the sample comprises roughly equal numbers of respondents in each stage of the hazard adjustment adoption process.

Third, it is also possible that increased risk perception will not lead to increased preparedness if people see the costs of preparing to be greater than their perceived risk or if they do not feel personally responsible for reducing those risks (Wachinger et al., 2013). If the caveats above are considered, measures of risk perception can still provide valuable insight into the process of preparedness.

Fourth, following Fishbein and Ajzen's (1975) distinction between an attitude toward an object and an attitude toward a behavior related to that object, Lindell and Perry (2004; 2012) noted that risk perception motivates the adoption of hazard adjustments but does not specify which hazard adjustment to adopt. Thus, risk perception is more likely to predict the number of hazard adjustments, whereas perceptions of the attributes of a hazard adjustment will be the best predictors of that hazard adjustment's adoption (for a more recent statement, see Ajzen & Fishbein, 2005).

In addition to its effect on hazard adjustment adoption, risk perception is also thought to influence information seeking. In the information seeking models described above, authors suggest that the motivation to seek additional information is influenced, in part, by the perceived risk (Dunwoody & Griffin, 2014; Griffin et al., 1999; Kahlor, 2010). For example, if people perceive a significant earthquake risk but are uncertain about how to reduce it, they may seek information about the hazard or hazard adjustments before taking protective actions. However, additional information may or may not increase people's risk perceptions (Kasperson et al., 1988). Of course, tests of the information seeking process are subject to the same causal ambiguity as preparedness actions.

Finally, there is some evidence that risk perception, defined as expected personal consequences of hazard impact, is correlated with affective responses (H.-L. Wei & Lindell, 2017). In turn, affective responses are correlated with people's responses during earthquakes (for a review, see Goltz et al., 2020), as well as their information seeking and hazard adjustment adoption before and in anticipation of an earthquake (Becker et al., 2012; Dooley et al., 1992; Doyle et al., 2018; Heller et al., 2005; Sun & Xue, 2020; R. H. Turner et al., 1986). In summary, risk perception and affective responses are important to examine as components of the household hazard adjustment process. Future research is needed to uncover why some studies find strong relationships between risk perception and hazards adjustment adoption, whereas others do not.

Earthquake Risk Zone Residence, Personal Experience, and Hazard Awareness

The influence of risk zone residency (i.e., living on or near a hazard source) on information seeking and hazard adjustment adoption is ambiguous. Some studies report that risk zone residency leads to higher risk perceptions and levels of hazard adjustment adoption, whereas others suggest the opposite (Lindell & Perry, 2000). One explanation for the inconsistent results is that prior experience with hazards and the severity of impacts, rather than merely living in a risk zone, influence risk perception and hazard adjustment adoption (T. K. McGee et al., 2009). Lindell and Perry (2000) and Solberg et al. (2010) conclude that earthquake experience consistently increases risk perception and, somewhat less consistently, hazard adjustment adoption. More recently, Demuth (2018) drew similar conclusions about the relationship between experience of severe weather and risk perception. These findings can be explained by the results from Lindell and Hwang (2008), which indicate that personal experience mediates the relationship of hazard proximity with risk perception and hazard adjustment adoption. Indeed, following the 2011 M9.0 Tohoku earthquake and tsunami, Japanese residents had higher earthquake anxiety levels (Nakayachi & Nagaya, 2016) and increased preparedness levels (Onuma et al., 2017). This relationship also implies that individuals who experience a mild event—or none at all, as is the case with Oregonians and a major earthquake—may form risk perceptions that underestimate the threat and, thus, fail to motivate protective action. This misalignment, which has been found in studies focused on both hurricane (Hasan et al., 2011) and wildfire (T. K. McGee et al., 2009) hazards, can be explained by the ways in which people interpret their experience (Baker, 1991; Demuth et al., 2016; Lindell & Perry, 2000). Additionally, Becker et al. (2017) note that different types of experience (direct, indirect, and vicarious) influence preparedness outcomes.

Research has also found that, despite residing in hazardous areas, people are inconsistently aware of their risk, which may be a result of nonexistent, inconsistent, or ineffective hazard education programs. Emergency management agencies employ hazard education programs to help people develop hazard awareness and motivate preparedness. Unfortunately, the effectiveness and prevalence of these programs are unknown since few hazard awareness programs are evaluated (Lindell et al., 1997; 2020). In the absence of comprehensive hazard awareness programs, many communities have hazard maps that are available through local government agency websites. However, these sites might not be well known to local residents and their contents might be difficult to understand (Hwang et al., 2001; Lindell, 2020b; MacPherson-Krutsky et al., 2020).

Even with access to hazard maps, residents seem to have trouble correctly identifying their risk zone. Arlikatti et al. (2006) and Zhang et al. (2004) found that, when presented with a map of hurricane hazard zones, between one- and two-thirds of residents could not correctly identify their hazard zone. These findings are supported by a study of tsunami evacuation maps in three Pacific Coast communities, which found that only 41 percent of those *who lived outside* the tsunami zone correctly interpreted their risk zone, whereas 29 percent thought they were inside, and 30 percent did not know (Lindell et al., 2019). By contrast, 84 percent of those *who were inside* the tsunami zone correctly interpreted their risk zone, while 10 percent thought they were outside, and 6 percent did not know. There were notable differences across the three communities, which might be due to differences in local tsunami hazard awareness programs. In summary, these studies suggest that residence in a hazard zone might have only a modest correlation with hazard adjustment, given that people may not be aware of their risk especially when a hazard rarely occurs.

Though links between risk zone residency, hazard experience, and perceived risk zone appear relevant, the extent to which they influence hazard adjustment adoption requires more study.

Individual and Household Characteristics

Research shows that household and individual characteristics have small and inconsistent influences on overall seismic hazard preparedness (Lindell, 2013b; Lindell & Perry, 2000; Solberg et al., 2010). Specifically, Lindell's (2013) review of North

American studies on hazard adjustment adoption found that characteristics such as female gender, education, income, age, and white ethnicity had weak and inconsistent relationships both in terms of significance and direction. Other demographic characteristics, such as marital status, children in home, and homeownership, had too few results to make reliable classifications. These findings suggest that *audience segmentation*, the use of specific characteristics to target underprepared populations, may not be an effective tactic for emergency management programs. Thus, further research is needed to identify the role, if any, demographic characteristics play in the hazard adjustment adoption process

Study Hypotheses

The influence of risk zone residency, hazard experience, risk perception, and affective reactions on information seeking and hazard adjustment adoption are illustrated in Figure 3.1, which extends Lindell and Hwang's (2008) model of hazard adjustment adoption and yields four research hypotheses.

H1: Residence in a severe earthquake shaking zone or liquefaction zone, or having earthquake experience, will be significantly correlated with past information seeking and past hazard adjustment adoption.

H2: Past information seeking and past hazard adjustment adoption will be significantly correlated with higher risk perceptions, affective responses, and knowledge of what to do during an earthquake.

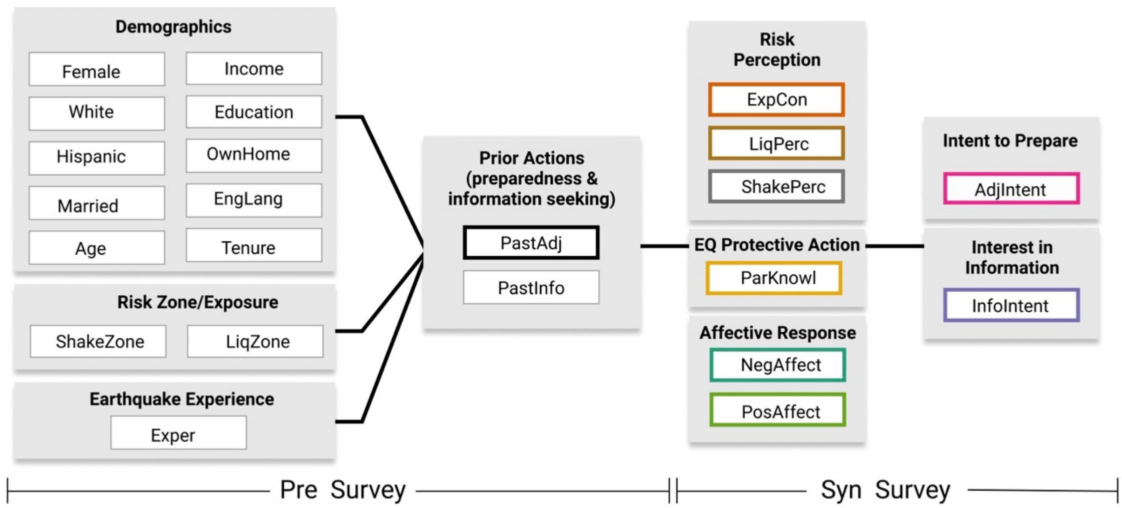

Figure 3.1 Hypothesized model relationships for information seeking and hazard adjustment variables.

H3: Risk perception, affective responses, and earthquake response knowledge will be significantly correlated with earthquake information search intentions and hazard adjustment adoption intentions.

H4: Past information seeking will be significantly correlated with past hazard adjustment adoption and information seeking intentions will be correlated with hazard adjustment adoption intentions.

Methods

Study Area

The Portland Metropolitan Area (PDX) is home to more than 2.5 million people and includes both urban and rural areas. At the heart of this region is the City of Portland, which is environmental hazards that include extreme summer and winter weather, flooding, and landslides, but most destructive of all is the potential for Cascadia Subduction Zone (CSZ) earthquakes (SIMT, 2020). Stretching from southern Canada to northern California, the CSZ can produce an M8.0 or greater earthquake, the likes of which has not been felt since 1700. Simulations suggest that such an earthquake would cause significant shaking, liquefaction, and landslides across western Oregon (Bauer et al., 2018), and cost tens of billions of dollars in damage (SIMT, 2020).

Despite their proximity to this major fault system, Oregonians have experienced fewer damaging earthquakes than their Washington neighbors to the north and California neighbors to the south (Hake, 1976; USGS, 2020). Local emergency management agencies responded to this and other hazards by developing the Regional Disaster Preparedness Organization (RDPO), a collaborative group that spans the five counties comprising PDX, to proactively plan across jurisdictions. In addition, the Oregon Public Broadcasting news service created an entire section devoted to articles highlighting the CSZ earthquake potential and areas for improvement. The section is aptly termed "Unprepared." Given the hazard potential and efforts across the region, PDX is an excellent place to better understand residents' current hazard adjustment adoption levels and how to improve them before "the Big One" happens.

Sample

During September and October 2019, we mailed questionnaires to a random sample of 2415 addresses that the Marketing Systems Group provided in Oregon's Columbia, Clackamas, Multnomah, and Washington counties. After 159 packets were returned as undeliverable, the sample included 2257 valid addresses. To participate in the survey, individuals had to be 18 years of age or older and living in one of the four counties. As an incentive to participate, we offered entry into a drawing to win two $50 Amazon gift cards. Questionnaire packets included a web link so participants could

Table 3.1 Demographic comparisons between sample and region (*From 2014-2018 Census)

	Sample	4-metro Counties*	Oregon State*
65 years or older (%)	31.9	15.9	17.6
Female (%)	57.6	50.4	50.4
White (%)	84.8	85.2	86.8
Home ownership (%)	75.4	65.0	61.9
Education, bachelor's degree or higher (%)	71.6	35.7	32.9
Household size (number of people)	2.4	2.6	2.5
Median Income	$82,813	$69,665	$59,393

choose to take the questionnaire electronically. A total of 403 people responded to the survey for a response rate of 17.8%, 88.6% of whom returned the questionnaire by mail and 11.4 % completed it online. A comparison of the sample demographics with Census information for the region is in Table 3.1. The sample is reasonably representative of the four counties and Oregon State with respect to race, household size, and sex. However, the respondents are older, have higher income, and are more educated than the region as a whole, which is consistent with other recent studies on environmental hazards (Brody et al., 2017; Lindell et al., 2017; Peers et al., 2020).

Survey Instrument

The questionnaire included 30 items measuring demographics, hazard zone location, earthquake experience and knowledge, risk perception and affective response, past hazard adjustment adoption, hazard adjustment adoption intentions, past information search, and information search intentions (Table 3.2; see Appendix B for questionnaire). In an effort to replicate measures, four questions with sub-items were incorporated from the Lindell and Prater (2000) Six City study. We used three styles of questions formats

Table 3.2 Measures

Variable description	Values	Label
Demographics		
Sex	Female = 1, Male = 0	Female
White ethnicity	White = 1, non-White = 0	White
Hispanic ethnicity	Hispanic = 1, non-Hispanic = 0	Hispanic
Marital Status	Married = 1, non-married = 0	Married
Age	22 to 94	Age
Income	Below $25K = 1 to above $100K = 5	Income
Education	Elementary = 1 to Graduate Degree = 6	Educ
Home Ownership	Own home =1, else = 0	HomeOwn
Language	English is primary = 1, else = 0	EngLang
Community tenure (time in a community)	0 to 76yrs	Tenure
Actual Risk Zone		
In severe earthquake shaking zone	Strong =1, Very strong = 2, Severe = 3	ShakeZone
In liquefaction zone	inside zone = 1, outside = 0	LiqZone
Earthquake Experience		
Experienced earthquake impacts (damage to city/property, death or injuries to people in your city/family, disruption to services)	No experience = 1 to Experienced all = 2	Exper
Prior Actions (information seeking and preparedness)		
Received/searched for earthquake risk information across sources (print media, broadcast media, internet, social media, peers, community groups, local emergency mgmt. groups)	Not at all =1 to Very great extent = 5	PastInfo
Hazard adjustments taken at time of survey	Have done = 1, else = 0	PastAdj

Affective Response & PAR knowledge		
Feeling optimistic, energetic, and alert toward the possibility of an earthquake	Not at all =1 to very great extent = 5	PosAff
Feeling depressed, nervous, and fearful toward the possibility of an earthquake	Not at all =1 to very great extent = 5	NegAff
Intended action during an earthquake	Drop, cover, and hold on =1, other = 0	ParKnow
Risk perception		
Expected earthquake consequences (damage to city/property, death or injuries to ppl. in own city/family, disruption to services) in next 10 years	Low expectations = 1 to High expectation = 5	ExpCon
Perceived earthquake risk zone	Inside= 2, Unsure = 1, Outside = 0	ShakePerc
Perceived liquefaction zone	Inside = 2, Unsure = 1, Outside = 0	LiqPerc
Intentions (information seeking and preparedness)		
Interest in receiving information related to earthquakes and hazards science, actions to take before, during and after an earthquake, how to get locally involved in disaster prep.	Not at all =1 to Very great extent = 5	InfoIntent
Hazard adjustments planned	Haven't done, but plan to = 1, else = 0	AdjIntent

including five-point Likert type items, multiple choice, and text entry. Fourteen questions were five-point Likert type items rated from *Not at all* (=1) to *Very Great Extent* (=5), 12 were multiple choice, and four were text entry.

Earthquake experience and knowledge were measured by asking respondents if they had experienced an earthquake that caused damage to property in their city, deaths or injuries to people in their city, damage to their home, injury or deaths to their family, or disruption to utilities. We generated the experience variable, Exper (α = .70), by computing the average rating across all five items. To measure earthquake protective action recommendation (PAR) knowledge, respondents were asked to select one of five possible actions they would take if earthquake shaking started while they were at home. We generated the variable, ParKnow, by recoding the responses into two categories, the recommended action of "Drop, cover, and hold on" (= 1) and all other responses (= 0).

To assess risk perception, we asked respondents to estimate how likely it was that an earthquake would occur in the next ten years that would cause damage to property in their city, deaths or injuries to people in their city, damage to their home, injury or deaths to their family, and disruption to utilities. This question and phrasing were taken directly from the Lindell and Prater (2000) questionnaire. We computed the average rating across the five sub-items in this question to generate the ExpCon variable (α = .92). A second risk perception question asked respondents to answer whether they thought their home was in a severe earthquake shaking zone (ShakePerc) or a liquefaction zone (LiqPerc). They could answer No (= 1), Unsure (= 2), or Yes (= 3). Affective responses were measured by three positive (optimistic, energetic, alert; PosAff α = .58) and three negative (depressed, nervous, fearful; NegAff $\alpha = .89$) items. The three measures of risk perception and two measures of affective response were kept separate for analyses.

We determined respondents' actual risk zones by using ArcMap to overlay the latitude and longitude of the respondents' addresses onto the Oregon Department of Geology and Mineral Industries Cascadia earthquake shaking layer (Bauer et al., 2018; Madin & Burns, 2013) and liquefaction susceptibility layer (Madin & Burns, 2013). The Cascadia shaking layer is the modelled ground shaking measured as peak ground acceleration during a CSZ earthquake. We converted peak ground acceleration values to Modified Mercalli Intensities (MMI) using the Wald et al. conversion table (1999). The MMI values in the study area are strong (MMI 6), very strong (MMI 7), and severe (MMI 8) shaking and were coded as 1, 2, and 3 for the ShakeZone variable, respectively. We coded liquefaction susceptibility categories for the LiqZone variable into none (=0) and liquefaction possible (=1; low, moderate, and high susceptibility).

To assess hazard adjustment adoption, we asked respondents whether they had adopted each of 16 emergency preparedness (e.g., wrenches to shut off utilities) and hazard mitigation measures (e.g., installed latches to keep cabinets closed; See Suppl. 1). They could select *No* (= 0), *Have not, but plan to do/get* (= 1), or *Yes* (= 2). All these items, which are used for basic survival, planning, or hazard mitigation, were selected from the Lindell and Prater (2000) study and amended based on feedback from local emergency managers. For the preparedness items, we added a 1-week supply of medicines, flashlight with batteries, non-electric can opener and increased 4-day to 2-week supply of food. For the mitigation measures, we omitted purchased hazard insurance, joined a community organization, and wrote a letter supporting action about earthquake hazards since Lindell and Prater (2000) reported low levels of adoption for these items.

From these items, we developed two hazard adjustment scales. The first scale, PastAdj (α = .71), represents hazard adjustments people had already completed at the time of the survey. The responses to the 16 items were coded as 1 if an adjustment had been completed and 0 if the respondent either had not done it but planned to do it or did not plan to do it. The PastAdj measure is the average across all items. The second scale, AdjIntent (α =.74), represents people's intentions to perform hazard adjustments. The responses to the 16 items were coded as 1 if respondents had not done it but planned to do so, and 0 otherwise. We then calculated an average across all items to measure AdjIntent.

We also asked participants to what extent *(not at all = 1 to very great extent= 5)* they had received or searched for risk and preparedness information from a list of seven sources (see Table 3.2). We calculated an average score, PastInfo (α = .77), across all seven sources. To assess interest in further earthquake risk and preparedness information, we asked participants to what extent they wanted to receive five types of risk and preparedness information (see Table 3.2). The average value of these items became the InfoIntent variable (α = .88).

Procedure and Analyses

We sent as many as four waves of survey materials until we received a response. Waves one and three consisted of full packets containing a cover letter, a letter of support from the Portland Metro RDPO, a questionnaire, a card to request additional hazard educational materials, and a stamped return envelope. Waves two and four were postcards reminding participants to fill out and return their questionnaires. We sent each wave within 7-12 days of the previous one.

Pearson correlations, Ordinary Least Squares (OLS) regression analysis, and Multivariate Analysis of Variance (MANOVA) are used to test the four research hypotheses. In the analyses that follow, there are 210 statistical tests on correlation coefficients and 127 on regression coefficients, so experiment-wise error rate is a concern (Ott & Longnecker, 2010). Specifically, the expected number of false positive tests would be FP = α x n, where FP is the number of false positive test results, α is the Type I error rate, and n is the number of statistical tests. If $\alpha = .05$ and $n = 337$, then FP = 34. Benjamini & Hochberg, (1995, [see Glickman et al., 2014]), for a more recent discussion) advocated that researchers (1) specify a false discovery rate d for the entire study, (2) sort the p_i significance values for the individual tests in ascending order $1 \leq i \leq n$, and (3) classify each $p_i \leq d \times i/n$ as statistically significant. Thus, only $p < .01$ is considered statistically significant.

Results

Correlational Analysis

As indicated in Table 3.3, there is no support for H1*, Residence in a severe earthquake shaking zone or liquefaction zone or having earthquake experience will be significantly correlated with past information seeking and past hazard adjustment adoption.* Specifically, shake zone, liquefaction zone, and experience had nonsignificant

Table 3.3 Means, Standard Deviations, and Pearson Correlations

	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1. Female	.58	.49	1																					
2. White	.85	.36	.03	1																				
3. Hispanic	.03	.17	-.01	-.41*	1																			
4. Married	.61	.49	-.20*	.06	-.02	1																		
5. Age	54.6	16.6	-.05	.13	-.01	.04	1																	
6. Income	3.6	1.37	-.22*	.01	-.06	.48*	-.16*	1																
7. Education	4.9	.93	-.05	-.01	.00	.09	-.14*	.38*	1															
8. OwnHome	.75	.43	-.11	.09	-.15*	.34*	.35*	.35*	.11	1														
9. EngLang	.99	.12	.05	.26*	-.53*	.05	-.04	.16*	-.01	.14	1													
10. Tenure	19.2	17.56	-.09	.13	-.08	.04	.50*	-.04	-.17*	.36*	.06	1												
11. ShakeZone	2.02	.30	-.06	.00	.04	-.05	-.06	.01	.04	-.05	-.07	-.05	1											
12. LiqZone	.53	.50	.07	-.02	.10	-.07	.08	-.07	-.04	-.15*	-.11*	-.07	.18*	1										
13. Exper	1.17	.24	.01	-.10	.07	-.06	.12	-.03	.04	.01	.06	.01	.06	-.01	1									
14. PastInfo	2.26	.81	.10	-.02	-.05	.02	.12	-.05	.10	.07	-.05	-.04	.05	.03	.11	1								
15. PastAdj	.54	.18	-.08	.05	.01	.29*	.24*	.21*	.12	.33*	.07	.15*	.05	-.02	.11	.35*	1							
16. PosAff	2.03	.73	.02	-.18*	.09	-.03	.15*	-.10	-.10	-.03	-.03	.10	-.01	.01	.10	.25*	.05	1						
17. NegAf	2.40	1.07	.25*	-.15*	.00	-.02	-.22*	.04	.09	-.05	.00	-.13	-.08	-.10	-.06	.20*	-.14*	.25*	1					
18. ParKnow	.37	.48	.14*	.02	-.03	.01	-.04	-.02	.03	-.02	.04	.01	.05	.08	.07	.24*	.11	.10	.20*	1				
19. ExpCon	2.96	.88	.28*	.03	-.05	.01	.01	-.18*	-.16*	.00	.03	-.07	.01	-.01	.03	.23*	.05	.19*	.29*	.08	1			
20. ShakePerc	1.45	.68	-.01	.08	.00	.12	-.11	.17*	.14*	.11	.05	.04	.11	-.03	.13	.07	.12	-.11	.05	.13	.10	1		
21. LiqPerc	1.71	.58	.10	-.04	.12	-.10	-.12	-.04	-.05	-.10	-.10	-.08	-.09	.17*	-.10	-.06	-.10	.00	.15*	-.01	.09	.21*	1	
22. InfoIntent	3.59	1.05	.07	-.06	.07	.01	-.07	-.08	-.05	-.06	-.03	-.01	-.07	-.07	.02	.16*	-.07	.19*	.32*	.03	.31*	.07	.09	1
23. AdjIntent	.11	.14	.10*	-.19*	.08	-.13	-.04	-.16*	.06	-.10	-.12	-.13	-.08	-.07	-.03	.17*	-.28*	.16*	.26*	.02	.13	.09	.15*	.20*

*Correlation is significant at the 0.01 level (2-tailed) correlations with PastInfo and PastAdj ($\bar{r}$ = .06). Although not hypothesized, shake zone, liquefaction zone, and experience also had nonsignificant correlations with the two affective response variables ($\bar{r}$ = -.02), ParKnow (*r* = .07), the three risk perception variables ($\bar{r}$ = .02), InfoIntent (*r* = -.04), and AdjIntent (*r* = - .06). However, it is important to note that the overwhelming majority of the respondents were located in the very strong (91%) shaking zone and very few of them were located in the strong (4%) or severe (5%) zones. Thus, it is possible that true correlations of ShakeZone with other variables were obscured by variance restriction in the shaking zone variable (Nunnally & Bernstein, 1994). The fact that the respondents reported very low levels of earthquake experience (58% had no direct experience) suggests that correlations of this variable with other variables might also have been obscured by variance restriction.

Table 3.3 indicates that there was some mixed support for H2, *Past information seeking and past hazard adjustment adoption will be significantly correlated with higher risk perceptions, affective responses, and knowledge of what to do during an earthquake.*

The average correlation of PastInfo with the two affective response variables and ParKnow was significant ($\bar{r}$ = .23), as was the correlation with ExpCon (*r* = -.23), but not the risk zone perception variables ($\bar{r}$ = .01). In contrast, the average correlation of PastAdj with the two affective response variables and ParKnow was not significant ($\bar{r}$ = .01), nor was the correlation with ExpCon (*r* = .05) or with the risk zone perception variables ($\bar{r}$ = .01).

There was also mixed support for H3*, Risk perception, affective responses, and earthquake response knowledge will be significantly correlated with earthquake information search intentions and hazard adjustment adoption intentions.* InfoIntent was significantly correlated with the affective response variables ($\bar{r}$ = .26) and ExpCon (*r* = .31), but not ParKnow (*r* = .03), or the risk zone perception variables ($\bar{r}$ = .08). Moreover, AdjIntent was significantly correlated with the affective response variables ($\bar{r}$ = .21) and LiqPerc (*r* = .15), but not ParKnow (*r* = .02), ExpCon (*r* = .13), or ShakePerc (*r* = .09).

We found stronger support for H4, *Past information seeking will be significantly correlated with past hazard adjustment adoption and information seeking intentions will be significantly correlated with hazard adjustment adoption intentions.* Table 3.3 shows that PastInfo is correlated *r* = .35 with PastAdj and InfoIntent is correlated *r* = .20 with AdjIntent. Although not hypothesized, PastInfo is correlated *r* = .16 with InfoIntent and *r* = .17 with AdjIntent, but PastAdj is correlated *r* = -.07 with InfoIntent and *r* = -.28 with AdjIntent.

Regression Analysis

The regression analyses presented in Table 3.4 and Figure 3.2 show a modest degree of support for the model in Figure 3.1. In Stage 1 of the model, three demographic variables (Married, Age, and OwnHome) and PastInfo are significant predictors of PastAdj (Adj R^2 = .24) but, contrary to H1, the prediction of PastInfo was not statistically significant.

Nonetheless, in Stage 2, PastInfo significantly predicts ExpCon (Adj R^2 = .13), ParKnow (Adj R^2 = .05), PosAff (Adj R^2 = .07), and NegAff (Adj R^2 = .14). LiqZone is the only significant predictor of LiqPerc (Adj R^2 = .03). Moreover, although not predicted by H2, Female gender also has significant regression coefficients in the prediction of ExpCon and NegAff. Education also significantly predicts ExpCon and White significantly predicts PosAff. Additionally, contrary to the model, there were no

Table 3.4 Regression models for PastAdj, AdjIntent, and associated intermediary variables.

	Stage 1			Stage 2[b]									Stage 3					
	1.DV: PastAdj			2.DV: ExpCon			2. DV: PosAff			2. DV: NegAff			3. DV: InfoIntent			3. DV: AdjIntent		
	b	**SE(*b*)**	**β**	***b***	**SE(*b*)**	**β**	***b***	**SE(*b*)**	**β**	***b***	**SE(*b*)**	**β**	***b***	**SE(*b*)**	**β**	***b***	**SE(*b*)**	**β**
(Constant)	.19	.04		2.90	.25		1.85	.14		2.57	.23		2.19	.19		.15	.02	
Female				.42	.08	.24				.39	.10	.19						
White							-.30	.10	-.20									
Married	.08	.02	.22															
Age	.00	.00	.14							.00	.00	-.20						
Education				-.10	.04	-.20												
OwnHome	.08	.02	.18															
PastInfo	.07	.01	.30	.23	.05	.21	.20	.04	.22	.31	.07	.24				.05	.01	.28
PastAdj										-.90	.29	-.20				-.30	.04	-.40
NegAffect													.23	.05	.23			
ExpCon													.28	.06	.24			
	Adj R^2 = .24			Adj R^2 = .13			Adj R^2 = .07			Adj R^2 = .14			Adj R^2 = .14			Adj R^2 = .14		
	$F_{4, 398}$ = 33.18			$F_{3, 394}$ = 20.34			$F_{2, 397}$ = 16.24			$F_{4,398}$ = 16.70			$F_{2, 390}$ = 32.12			$F_{2, 398}$ = 34.20		
	p = .00			p = .00			p = .00			p = .00			p = .00			p = .00		

[a.] Values are significant at p = 0.01.

[b.] The models for LiqPerc, ShakePerc, and ParKnow had only one significant predictor each, so multiple regression

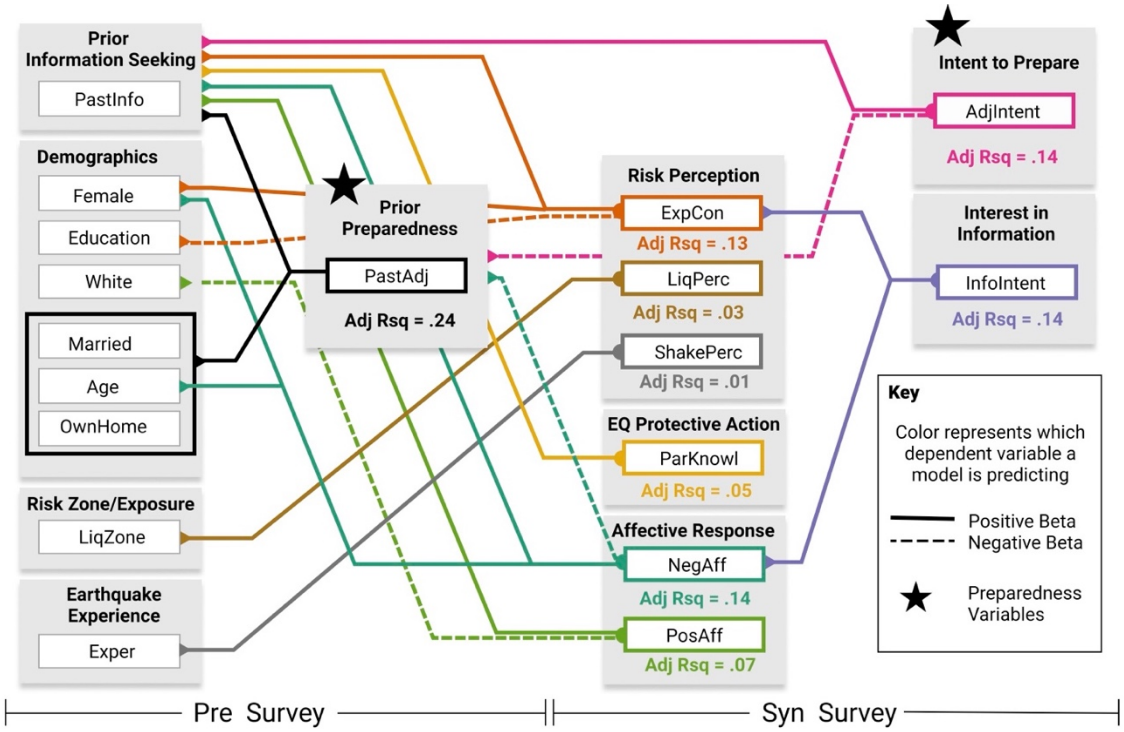

Figure 3.2 Revised model relationships for information seeking and hazard adjustment variables. The ShakePerc model is not significant at p=0.01.

significant predictors for ShakePerc. Finally, the analysis of Stage 3 shows that ExpCon, and NegAff are the only significant predictors of InfoIntent (Adj R^2 = .14) and PastInfo and PastAdj are the only significant predictors of AdjIntent (Adj R^2 = .14).

Discussion

<u>The influence of risk zone residency and experience on information seeking and hazard adjustment adoption</u>

The missing support for H1 is due to lack of relationships among variables, which is consistent with some previous studies, and issues with the risk zone residency and experience measures. We found neither of the two risk zone variables nor earthquake experience to predict past hazard adjustment adoption. These results for the risk zone variables are not completely surprising given the inconsistency of relationship between hazard proximity and hazard adjustment adoption in the studies reviewed by Lindell and Perry (2000) and the indirect relationship that hazard proximity has with hazard adjustment adoption (Lindell & Hwang, 2008). In addition, the absence of a significant correlation of experience with hazard adjustment adoption is consistent with most previous studies (Lindell & Perry, 2000), although direct effects were reported by Lindell and Prater (2000) and Lindell & Hwang (2008). Similarly, neither of the two risk zone variables nor earthquake experience predict past information seeking, which is consistent with findings by Mileti and Darlington (1997).

With regards to the variable measures, we only assessed *direct* experience with earthquake hazards, which was quite low in our sample, and the majority of people were located in one of the three shaking zones, restricting the variance of both the experience and shaking zone variables. Future studies could approach this issue by continuing the work of Becker et al. (2017) and examining measures of experience that include other hazards and vicarious experience, which may provide better variation for places that have little direct experience, like the PDX region.

Although neither risk zone nor experience significantly predicts past adjustment adoption, other variables do. Specifically, past information, married, age, and homeownership (β = .30 .22, .14, and .18, respectively) all have significant regression coefficients. The effect of past information on past adjustment adoption is consistent with other studies on earthquakes (e.g., Mileti & Darlington, 1997; Mileti & Fitzpatrick, 1992). Similarly, the effects of the demographic variables on past adjustment adoption are consistent with some previous research, although, as noted previously, they tend to be small and inconsistent across studies (Lindell & Perry, 2000).

The influence of past actions (information seeking and preparedness) on hazard awareness (risk perception, affective response, and knowledge of what to do in an earthquake)

The regression analysis for protective action recommendation (PAR) knowledge shows that past information seeking is the only variable to have a significant coefficient ($\beta = .24$; adj $R^2 = .05$), leading to the partial support for H2. This appears to be a new finding because, to our knowledge, no previous studies have assessed people's PAR knowledge, let alone what predicts this knowledge. In addition to past information seeking, female gender and education have significant coefficients for the regression analysis for expected consequences ($\beta = .21$, .24 and -.20, respectively; adj $R^2 = .13$). The effect of past information seeking on expected consequences is broadly consistent with Mileti and Fitzpatrick (1992) and Mileti and Darlington (1997), although the measures of past information and expected consequences are different. However, this finding conflicts with Wei and Lindell (2017), who reported a nonsignificant effect. As noted earlier, the effect of female gender is well documented although the effect of education appears to be inconsistent (Solberg et al., 2010).

By contrast, the regression analysis of shake zone perception was not significant with only experience as a predictor ($\beta = .13$; adj $R^2 = .01$), whereas the regression model for liquefaction zone perception had only one predictor, liquefaction zone, but was significant ($\beta = .17$; adj $R^2 = .03$). Since both of the risk zone perception variables are very poorly predicted by the variables measured in this study, further research is needed to identify better predictors. However, the underlying problem might well be that people's responses to these items were little more than guesses, in which case there are no better predictors to be found. That possibility suggests that local authorities need to find better ways to communicate risk zone information.

Past information seeking has significant correlations with positive and negative affective response, PAR knowledge, and expected consequences (r = .25, .20, .24, .23, respectively). These effects were maintained in significant regression coefficients when other variables are controlled. These results suggest that past information seeking has positive cognitive (PAR Knowledge) and affective (positive affect) impacts, but also somewhat negative (expected consequences and negative affect) impacts. One possible explanation for the apparent conflict between the positive and negative impacts of past information seeking is that those who have sought information may feel more positive about their level of hazard awareness and ability to reduce risk while simultaneously recognizing the potential for negative impacts. This result may also represent coinciding information processing styles where, according to Griffin et al. (1999), *heuristic* processing is linked with positive affective states while *systematic* processing is linked with negative affective states. More study is needed to understand this curious result and how information seeking influences affective states and vice versa.

Finally, past hazard adjustment adoption has a significant correlation with negative affective response (r = -.14), but not with positive affect, PAR Knowledge, or expected conditions. With other variables controlled, past hazard adjustment remained a significant regression coefficient (β = -.20) in predicting negative affect along with Female gender, Age, and past information seeking (β = .19, -.20 and .24). This finding suggests that prior hazard adjustment along with information seeking behavior can influence negative affective response to a hazard risk and not just the other way around as is typically proposed in information seeking models (Dunwoody & Griffin, 2014; Griffin et al., 1999). This result also provides impetus for future studies to assess both prior and intended actions with respect to information seeking and hazard adjustment.

The influence of hazard awareness (risk perception, affective response, and knowledge of what to do in an earthquake) on intentions to seek information and adopt hazard adjustments

The partial support for H3 is found because expected consequences and the positive and negative affective response items, but not the other risk perception variables, have significant correlations with information search intention (r = .31, .19, .32, respectively). However, only expected consequences and negative affect had significant regression coefficients (β = .24, .23, respectively; adj R^2 = .14). These results are important because they indicate that, although these two variables are significantly correlated in this study (r = .29) as they were previously (r = .34 in Wei & Lindell, 2017), we found that both variables made essentially equal and independent contributions to the prediction of information search intention. This is notable because expected consequences and negative affect have two common predictors (Female gender and PastInfo), but also some distinctly different predictors (see Table 3.4). Moreover, the disattenuated correlation between expected consequences and negative affect is $r_d = r_{12} / \sqrt{r_{11} r_{22}}$ = .29/(.96 * .89) = .32, where r_d is correlation corrected for unreliability in the variables, r_{12} is the observed correlation, and r_{11} and r_{22} are the reliabilities of the two variables. The finding that r_d is much less than 1.0 supports a conclusion that the two variables are measuring different constructs. Thus, a challenge for future research is to identify the aspects of past information that influence expected consequences and negative affect and to explain why the demographic variables have different patterns of negative correlations with them.

Moreover, liquefaction zone perception, but none of the other risk perception variables, has a significant correlation with hazard adjustment adoption intentions (r = .15). However, this variable does not retain a significant regression coefficient when controlling for other variables. Overall, the significant correlation and regression coefficients for expected consequences with information search intention are consistent with previous earthquake hazard adjustment research (e.g., Mileti & Darlington, 1997; Mileti & Fitzpatrick, 1992), although the association is only moderate. This suggests other factors mentioned in the literature, such as individual characteristics, perceived ability to acquire information, community participation, and social norms, may be more influential on information seeking-behavior (Becker et al., 2012; Dunwoody & Griffin, 2014; Kahlor, 2010).

<u>The influence of information seeking on hazard adjustment adoption and the relationship between intentions and actions</u>

We found partial support for H4 with past information seeking behavior predicting past hazard adjustment adoption (r = .35, β = .30) and information seeking intention correlating with, but not predicting hazard adjustment adoption intentions (r = .20). These results are consistent with previous research that found information seeking to be highly predictive of seismic hazard adjustment adoption (Mileti & Darlington, 1997; Mileti & Fitzpatrick, 1992; Turner et al., 1986). One explanation for an effect of information seeking on hazard adjustment adoption is that the available information on earthquake hazard and earthquake hazard adjustments from credible sources such as emergency managers and emergency management websites encourages people to adopt earthquake hazard adjustments. Moreover, people who are already motivated enough to seek information are also likely to be motivated enough to act on that information once they obtain it. However, the finding that information seeking intention has a nonsignificant regression coefficient in the prediction of hazard adjustment adoption intentions when controlling for the affective response variables suggests that the explanation is more complex. This result does not conflict with previous seismic hazard adjustment because these studies did not include affective responses as predictors. Thus, the prediction of who engages and why they do so requires further study.

By contrast, there is a negative influence of past hazard adjustment adoption on hazard adjustment adoption intention. One explanation for this finding would be that respondents view adoption of additional hazards adjustments as having a diminishing return on investment (Wachinger et al., 2013). However, Lindell et al. (2009) found that most earthquake hazard adjustments are perceived to have relatively high efficacy in protecting persons and property but relatively low resource requirements. Consequently, a “rational” benefit/cost analysis does not appear to provide a completely satisfactory explanation for negative influence of past hazard adjustment adoption on hazard adjustment adoption intention.

It is important to note that past hazard adjustment adoption is only moderately high (M = .54) and hazard adjustment adoption intention only adds a small increment (M = .11), so only about two-thirds of the hazard adjustments will be adopted even if the respondents' reports of their past adjustment adoption are accurate and they follow through on their intentions. This might be an overestimate because people's self-reports of their hazard adjustment adoption are poorly correlated with independent assessments (Joffe et al., 2016). However, even a zero correlation between self-reports and independent assessments does not necessarily mean that the former are overestimated, so further research is needed to assess the accuracy of self-reports. Moreover, the correspondence between intentions and actual behavior can vary substantially as a function of many different conditions that emergency managers cannot influence (Ajzen & Fishbein, 2005), such as lack of, or more immediate demands for, a household's financial resources. Nonetheless, Kang et al. and Paton et al. (2007; 2005, respectively) found significant correlations between intentions and later behavior. Moreover, even if an upward bias in respondents' self-reports of their hazard adjustment adoption overstates community preparedness for future disasters, it has no effect on model fit as long as it is not so severe as to produce a "ceiling effect" or a "floor effect" that causes variance restriction (Lindell & Perry, 2000). The available data from PDX indicates that neither of these effects is a problem.

Study Limitations

Study limitations include the sample, generalizability of findings, and imperfect model fits. Though we had hoped for a response rate closer Lindell and Prater's (2000) 35 percent, ours was less than 20 percent, which is consistent with a broader reduction in mail survey response rates over the last 50 years (Kohut, Keeter, et al., 2012; Kreuter, 2013). Despite the modest response rate, ~400 responses provided a large enough sample to provide adequate statistical power for detecting correlations of a practically meaningful size.

A second limitation includes whether we specified the models correctly. Although we included variables that have been shown to influence household hazard adjustment adoption, the model fits were relatively low and accounted for between 1 and 24 percent of the variance in the dependent variables. This is due, in part, to relevant variables that were omitted in order to avoid losing respondents because of excessive questionnaire length. One discouraging observation here is that the Six City study had almost twice the response rate despite its questionnaire being eight pages rather than the present study's four pages.

A third limitation is the imperfect reliability, ranging from $.58 \leq \alpha \leq .92$, in the measurement of the model's variables. However, since increasing the reliability of the variables' measures can only increase correlations, imperfect reliability does not threaten any of the conclusions about hypotheses that are supported. Yet, improving the reliability of the variables' measures might turn nonsignificant correlations into significant correlations, so further research to improve the reliability of measures is needed.

A final limitation is the cross-sectional nature of this study. For the regression modelling, we placed information seeking variables before preparedness variables, but this ordering may not represent reality. Given the nature of our cross-sectional data, it is impossible to know whether all information seeking occurred before all protective actions or if, more realistically, people engaged in multiple cycles of seeking information and taking protective actions prior to taking our survey. We heeded the recommendations of Weinstein and Nicolich (1993) and Bubeck et al. (2012) by measuring both past hazard adjustment adoption and hazard adjustment adoption intentions, as well as past information seeking and information seeking intentions. However, many researchers such as Siegrist (2013, 2014) still recommend longitudinal studies to determine whether and how those intentions translate into actual adoption of hazard adjustments, despite their challenges (Hudson et al., 2019).

Conclusions

The overarching goal of this work is to better understand what motivates household seismic hazard adjustment adoption, essentially earthquake preparedness. Specifically, the objectives of this study are to examine gaps in our understanding of how information seeking behavior influences preparedness and what role additional variables, such as demographics, risk zone residency, risk perception, and affective (emotional) response to earthquakes, play in the household hazard adjustment adoption process. Furthermore, in an attempt to better understand the relationship between intentions and actions, this research assesses not only individuals' history of seeking out risk and preparedness information and getting prepared, but also their intentions to do both in the future. To carry out these goals, we sent a questionnaire to a random sample of people living in the Portland, Oregon metro region and received about 400 responses. We use the PADM framework to organize and test the hypothesized relationships in Figure 3.1.

Our results provide at least partial support for most of the proposed links in our hypothesized model of information seeking and hazard adjustment adoption (Figure 3.2). Specifically, that female gender maintains a positive association with risk perception, as is consistent with previous studies (see review by Lindell, 2013a). Additionally, females, older adults, and those who sought out information have more negative feelings toward the possibility of earthquake occurring in the region. The demographic variables of age, homeownership, and a married marital status, in addition with past information seeking, positively influence hazard adjustment adoption; however, none of the variables we measured significantly influence past information seeking. Thus, more exploration of the factors that influence information seeking is needed. We also find risk zone residency and experience to have varying and small influences on risk perception, which is consistent with some previous studies (Becker et al., 2017; Lindell & Perry, 2000), and no influence on information seeking nor hazard adjustment adoption; this lack of relationship may be due to the low levels of earthquake experience and a lack of variance in hazard risk zone locations within our sample. Future studies should assess the effects of experience and risk zones in areas that have more diversity on these variables than our study area.

In our quest to understand how past information seeking and preparedness actions lead to future intentions, we find both direct and indirect influences (see Figure 3.2). For example, past hazard adjustment adoption and past information seeking behavior directly predict intentions to adopt future adjustments; those who searched for earthquake or preparedness information have higher intentions to prepare, while those who already took steps to get prepared have lower intentions to take additional steps. In contrast, past information seeking behavior predicts the intermediate variables of risk perception and negative affective response; those who searched for additional information have higher risk perceptions and more negative feelings about the possibility of an earthquake. Risk perception and negative affective response are then the two predictors of intent to seek information. In this way, past information seeking does not directly influence intentions to seek information, but it does have an effect on variables that do. Though these findings are a step forward in understanding the connections between past and future preparedness actions, more work is needed to test causal chains that lead to household hazard adjustment adoption.

The findings presented here support existing theories that information seeking along with variables such as risk perception and affective response are essential pieces to the hazard adjustment adoption process; however, more study is needed to refine and test information seeking models (Dunwoody & Griffin, 2014; Kahlor, 2010) and investigate how they correspond with the PADM and other models of protective action. This study also allows for comparisons across studies by using and comparing to the previously implemented risk perception and preparedness items of the Six Cities Study (Lindell & Prater, 2000), which helps test the PADM constructs. To build on this work, we recommend longitudinal studies that replicate existing measures and assess changes in hazard adjustment adoption across locations and time.

CHAPTER FOUR: FROM INFORMATION TO PROTECTIVE ACTION ALONG THE CASCADIA SUBDUCTION ZONE: EVALUATING RISK COMMUNICATION AND PUBLIC PREPAREDNESS IN METROPOLITAIN PORTLAND, OREGON

Abstract

A Cascadia Subduction Zone (CSZ) earthquake will cause widespread damage along the Pacific Northwest coast of the United States. It is therefore crucial to understand how to reduce future impacts across this region in order to assess the effectiveness of current strategies for informing the public and motivating households to prepare. Here we use the Protective Action Decision Model (PADM) as a framework to evaluate if decades of risk and preparedness campaigns have established protective knowledge and promoted protective actions for residents of the Portland, Oregon metropolitan (PDX) region. We also compare PDX preparedness levels to those in other PNW regions. We find that the majority of PDX residents (63%) do not intend to 'drop, cover, and hold on' when earthquake shaking starts and that, although they are generally aware of earthquake hazards in the area, they are less aware of the specific risks for their homes. Further, PDX residents seem to be less prepared than neighboring states of Washington and California, though more testing is needed to verify this finding. Our results suggest that though strategies to increase general knowledge of the risk posed by a CSZ earthquake have been beneficial, significant gaps remain in translating broad awareness into personal knowledge and actions. This work provides guidance to PDX emergency educators for more targeted messaging and provides methods to measure

PADM constructs in other regions for future comparisons. By paying close attention to preparedness gaps, local officials can use their limited resources more effectively to develop strategies to inform their communities and improve preparedness before a major earthquake strikes.

Introduction

Upwards of 7 million people living on the west coast of the United States will be impacted by the next Cascadia Subduction Zone (CSZ) megathrust earthquake (Schulz, 2015). Since this 800-mile fault zone was identified in the late 1980s (Atwater, 1987; Heaton & Hartzell, 1987), scientists have focused efforts on modelling and estimating the impacts such an event will have on the region. These simulations inform mitigation strategies and education campaigns aimed at reducing risk and preparing households. Despite these efforts and others around the county, national levels of household preparedness have not measurably increased over the past decade (FEMA, 2019), and there is no obvious reason to believe that the CSZ is any different. It is therefore imperative that the link between risk information and protective response is better understood.

Theoretical models help to frame the psychological, environmental, and social variables that affect preparedness behavior. These include the Protective Motivation Theory (PMT—Rogers, 1975), the Protective Action Decision Model (PADM— Lindell & Perry, 2012), and the Risk Information Seeking and Processing Model (RISP—Griffin et al., 1999). Built from decades of research, these models help to organize research focused on understanding what motivates people to prepare. However, these models and their assumptions need testing and application, especially in different geographic locations with varied hazards and cultural influences. Applying these models to different locations helps to identify areas that need further research – ultimately guiding strategies to help communities use their resources more effectively to motivate preparedness.

In this study, we examine key constructs in the PADM including perception of information sources, perception of earthquake risk, and household preparedness for the Portland metropolitan (PDX) region, which is at great risk of a CSZ megathrust earthquake. In addition to this local assessment, we go further by comparing household preparedness in PDX with that of the Los Angeles (LAX) and Seattle (SEA) areas from a previous survey (Lindell & Prater, 2000). Our study provides a benchmark for examining theoretical constructs of protective action in a specific location, and offers tools, such as survey questions, that can be used to carry out comparison studies in other regions. Having a better understanding of how information translates into preparedness actions at an individual and theoretical level is needed to improve household preparedness.

Literature Review

We begin this section by discussing the PADM, then examine key constructs that researchers use to test the effectiveness of earthquake and risk communication strategies. Next, we discuss the prevalence of household preparedness across the CSZ. We conclude this review by exploring the influence that perceptions of stakeholders and risk messages have on motivating individual preparedness.

The Protective Action Decision Model – From Information to Action

The PADM is based on decades of research on how information processing influences environmental and psychological factors that lead to protective action decision-making. The PADM is powerful in that it can be applied to protective actions adopted for different hazards, such as earthquakes and hurricanes, and at different times in the hazard cycle, such as during an event (e.g., 'drop, cover, and hold on' after earthquake shaking begins), or in the time between events (e.g., installing latches to prevent items falling when an earthquake occurs). It also organizes the factors into informational inputs, pre-decision processes, core perceptions, decision-making, and ultimately behavioral responses that provide context for studies to examine its components. Despite the ample research on which the PADM was founded, Lindell and Perry (2012) acknowledge that there still remain question about what motivates protective action. They call for additional study to investigate how people internalize and act on information and how mental models vary across individual and regional contexts. These goals seem especially relevant in a time when modes of communication have increasingly moved online and are influencing how people receive, understand, and act on hazard and risk information.

Evaluating the Effectiveness of Earthquake Risk Communication

Earthquake risk and preparedness information strategies vary in terms of scale, frequency, and focus, but their effectiveness at promoting awareness and preparedness is hard to measure and, indeed, rarely measured. Information about earthquake hazards, specifically in the CSZ, is distributed across national and local news media (broadcast, electronic, and print), government agency meetings and websites, and more recently, social media platforms. Across these channels, individuals can learn about the science of earthquakes, how to prepare, what to do during an earthquake, and local resources. However, despite the presence of this information, few studies assess whether these strategies are effective in getting CSZ residents to take the preliminary steps toward protective action including paying attention to the information, understanding the threat and alternative protective actions, and feeling motivated to prepare (Lindell & Perry, 2012). Additionally, since education campaigns and strategies vary across municipalities, it is unclear whether regional differences influence the levels of household preparedness.

To evaluate the effectiveness of earthquake education campaigns on households, it is helpful to assess key factors in the PADM that include, (1) threat/risk comprehension, (2) protective action comprehension and perception and (3) protective response. Disaster research has examined these items using a series of methods.

Threat/Risk Comprehension by Risk Area Identification

To examine one aspect of risk/threat comprehension, research has assessed whether residents can identify their mapped risk zones. The ability of residents to correctly identify their risk zone suggests they have some awareness of the risk specific to their residence and could take actions to reduce it. Two studies of coastal Texas residents found that, when given hurricane risk area maps, only 36 percent (Arlikatti et al., 2006) and 66 percent (Zhang et al., 2004) of respondents correctly identified their risk zone. This significant variability suggests that map-reading skills, along with hazard map type, may influence how people perceive their risk zone. Moreover, only one study examines resident's ability to identify risk zones without a map, which may better reflect resident's passive understanding of a hazard; Lindell et al. (2019) found that 84 percent of residents *inside* and 41 percent of those who live *outside* the mapped tsunami zone correctly identified their risk zone. To our knowledge, no studies focus on risk zone identification of earthquake hazards such as shaking and liquefaction susceptibility, both of which could cause significant and differential impacts across a region.

Comprehension and Perception of, and Response To, ‘Drop, Cover, and Hold On’

Researchers evaluate people’s protective action perceptions in a variety of ways that include assessing awareness of those actions, beliefs about their effectiveness and resource requirements, and intentions to take them. Perhaps the most well-known earthquake protective action recommendation (PAR) is to ‘drop, cover, and hold on’ when shaking starts. This action is aimed at reducing the immediate hazards of earthquake shaking that include projectiles and trips or falls, which are the leading causes of serious injuries and death during an earthquake event (Johnston et al., 2014; Wood & Bourque, 2018).

Whether people take this action during earthquake shaking appears to vary both by country and level of shaking (Goltz et al., 2020; Lindell et al., 2016). Interestingly, Goltz et al., found that only when shaking was moderate or higher did the majority of people adopt this protective action. Additionally, they found that when strong shaking was felt, people in only New Zealand and Japan ‘dropped and covered,’ whereas those in the U.S., Mexico, China, Pakistan, Haiti, and Nepal either ran outside or took no action. In other research, Lindell et al. (2016) found the residents of Christchurch NZ were even more likely to ‘drop and cover’ than those in Hitachi JP. Some of this variability in response may be due to changing recommendations, quality of local infrastructure, or misinformation leading people to take an action not recommended by local authorities (GHI, 2015). The latter appeared to be the case in a study by Arlikatti et el. (2019) that found Chinese respondents rated their intention to adopt the ‘triangle of life,’ an unproven protective action, statistically significantly higher than ‘drop, cover, and hold on,’ which is local authorities’ PAR. These cultural differences suggest that more study is needed to understand how local protective responses are likely to vary during an earthquake.

Studies also investigate PAR knowledge by examining the effectiveness of earthquake drills, which practice ‘drop, cover, and hold on,’ for increasing protective action knowledge and likelihood of adoption during an earthquake. Vinnell et al. (2020) found that New Zealanders who participated in earthquake drills had increased knowledge of this action, were more likely to take the action during an earthquake, and had higher overall earthquake preparedness. Moreover, 66% and 21% of Vinnell et al.’s respondents (who did and did not participate in a drill, respectively) correctly selected ‘drop cover and hold on’ as the action they would take if inside when earthquake shaking started. During a later earthquake, 63% of those who participated in a shakeout drill and 20% who did not participate actually did ‘drop cover and hold on,’ suggesting behavioral intentions before an earthquake are later implemented as actions taken during an earthquake. In contrast, Adiyoso and Kanegae (2013) found that for students in Indonesia whose schools participated in earthquake drills, only 2 percent ‘dropped and covered’ during earthquake shaking despite 89% selecting ‘drop, cover, and hold on’ as the best earthquake response. Thus, continued study is needed to determine the relationship between intended and actual protective actions with respect to ‘drop, cover, and hold on.’

Protective Response and Household Preparedness Along the CSZ

Surveys, such as the annual National Household Survey (FEMA, 2018), shed light on national preparedness trends, but these samples are too broad to identify results by state and hazard type. Because of this, it is unclear how seismically prepared households are along the West Coast or how levels have changed over time. As such, it is difficult to assess program effectiveness and target resources to address location specific disaster preparedness needs. Additionally, Kirschenbaum (2005) notes that no consensus exists in terms of empirically measuring preparedness, which adds to the difficulty in comparing across studies and regions. For example, measures of earthquake preparedness range from free responses (Jackson & Mukerjee, 1974) to a 27-item inventory (Mulilis et al., 1990). Replicating prior methods of assessing preparedness can aid in future comparisons.

Several studies compare preparedness between and within countries (Greer, 2012; Onuma et al., 2017; Paton et al., 2010), but there is limited study across the CSZ region in the U.S. One such study by Lindell and Prater (2000) compared household preparedness across residents in six cities in Washington and California located in moderate to high seismic hazard areas. They found hazard awareness and experience to be higher in California, a state that experiences more frequent earthquakes than Washington. They also found significant, although small, differences in hazard adjustment adoption. Since Lindell and Prater’s study, government agencies (e.g., CREW, 2013), science agencies (e.g., Gomberg et al., 2017), and the news media alike have increased their coverage of CSZ earthquakes (e.g., Schulz, 2015); the Seattle metro region also experienced very strong shaking from the M6.8 Nisqually earthquake in 2001 that raised public awareness of regional earthquake hazards and motivated infrastructure upgrades (King 5 News, 2021; Moriarty, 2011). Despite these recent events, we could find no additional comparisons studies of household preparedness across this region. However, local emergency management agencies have conducted local preparedness assessment surveys (DHM Research, 2017; Herbert Research, Inc., 2004; PRR, Inc., 2015). These projects are infrequent, and vary in question type and style of analysis, but they do offer additional information about regional preparedness. Through understanding regional preparedness differences across the CSZ, emergency managers can better assess communication strategies and target regional preparedness needs.

Perceptions of Information Sources Influence Preparedness Actions

How people act on earthquake risk information is influenced by their perceptions of information sources and the channels by which information is delivered. *Sources*—which Drabek (1986) categorized as authorities, news media, and peers—transmit messages through *channels* (e.g., one-on-one conversations, print media, broadcast media, social media, and internet websites) to *receivers*. Research on persuasion has documented that risk information sources must be seen as credible (knowledgeable and trustworthy) for people to pay attention (Gass & Seiter, 2014). In examining beliefs about seismic hazard knowledge across sources in the U.S., researchers find the lowest ratings for peers (friends and family) and the highest ratings for state and local governments (Arlikatti et al., 2007; Lindell & Whitney, 2000). However, both of these studies find that, despite peers being rated lowest in terms hazard knowledge, perceived peer knowledge is significantly correlated with seismic adjustments, whereas authorities' knowledge is not. In addition, Arlikatti et al. (2007) found similar patterns for ratings of perceived trustworthiness across sources. These findings suggest a complex relationship between perceived credibility of sources and hazard adjustment and motivate further study. More recently, Wei et al. (2018) found differences between American and Chinese respondents in terms of the effect stakeholder perceptions had on hazard adjustment adoption for respiratory infectious diseases. The Americans were more strongly influenced by peers, whereas the Chinese were more influenced by authorities. Thus, cultural and regional differences appear to impact how stakeholder perceptions translate into protective action. Continuing to assess how stakeholder perceptions of information sources vary by region will help inform how to most effectively disseminate risk information.

In addition to perceptions of source credibility, the content of risk messaging influences perceptions of risk and protective actions. Important message elements include descriptions of the hazard, location of impact, protective action guidance, timing, and messaging style—especially the degree to which it attracts attention and facilitates comprehension (Lindell, 2018). Other message qualities include how well they convey credibility and how consistent, specific, certain, clear, accurate, and frequent they are (Mileti & Peek, 2000; Peek & Mileti, 2002; Wood et al., 2018). In addition, an even broader literature on persuasion has characterized messages in terms of their length, the number and ordering of arguments, the time it takes to present, whether information is repeated, and how extreme the position is as well as the style, clarity, and forcefulness of the message (Gass & Seiter, 2014). More specifically, Persuasive Arguments Theory proposes that the degree to which messages provide information that is new, valid, and relevant characterizes their impact (J. C. Turner, 1991).

Our study aims to assess peoples' perceptions of risk information sources and channels, specifically with respect to their ability to provide content that is new, accurate, relevant, and understandable. By comparing sources, we aim to enhance our understanding of which ones are most effective at providing risk and preparedness information to households in the PDX region and compare our results across those of previous studies.

Research Questions

The following research questions assess four specific aspects of the effectiveness of efforts along the CSZ in increasing household PAR knowledge, threat perceptions, and preparedness.

Q1: What percentage of the respondents expect to comply with emergency managers' protective action recommendation to 'drop, cover and hold on' during earthquake shaking?

Q2: How accurate are respondents' perceptions of the earthquake shaking and liquefaction zones in which they live?

Q3: Are hazard adjustment adoption levels in a current Portland sample significantly different from those in the 2000 Six City study?

Q4: Are there significant differences among information sources with respect to the perceived attributes of the information they provide?

Methods

Study Area

The Portland metropolitan area (PDX) include four counties - Multnomah, Washington, Clackamas, and Columbia - in northwest Oregon State. The location along the CSZ and the earthquake education campaigns conducted by emergency managers make this area well suited for investigating household preparedness to earthquake hazards. Situated between Washington and California, Oregon has had fewer damaging earthquakes than its neighbors. Nonetheless, an impact analysis of three of the four counties suggests a M9.0 CSZ earthquake will severely impact the region with casualties in the thousands to low tens of thousands and building repair costs from $23 - 36 billion (Bauer et al., 2018). Because of this, local government groups, such as the Regional Disaster Preparedness Organization (RDPO), and news media have funneled resources into educating the public about the regional earthquake hazards and steps they should take to prepare (for example, see opb.org/tag/unprepared/ and publicalerts.org/). However, there has of yet been no regional assessment of the efficacy of these efforts.

In 2016, the Portland Bureau of Emergency Management (PBEM) contracted with DHM, Inc. to conduct a series of surveys (online and phone) and focus groups with city residents to investigate barriers and motivations for preparing (DHM Research, 2017). Key findings include that the majority of people were aware a natural disaster could happen in the region (74%) and that it could impact their daily lives (77%), but fewer had taken steps to get prepared (e.g., 52% had an emergency kit, 46% had discussed an emergency meeting place, and 37% had discussed what they would do if utilities were out for an extended period of time). They also found government officials to be the most trusted messengers for emergency preparedness information. This finding applied more for adults over age 45, whereas those under 45 trusted peers and family as much or more than government sources. The PBEM study did not examine if people knew their specific risk zone or what protective action(s) to take during a specific hazard event. Though these efforts produced a series of valuable insights, more study is needed to understand if these results extend beyond city limits to the metro region, how they apply to earthquake hazard specifically, and how they compare with other CSZ regions.

Procedure

During the Fall of 2019, we sent survey packets to a random sample of 2415 addresses in the PDX region. The packets contained a cover letter, letter of support from RDPO, questionnaire (see Appendix B), stamped return envelope, and post card to request additional risk and preparedness information. Following Dillman's (2000) procedure we sent up to four waves of materials alternating between a full survey packet and reminder post card. For valid addresses who had yet to respond, we sent additional waves 7 to 12 days after the previous one. Our sample included 2257 valid addresses after accounting for 159 undeliverable packets. Participants had to be residents of one of the four PDX counties and at least 18 years old. As an incentive, participants were entered to win a raffle of two $50 Amazon gift cards. We received 403 responses for a response rate of 17.8%. Compared to regional averages, the respondents in our sample are wealthier, more educated, and older (see Table 3.1), which are commonly over-represented in recent mail surveys of environmental hazards (Brody et al., 2017; Lindell et al., 2017; Peers et al., 2020).

Table 4.1 Measures

Variable description	Label
Earthquake Knowledge	
Anticipated correct action during an earthquake (Drop, cover, and hold on)	ParKnowl
Risk area identification	
Perceived earthquake risk zone	ShakePerc
Perceived liquefaction zone	LiqPerc
Actual Risk Zone	
In severe earthquake shaking zone	ShakeZone
In liquefaction zone	LiqZone
Preparedness	
Hazard adjustments taken at time of survey	PastInfo
Hazard adjustments planned (haven't done, but plan to do)	AdjIntent

Survey Instrument

To assess whether respondents knew what action to take when earthquake shaking started, we provided five possible response options including the recommended protective action of 'drop, cover, and hold on.' The PAR knowledge variable was generated by coding 'drop, cover, and hold on' as 1 and the others as 0. See Table 4.1 for descriptions of the measures.

We assessed residents' perceived risk zones for both earthquake shaking and liquefaction by asking respondents whether they thought their home was in a severe shaking zone (ShakePerc) or a liquefaction zone (LiqPerc) (*No=1; Unsure=2; Yes=3*). We used ArcMap to determine respondents' actual risk zones by overlaying the latitude and longitude of the respondents' addresses onto the Oregon Department of Geology and Mineral Industries Cascadia earthquake shaking layer (Bauer et al., 2018; Madin & Burns, 2013) and liquefaction susceptibility layer (Madin & Burns, 2013). The Cascadia shaking layer is the modelled ground shaking measured as peak ground acceleration during a CSZ earthquake. We converted peak ground acceleration values to Modified

Mercalli Intensities (MMI) using the conversion table in Wald et al. (1999). The ShakeZone variable includes MMI values of 6 (*strong=1*), 7 (*very strong=2*), and 8 (*severe=3*). The region includes liquefaction susceptibilities ranging from none to high. For the LiqZone variable, we coded the susceptibilities into two categories (*none=0; low, moderate, and high susceptibility=1*).

To measure hazard adjustment adoption, we asked respondents whether they had adopted (*No =1; Have not, but plan to do/get = 1; Yes = 2*) each of 16 emergency preparedness and hazard mitigation items (Table 4.2). We used the list of items from the Lindell and Prater (2000) study but amended or removed some based upon feedback from local emergency managers and responses to previous surveys. For example, we added 1-week supply of medicines since emergency agencies now stress this and omitted the purchase of hazard insurance since Lindell and Prater (2000) reported low levels of adoption. From these responses, we created two scale measures, PastAdj (α = .71), which represents the adjustments completed at the time of the survey and AdjIntent (α =.74), which represents the adjustments respondents intend to complete following the survey. For PastAdj, we coded items as 1 if they answered ‘Yes’ and 0 for all other responses. For AdjIntent, we coded items 1 if they answered ‘Have not, but plan to do/get’ and 0 for all other responses. We then averaged values across all 16 items for each measure.

We assessed peoples’ perceptions of information sources by asking what extent (*Not at all =1; Very great extent=5*) five information sources (peers, emergency managers, live radio/TV broadcasts, emergency management websites, and earthquake hazard maps) provided information that was new to them, accurate, easy to understand,

Table 4.2 Percent adoption of hazards adjustments across studies. Boxes indicate most adopted items (>65%), followed by items in parentheses (35-65%), and least adopted items are underlined (<35%).

		Our Study				Six City Study		Local Authority Surveys[a]			
			99% C.I.		2019	1999		2016	2010	2004	2015
Preparedness Items and Adjustments	**N**	**SE**	**Lwr**	**Upr**	**PDX**	**LAX**	**SEA**	**POR**	**CAL**	**KWA**	**SEA2**
1. Have a non-electric can opener	393	0.8	95	100	**97**						
2. Have a flashlight and extra batteries	392	1.2	91	97	**94**				80 +	94	
3. Have wrenches to operate utility shutoff valves and switches.	395	1.8	80	90	**85**	90	90				
4. Have at least 1-week supply of prescription medicines	384	2	74	85	**79**						
5. Have a fire extinguisher	393	2.2	69	80	**75**	68	76			77	
6. Learned the location of nearby medical emergency centers	387	2.3	64	76	**70**	77	82				
7. Learned where and how to shut off water, gas, and electric utilities	390	2.5	55	68	**(62)**	83	84				
8. Have a *2-week (4 day)*[b] supply of dehydrated or canned food for yourself and your family	392	2.5	49	62	**(56)**	69	72	(59)		(62)	(47)
9. Strapped water heaters, tall furniture, and heavy objects to the building walls	393	2.5	47	60	**(54)**	66	34	(43)		(53)	
10. a working transistor radio with spare batteries	389	2.5	46	59	**(52)**	81	82				
11. Have at least 4 gallons of water in plastic containers	387	2.5	34	47	**(40)**	78	(46)		(40)		
12. Signed up for alerts	394	2.4	31	43	**(37)**			(45)			
13. Developed a household earthquake emergency plan	385	2.2	18	29	**23**	(51)	(35)	(36)	(40)	22[c]	
14. Attended meetings to learn about *emergency preparedness (earthquake hazard)*[b]	392	2.1	17	27	**22**	27	22			67[d]	
15. Contacted the Red Cross or government agencies for information about earthquake hazard *& emergency preparedness*	394	1.8	11	20	**15**	18	16				
16. Installed latches to keep cabinets securely closed	391	1.5	5	13	**9**	33	15				
			Average Adoption[e]		**50**	58	64				

[a] Local survey sources; State of California (Bourque et al., 2010); City of Seattle, WA (DHM Research, 2017); King County, WA (Herbert Research Inc., 2004); Portland, OR (PRR Inc., 2015)

[b] Language modified slightly from Six City Study. Updated or added phrases are italicized with original text in parentheses.

[c] Response to one of three questions related to developing household plans including, home escape plan (55%), out of state contact plan (22%), and family meeting place plan (16%)

[d] Response to “took classes, such as first aid, CPR, or disaster preparation class”

[e] Only includes items in common. Means were not calculated for local surveys due lack of items in common.

and relevant to their needs. For each information attribute, we computed the mean rating for each information source. We calculated mean ratings for each information source by attribute.

Analyses

Data analyses include descriptive statistics, mean comparisons, χ^2 tests, and Multivariate Analysis of Variance (MANOVA) to address the four research questions. We examined the response frequency for the five protective actions response options to investigate Q1. To test Q2, we conducted χ^2 tests of the association between actual and perceived earthquake hazard zones. To investigate Q3, we computed the percent adoption of twelve hazard adjustments that are common to the PDX and LAX/SEA questionnaires. To assess whether the percent hazard adoption in PDX was significantly different than in LAX and SEA reported in Lindell and Prater (2000), we examined whether values in LAX and SEA fell outside the 99% confidence interval for PDX. We also examined household preparedness surveys conducted by local authorities to see which, if any, comparisons could be made across hazard adjustment adoption percentages.

To explore Q4, we began by computing mean ratings of each information source on each attribute. We next assessed interrater agreement using r^*_{wg}, which ranges $-1 \leq r^*_{wg} \leq 1$. This index measures the degree to which respondents agreed in their ratings of information sources for each attribute (James et al., 1984; LeBreton & Senter, 2008), and is calculated as follows,

$$r^*_{wg} = 1 - \frac{\sigma^2_{obs}}{\sigma^2_{exp}},$$

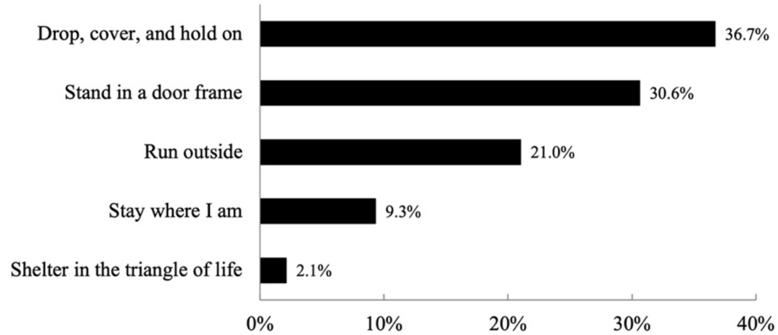

Figure 4.1 Breakdown of actions respondents said they would take if earthquake shaking began when they were at home.

where $\sigma^2{}_{obs}$ is the observed variance and $\sigma^2{}_{exp}$ is the expected variance of a random response (i.e., a uniform distribution) given the number of response categories. In our case, there were five response categories (c = 5), so $\sigma^2{}_{exp} = (c^2 - 1)/12 = 2.0$. According to Dunlap et al. (2003), a value of $r_{wg} > .12$ is statistically significant for variables that have five categories and $N > 150$. Second, we conducted a MANOVA to test whether significant differences existed among the five information sources across the four attributes. We followed the MANOVA by conducting a series of paired samples *t*-tests to determine which information sources had statistically significant differences for each attribute.

Results

Regarding Q1, *What percentage of the respondents expect to comply with emergency managers' protective action recommendation to 'drop, cover and hold on' during earthquake shaking*, Figure 4.1 shows that only 37% of respondents expected to 'drop, cover, and hold on.' The remainder said they would 'stand in a door frame' (31%), 'run outside' (21%), 'stay where they were' (9%), or 'shelter in the triangle of life' (2%).

In the analysis for Q2, *How accurate are respondents' perceptions of the*

Table 4.3 Risk zone residency compared with perceived risk zone.

	Is your home located in a ____ [liquefaction; severe shaking] risk zone?				
Mapped Risk Zone	No	Unsure	Yes	**Total**	Significance
Liquefaction Susceptibility (all options)					
High	20	44	9	**73**	$\chi_6^2 = 13.31$
Moderate	12	27	4	**43**	$p = 0.04$
Low	23	53	5	**81**	
None	76	96	7	**179**	
Liquefaction Susceptibility (dichotomy)					
Possible (lo, mod, hi)	55	124	18	**197**	$\chi_2^2 = 10.93$
None	76	96	7	**179**	$p = 0.00$
Total	**131**	**220**	**25**	**376**	
Earthquake Shaking (all options)					
Severe (MMI 9)	1	4	14	**19**	$\chi_4^2 = 5.86$
Very Strong (MMI 8)	38	115	196	**349**	$p = 0.21$
Strong (MMI 7)	2	7	4	**13**	
Earthquake Shaking (dichotomy)					
Severe Shaking	1	4	14	**19**	$\chi_2^2 = 2.53$
Other (MMI 7 & 8)	40	122	200	**362**	$p = 0.28$
Total	**41**	**126**	**214**	**381**	

earthquake shaking and liquefaction zones in which they live, Table 4.4 reveals a nonsignificant association between mapped and perceived shaking zone. This result is the same whether categorizing the shaking zones as strong, very strong, and severe (χ_4^2 = 5.86, $p > .01$) or dichotomizing the zones as inside severe vs. outside severe ($\chi_2^2 = 2.53$, $p > .01$). This lack of significance may be because 92% of the respondents were in the very strong shaking zone. Since the mapped zone was essentially a constant, it is difficult to draw any conclusions about respondents' literal risk area accuracy for shaking zones. However, if one considers the possibility that the respondents did not differentiate among the three shaking zones—Strong, Very Strong, and Severe—then the majority (56%) were aware that they were at significant risk, an additional 33% were unsure, and only 11% thought they were not at risk.

Table 4.3 shows that there is also a nonsignificant association between mapped and perceived liquefaction zone (χ^2_6 = 13.31, p > .01) when mapped liquefaction zone is categorized as none, low, moderate, or high. However, the test is significant (χ^2_2 = 10.93, p < .01) when actual liquefaction zone is categorized as a dichotomy (outside vs. inside). The majority (59%) were unsure, 47% thought they were not at risk, and only 7% thought they were at risk to liquefaction, even though 52% were in an area that has some liquefaction susceptibility.

The analysis of Q3, *Are hazard adjustment adoption levels in a current Portland sample significantly different from those in the 2000 Six City study,* revealed similarities and differences. Of the twelve hazard adjustment items common to the two studies, three had comparable levels of adoption across all three metro areas; items are considered comparable if percentages in the LAX and SEA areas fell within the 99 percent confidence interval of the PDX sample (see Table 4.2). The three comparable items are the single most commonly adopted item, *'wrenches to shut off utilities',* and the two least commonly adopted items, '*attending meetings'* and '*contacting experts for information about earthquake hazards'.* The PDX sample had a lower percent adoption than the LAX and SEA samples for six items—'*learning locations of medical centers'*, '*how to shut off utilities'*, '*having a 4-day to 2-week supply of food'*, '*owning a portable radio',* '*developing a family plan*', and '*installing cabinet latches'*. For two items—'*having a fire extinguisher'* and '*having stored water',* PDX had an adoption level that was comparable to SEA, but lower than LAX. For '*strapping heavy objects to the wall'*, the PDX percent adoption was between those in SEA and LAX, with LAX having the highest percent adoption. Overall, the three most frequently adopted adjustments (above 65% adoption across locations) were '*owning wrenches'*, '*having a fire extinguisher'*, and '*learning where nearby emergency medical centers are located,'* whereas the three least frequently adopted adjustments (below 35% adoption across locations) were '*attending meetings'*, '*contacting experts'*, and '*installing cabinet latches.*' The mean percent of adoption (across respondents and adjustments) was highest in LAX (64%) followed by SEA (58%) and lowest in PDX (50%).

Though many similar concepts were covered in the surveys from local emergency management agencies, we found it challenging to make direct comparisons with our hazard adjustment adoption percentage results. This difficulty was due to a combination of question wording, type of response options provided, and a lack of questions about certain items. For example, one emergency management survey asked three questions related to household emergency plans including making an escape plan, designating an out of state contact, and deciding on a family meeting place (Herbert Research Inc., 2004), which did not directly match our more basic question of whether respondents had developed a household earthquake emergency plan. For the sixteen hazard adjustments in our survey, eight items had at least one analogue across the four additional surveys we examined (Table 3). The survey with the most corresponding items had six (Herbert Research Inc., 2004) and the least had only one (PRR Inc., 2015). CAL and KWA had similar levels of adoption as PDX for '*having a flashlight'* and POR and KWA had similar levels for '*having a 4-day to 2-week supply of food'* and '*strapping down heavy objects.*' KWA also had comparably low levels of adoption with PDX for developing '*a*

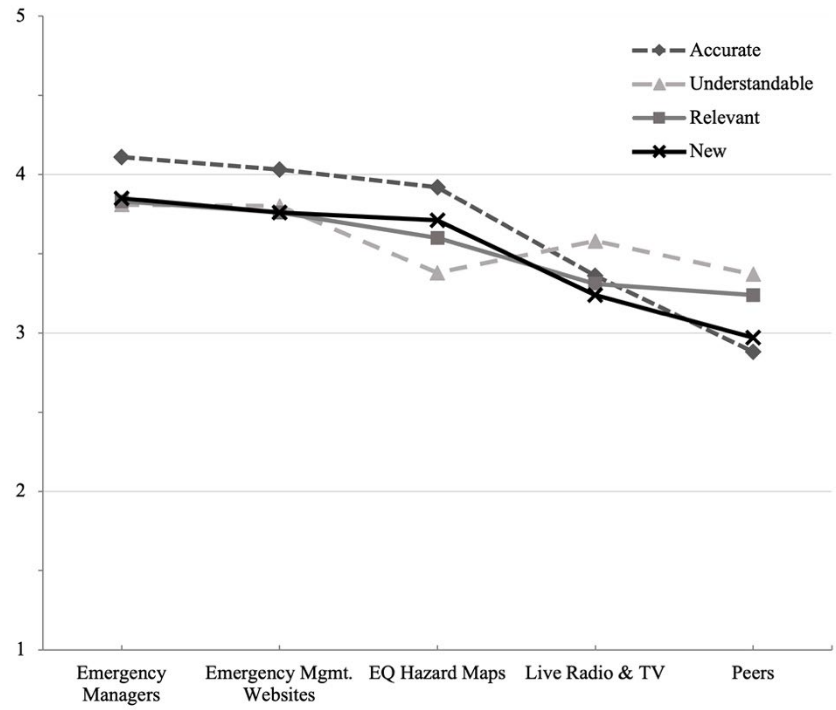

Figure 4.2 Mean ratings of information types, by attributes.

household emergency plan,' whereas, for the same adjustment, POR and CAL had similar adoption percentages as LAX and SEA.

With respect to Q4, *Are there significant differences among information sources with respect to the perceived attributes of the information they provide,* the MANOVA revealed statistically significant differences among the profiles for the five sources ($F_{20,322} = 547.10$, $p < .001$, Wilks' $\Lambda = .03$). Specifically, Figure 4.2 shows that the mean ratings of information sources across all attributes are as follows—emergency managers ($M = 3.9, \alpha = .90$), emergency management websites ($M = 3.8, \alpha = .92$), earthquake hazard maps ($M = 3.7, \alpha = .86$), live radio and television ($M = 3.4, \alpha = .91$), and peers ($M = 3.1, \alpha = .84$). The rank ordering of these means is consistent for all four attributes except ease of understanding, where earthquake hazard maps are rated below the mean of the five sources ($M = 3.4$) rather than above it, and live radio/TV are rated at the mean of the five sources rather than below it. The average interrater agreement across all items was statistically significant, but moderate ($r^*_{wg} = .42$), and similar across information sources. Interrater agreement was highest for peers ($r^*_{wg} = .48$), followed by meetings with emergency managers ($r^*_{wg} = .47$), live radio/TV ($r^*_{wg} = .40$), emergency management websites ($r^*_{wg} = .41$), and hazard maps ($r^*_{wg} = .33$).

We found statistically significant differences among the information sources for each attribute except between emergency manager meetings and emergency management websites, which were not significantly different for any of the attributes. Specifically, for the *new to you* attribute, there were significant differences between mean ratings for peers and live radio/TV ($t_{373} = -3.72$, $p < .001$) and between live radio/TV and hazard maps ($t_{374} = -6.77$, $p < .001$), but not among emergency managers, emergency management websites, and hazard maps. There was a similar pattern for the *accurate* attribute; there were significant differences between mean ratings for peers and live radio/TV ($t_{372} = -7.95$, $p < .001$) and between live radio/TV and hazard maps ($t_{370} = -8.58$, $p < .001$), but not among emergency managers, emergency management websites, and hazard maps. For the *ease of understanding* attribute, there were significant differences between mean ratings for peers and live radio/TV ($t_{370} = -3.42$, $p < .05$), and between live radio/TV and emergency management websites ($t_{368} = -3.60$, $p < .001$), but not between hazard maps and peers or between emergency managers and their websites. For the *relevant* attribute, there were significant differences between mean ratings for live radio/TV and hazard maps ($t_{371} = -4.06$, $p < .001$), and between hazard maps and emergency management websites ($t_{368} = -2.75$, $p < .05$), but not between peers and radio/TV or between emergency managers and their websites. The difference between the consistently highest rated information source, meetings with emergency managers, and the lowest rated information source, peers, was largest for the *accurate* attribute ($t_{370} = -21.66$, $p < .001$) followed by *new to you* ($t_{368} = -14.06$, $p < .001$), *relevant* ($t_{373} = -10.34$, $p < .001$), and closest—but still significantly different—for the *ease of understanding* ($t_{73} = -7.45$, $p < .001$). Overall, the differences between the highest (emergency managers) and lowest (peers) rated information sources ranged from 20-25% of the range of the rating scale.

Discussion

PAR Knowledge for 'Drop, Cover, and Hold On'

The results show that only 37% of the respondents have an appropriate intention about what to do during an earthquake. This value is hard to interpret since few studies examine whether intentions of what to do during an earthquake translates into actually doing it during a real event, but it does represent an upper estimate. If PDX residents respond more like New Zealanders in Vinnell et al.'s study (2020), a similar percentage will 'drop, cover, and hold on.' If, however, they respond more like Adiyoso and Kanegae's (2013) respondents, a much smaller percentage will actually take this action during an earthquake. Interestingly, the second most selected action was to 'stand in a door frame.' This action has not been recommended for a long time, yet it persists as a common intention. One in five of the PDX respondents selected 'run outside' and a little less than 1 in 10 selected 'stay where I am.' In a real earthquake where people experienced strong shaking, these two actions were the most common responses across countries (Goltz et al., 2020). It is therefore possible that during a Cascadia quake, where shaking will meet or exceed strong shaking, a larger portion of PDX than reported may take these actions. One positive finding in our study was that only about 2 percent of people selected the debunked action of 'sheltering in the triangle of life.' This finding is in contrast to Arlikatti et al.'s (2019) finding in China and suggests that misperceptions about PARs vary by region. What determines these misperceptions (stakeholder perceptions, media access, etc.) requires further study.

Since the majority of respondents in our study do not intend to 'drop, cover, and hold on,' local emergency managers should consider how to improve PAR knowledge in the region through drills or other styles of education campaigns. Additionally, it may be worth conducting education campaigns that explicitly address what *not* to do, such as 'standing in a door frame,' to combat misperceptions that exist in the region.

Earthquake Risk Zone Accuracy

Our results indicate that residents' perceived risk zones correspond poorly with their actual risk zones. This finding is consistent with Mileti and Darlington's (1995) evaluation of a San Francisco Bay earthquake newspaper insert, which found that only 44% of their household sample understood the insert's shake map even though 82% considered the rest of the insert easy to understand. It is also an interesting extension of previous research on Texas coastal residents' risk zone accuracy (Arlikatti et al., 2006; Zhang et al., 2004) because PDX residents were not given a map of risk zones to locate themselves, so they had to rely on what they already knew or seek out additional information before returning the questionnaire. The correspondence between residents' actual and perceived risk zones is worst when the shaking risk zones are strictly defined according to the MMI categories. However, if one recognizes that the respondents are more likely to remember the 'gist' of their risk area categories, as would be predicted by Fuzzy Trace Theory (Reyna et al., 2016), then the results indicate that PDX residents are moderately well aware of their seismic shaking risk. This result suggests that regional earthquake education campaigns and news media have been moderately effective in communicating the potential for severe earthquake shaking in the region but need to ensure that people are more aware of their location-specific shaking risk. One possible solution would be to provide information about the expected damage associated with each MMI category, similar to the recent impact-based tornado warnings that the National Weather Service is providing (Mark A. Casteel, 2016, 2018). In contrast, people were generally unsure of their liquefaction risk, perhaps because they were unsure of what the term '*liquefaction*' meant. Since liquefaction can cause serious earthquake damage, future risk education campaigns may benefit from including more specific information about this hazard.

Comparing Seismic Adjustment Levels Across CSZ

The finding that the single most frequently and three least frequently adopted hazard adjustments from the Six City study were in those same positions in the PDX survey, conducted two decades later and in a different metropolitan area, indicates that the popularity of these items is quite steady over time and location. The most frequently adopted items, '*learning the location of medical centers'* and '*owning a fire extinguisher,*' are useful for other purposes or require little effort (Lindell et al., 2009; Lindell & Whitney, 2000). The least frequently adopted items, '*attending a meeting to learn about earthquake hazards*' and '*developing an emergency earthquake plan',* require time, effort, or expertise and are not useful for other purposes. Though this study did not assess peoples' perceptions of hazard adjustment attributes, the percent adoption of the items above provides further support for the proposition that both *hazard-related* *attributes* (e.g., utility for many purposes, perceived efficacy at protecting persons and property) and *resource-related attributes* (e.g., cost, effort, skill) influence hazard adjustment adoption. This conclusion is somewhat inconsistent with Lindell and Prater (2002) and Terpstra and Lindell (2013), who found that their measures of hazard-related attributes, but not resource-related attributes, were related to hazard adjustment adoption. Since it seems theoretically implausible that the resource-related attributes of cost, effort, and skill are irrelevant to people's hazard adjustment adoption, further study is needed to determine whether the absolute scale on which the resource-related attributes have been measured is most relevant to hazard adjustment adoption. One alternative measurement procedure would draw on Mulilis and Duval's (2003) Person Relative to Event model to address each hazard adjustment's resource-related demands (*relative to the person)*, rather than its absolute demands. For example, a relative response scale might be worded 'How much money does each of the following actions cost? *Much **less** than I can afford* = 1, *Much **more** than I can afford* = 5' rather than the previous absolute response scale 'To what degree does each of the following actions cost a lot of money? *Not at all* = 1, *Very great extent* = 5.'

It is interesting to note that PDX adoption levels of preparedness items more closely match SEA than LAX. This is understandable given the earthquake history in each region. Oregonians and Washingtonians have experienced fewer and, over the past century, less severe earthquakes than Californians. Moreover, Oregonians have experienced even fewer and less frequent earthquakes than Washingtonians; their overall low hazard adjustment adoption rates in comparison to the other regions quite possibly reflects this lack of experience. This lack of earthquake experience appears to directly translate to lower levels of hazard adjustment adoption, which is generally consistent with the findings from research on other hazards as well (Bamberg et al., 2017; Bubeck et al., 2012; Lindell, 2013b; Poussin et al., 2014).

In addition to its utility as a comparison to Lindell and Prater's (2000) Six City study of SEA and LAX area residents, our PDX survey also provides some limited comparisons with preparedness surveys carried out by local authorities in the CSZ region. Though only a few adjustments could be compared, the results suggest that there are similar adoption levels across certain adjustments and regions. However, it is the lack of analogous items that underscores the need for more studies, academic and local, to be done in ways that make comparisons possible. Existing surveys provide helpful diagnostic information for localities, but their results cannot be used to track changes over time or to compare across geographic boundaries. A possible solution involves local authorities and disaster preparedness researchers establishing prior agreement on questionnaire items and collaborating to develop new reproduceable survey questions where needed. Additionally, for local authority surveys, we had issues accessing the raw data due to broken links and deactivated principal investigator email accounts. Instead, we relied on results reported in fact sheets and summary reports, which allowed for less robust comparisons. One solution for this issue would be to institute better reporting practices where researchers and local governments archive preparedness survey data and instruments in places such as National Science Foundation-supported Natural Hazards Engineering Research Infrastructure databases clearinghouse, which outlives projects and positions and make this valuable information accessible to future researchers (see www.designsafe-ci.org/).

Perceptions of Information Sources

It is significant that, on average, respondents felt that meeting with emergency managers and visiting emergency management websites consistently provided the best information about earthquake risks and hazard adjustments. Unfortunately, Table 3 shows that meetings with emergency managers is one of the least popular hazard adjustments and this is probably because such meetings are rated as higher than average in their requirements for time/effort and required cooperation with others (Lindell & Whitney, 2000; Lindell et al., 2009). Thus, there is a need to identify ways for emergency managers to communicate with risk area residents in ways that overcome the disadvantages of meetings.

Respondents viewed peers, followed by live news broadcasts (radio or TV), as information sources that provided the least helpful information about risk and preparedness on almost all attributes. Interestingly, earthquake hazard maps tied with peers as least understandable. This finding is consistent with previous studies that find low levels of map comprehension for both hurricane risk area maps (Arlikatti et al., 2006; Zhang et al., 2004) and multi-hazard maps (MacPherson-Krutsky et al., 2020)—see Lindell (2020) for a general review. In tandem with previous research, the low mean rating of hazard map understandability indicates that existing hazard maps may need revision to provide better landmarks that allow people to identify their locations. Alternatively, maps may need to be supplemented with geocoding applications that pinpoint people’s home locations on the map after they enter their street addresses (e.g., HazardReady.org; MacPherson-Krutsky, 2016).

The ratings of information sources differed the most for the *accurate* attribute, which is in agreement with previous findings that peoples' trust in risk and preparedness information varies by the source they receive it from (Lindell, 2018). In the present study, respondents perceived information provided by local government and state agencies to be most accurate, whereas information provided by peers and media is perceived as least accurate. This difference (M = 4.1 vs. 2.9) is not only statistically significant but is roughly 30 percent of the response scale. Our results complement those of Arlikatti et al. (2007) who also found ratings of expertise and trustworthiness to be highest for authorities and lowest for peers. This tendency can also be seen for earthquake hazard knowledge and protection responsibility (Lindell & Whitney, 2000) and volcano hazard knowledge (Lindell & Perry, 1992, Chapter 6). In contrast to Arlikatti et al. (2007), where news media and authorities had almost the same ratings of expertise and trustworthiness, PDX respondents rated news media sources as being significantly less accurate. This finding appears to be due to the decline in perceptions of news media credibility over time, which suggests that there may be limitations in the use of this information channel to promote household hazard adjustment adoption (Kohut, Doherty, et al., 2012).

Study Limitations

Study limitations include the response rate and generalizability of findings. Though we had hoped for a response rate closer Lindell and Prater's (2000) 35 percent, it was less than 20 percent, which is consistent with a broader reduction in mail survey response rates over the last 50 years (Kohut, Keeter, et al., 2012; Kreuter, 2013). Despite the modest response rate, ~400 responses provided a large enough sample to provide adequate statistical power for detecting correlations of a practically meaningful size.

The ability to make consequential comparisons between this study and the Six City study is a second limitation. Since an additional survey with substantial item overlap with the Six City study has not been conducted in SEA or LAX in recent years, we cannot determine whether the variations in the PDX sample are related to temporal changes or regional differences in hazard adjustment adoption. The local authority surveys provide additional information across time and regions, but because there were so few comparable items, conclusions are limited. The present study uses the same questionnaire items from the Six City study to help make other comparisons and distinctions possible for future studies.

Conclusions

Our study provides an assessment of key points in the protective action decision making process for residents in PDX, an area at great risk from a CSZ earthquake. We examine knowledge of protective action recommendations, knowledge of risk zones, household preparedness levels compared to CSZ neighbors, and whether perceptions of information sources follow previously identified trends. Overall, we find that PDX residents are generally aware (i.e., have the 'gist') of the earthquake threat for their region but are less aware of the level of shaking they could expect at their homes. They also seem to be uncertain or unaware of liquefaction hazards. Additionally, the majority of respondents say they will take some action other than the recommendation of 'drop, cover, and hold on' when earthquake shaking starts. They also appear to be somewhat less prepared than their neighboring states of Washington and California. Furthermore, PDX residents have similar perceptions of information sources as found in previous studies except with respect to perceived accuracy of news media. PDX residents rated news media significantly lower than local officials across all attributes, whereas previous studies rated the two sources similarly. This finding is notable and has implications for how risk and preparedness messaging is distributed in the PDX region. To better understand this finding, future studies could examine the relationship between information source perceptions and hazard adjustment levels in PDX and elsewhere.

The results presented here suggest that, although government agencies and news media alike have invested tremendous effort in the past few decades in publicizing the potential for a CSZ megathrust earthquake, significant gaps remain in terms of translating broad awareness into personal knowledge and actions. Thus, more emphasis should be placed on providing individualized information and training around a Cascadia earthquake. In addition to existing education efforts, we recommend highlighting liquefaction hazards. Since liquefaction is likely to cause major disruption in the CSZ, as it has in previous earthquakes (e.g., 2010 Christchurch earthquake—Ballance, 2021; Cubrinovski et al., 2014), it is important for people to be aware of how liquefaction will disrupt their homes and ability to travel across the region. A second recommendation includes conducting more earthquake drills that teach ‘drop, cover, and hold on’ and also emphasize which actions *not* to take, such as standing in a doorway, and why. In particular, emergency managers and the news media should promote participation in Shake Out drills to increase earthquake knowledge and intentions to engage in appropriate shaking responses (Adams et al., 2017; Vinnell et al., 2020).

Finally, we recommend that future research continues to use and refine measures of preparedness to allow for better comparison across studies. These comparisons offer valuable information on how preparedness knowledge and actions vary across regions that could be used to develop targeted strategies motivate household preparedness. For example, if we knew that PDX residents were unique in their lack of water storage across the CSZ and this was a persistent finding, local emergency managers and researchers could focus efforts on understanding this discrepancy and develop approaches to resolve it. The current lack of consistent variable measures across surveys makes it challenging to understand where to focus resources to improve household preparedness locally and regionally.

The research discussed above offers an approach to test effectiveness of risk communication strategies at promoting household preparedness in a specific region. Studies like this offer better assessments of local gaps in preparedness knowledge and actions, while also examining how theoretical model constructs based on broad scientific knowledge apply in particular settings. Developing a 'culture of preparedness' (FEMA Agency, 2019) in the U.S. requires a better understanding of cultural and regional differences that influence willingness to receive and accept risk information, and factors that most strongly influence preparedness behavior. With this knowledge, emergency managers and educators can design and implement location-specific strategies targeted to meet their residents' needs.

CONCLUSION

Natural hazards have always been a facet of the landscape, but they are becoming more destructive as they intersect with growing populations and as climate change increases their frequency and intensity (FAO, 2021). Though we know empirically that investing in preparedness reduces disaster impacts, communities often fail to do so. As a result, the number of injuries, lives lost, and economic impacts are likely greater than they could be (Lightbody, 2017). To become more resilient, FEMA calls for a 'Culture of Preparedness' where everyone, from the individual to the national government, strives to be prepared (FEMA, 2018). Since households are the true first responders after an event, significant focus has gone toward promoting preparedness at that level. Despite this focus, U.S. preparedness levels have remained mostly stagnant (FEMA, 2020; HealthCare Ready, 2020).

Though studies have expanded our understanding of what motivates household preparedness and led to the development of theoretical models, gaps remain in our knowledge of which factors are most influential, which aspects of these models need to be refined, the effectiveness of current risk communication methods, and how to apply scientific understanding in community contexts. The work presented here focuses on aspects of household preparedness that include (1) examining how effective hazard maps are at helping people understand their risk, (2) assessing which factors are the strongest predictors of household preparedness and (3) measuring the effectiveness of recent strategies at providing residents with practical knowledge of hazard risks and motivating preparedness.

The results of Chapter 2 suggest that hazard maps may not be the best method for communicating risk to general audiences. MacPherson-Krutsky et. al (2020; Chapter 2) found that 26% of students incorrectly answered questions that required them to use a map legend and interpret risk, a value that would likely be higher for a general audience. Additionally, in Chapter 4, PDX residents rated hazard maps as least understandable compared to other sources of information. Since hazards maps are frequently used to communicate risk, these findings motivate the need to examine what alternative communication methods could be used and how to improve existing maps such that people can understand them more easily.

The most important finding from Chapter 3 is that information seeking behavior is the strongest predictor of preparedness. That is, people who seek out information about risk and what to do are the most likely to be prepared. This finding supports and expands previous research in our finding that information seeking not only influences past preparedness, but also influences intentions to prepare, feelings about earthquake threat (positive and negative affect), knowledge of protective recommendations, and risk perception. Future research should build on this by exploring what motivates information seeking behavior around natural hazards and risk.

Chapter 4 provides a series of valuable insights into levels of household preparedness in PDX and compares them with other communities at risk to a CSZ earthquake. This research highlights both community level and empirical gaps. At the community level, we find the majority of PDX residents are not aware of earthquake induced liquefaction hazards or which protective actions they should take during an earthquake. These results highlight practical needs of the community and have implications for how local emergency managers develop future risk messaging. Methodologically, we find a major limitation to be the ways in which researchers and local authorities measure 'preparedness' in public surveys. This inconsistent measurement reduces our ability to develop a baseline understanding of preparedness across a region and to address regional needs. For a CSZ earthquake, understanding and improving regional preparedness is key.

Cumulatively, these three chapters examine what factors influence household preparedness among specific populations. These findings help expand our understanding of the PADM variables and provide tangible evidence to guide improvement of existing and development of new education strategies. The results presented here also highlight that the link between risk education and preparedness is not direct. Many factors influence how people understand information, personalize risk, and take preparedness actions. By continuing to examine how risk information translates into protective action at the household level, we can more effectively develop risk education tools that increase community resilience. Carrying out this work relies on the collaboration of emergency managers, researchers from across disciplines, and individuals. It is only through developing and fostering these relationships that environmental hazard and protective action research can be applied to help develop a 'culture of preparedness.'

"*Hazardous events need not devolve into full-blown disasters.*

Risks need not become insurmountable.

Disaster risk can be reduced and managed." - FAO, 2021

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APPENDIX A

Chapter Two Tables

Table A.1 Hazard Map Evaluation Rubric (full)

High Performance - 3	Moderate Performance - 2	Poor Performance - 1	References
Visual (design components, map features, color/texture)			
V1. Aerial imagery base map used (or pops up as first map)	If interactive, aerial imagery is not primary map, but is available for selection	Aerial imagery is not used as base map and if interactive, aerial map is unavailable for selection	Dransch, Rotzoll, & Poser, 2010; Haynes, Barclay, & Pidgeon, 2007; Nave, Isaia, Vilardo, & Barclay, 2010
V2. Landmarks are clearly visible (roads, neighborhoods, rivers, etc.) to help viewer orient/locate oneself	Some landmarks are present, but are not clearly visible or do not help with viewer orientation	No or few landmarks are shown making orientation difficult	Cao, Boruff, & Mcneill, 2016; Kunz & Hurni, 2011
V3. Important map components are present and well-positioned on page (e.g., descriptive title, north arrow, scale bar, legend)	One important map component is missing and/or hard to locate on page	Two or more map components are missing	Brewer, 2005; Centers for Disease Control and Prevention, 2012
V4. Visual hierarchy is achieved through appropriate colors, symbols, font size, line width, and other symbolization techniques. • Most important map elements are emphasized • Base map is complimentary and does not distract	Visual hierarchy is mostly achieved, • Most important map elements are emphasized • Other imagery distracts from primary message	Visual hierarchy is not achieved, • Unimportant features are too prominent • Difficult to see data and intended information	Brewer, 2005; Centers for Disease Control and Prevention, 2012; Kunz & Hurni, 2011

V5. Appropriate color schemes are used on all data: • Sequential for increasing values (e.g. intensities) • Diverging for values above/below critical value (e.g temperature - freezing) • Qualitative for nominal data (e.g. trees, water, desert are green, blue, yellow, respectively)	Multi-hazard: appropriate color scheme are primarily used, but one or more data layers do not have appropriate color schemes	Multi hazard: incorrect schemes were used on all data layers Single hazard: incorrect scheme is used on data layer	Brewer, 2005; Hagemeier-Klose & Wagner, 2009; Harrower & Brewer, 2003; Robinson, 1952
V6. Colors match hazard color (flood = blue, landslide = brown). If not applicable (e.g. earthquake), score = n/a)	Multi hazard: one data layer color does not match hazard color, but all others do	Multi hazard: two or more layers colors do not match respective hazard color Single hazard: color does not match hazard	Brewer, 2005; Hagemeier-Klose & Wagner, 2009; Kunz & Hurni, 2011
V7. Less than 5 color classes are used (7 or less is ideal)	Multi hazard: 6-7 classes for at least one data layer Single hazard: 6-7 classes are used	Multi hazard: more than 7 color classes used for at least one data layer Single hazard: more than 7 color classes used	Thompson, Lindsay, & Gaillard, 2015
V8. Legend colors are matched exactly with those on map	Legend colors are not matched exactly, but it is easy to tell which legend items match with data	Legend colors do not match exactly (could be due to transparency issues)	Brewer, 2005
V9. Color-blind friendly schemes are used	Color-blind friendly schemes are generally used, but some data layers pose issues	Color-blind friendly schemes are not used- hard to distinguish classes or data layers	Harrower & Brewer, 2003; Thompson et al., 2015

Content (language, text, verbiage, data)			
C1. Auxiliary information is present along with mapped data (photos, personal quotes, audio recordings, descriptions, etc.)	Some auxiliary information is included, but more would help clarify concepts and hazard threat	Auxiliary information is not provided	Cao et al., 2016; Dransch et al., 2010
C2. Risk messaging is included and positively framed (e.g. “take these simple steps to reduce your flood risk” instead of “Flooding may cause loss of life”)	Risk messaging is included and mostly positive	No risk messaging or risk messaging is negative/fatalistic (e.g. “Prepare or suffer”)	Dransch et al., 2010
C3.Maps are personalized/customizable • Multi hazard: can zoom to areas of interest (AOI) • Single/Multi: community resources provided • Single hazard: Inset map to show AOI at finer scale		Information is not personalized or customizable (e.g. no zoom function, local resources, or inset maps included)	Bell & Tobin, 2007; Dransch et al., 2010
C4. Information appears to be accurate and up-to date (e.g. no broken links, outdated imagery) and is presented in a clear and concise manner	Information appears to be accurate and mostly up-to date, but could be presented more clearly.	Information appears to be outdated, links are broken, and no or poor/lengthy explanation lengthy is included	Nave et al., 2010

C5. Protective measures are included along with risk to facilitate preparedness rather than fatalism.	Some protective measures are included	Protective measures are not included on page	Crozier, McClure, Vercoe, & Wilson, 2006; Maidl & Buchecker, 2015
C6. Jargon/specialized terms are not used in map or descriptions	Uses specialized terminology, but explains in succinct easily understood terms (images or explanatory text)	Uses jargon in legend (100-yr floodplain, peak ground acceleration, debris flow, etc.) and does not explain	Bell & Tobin, 2007
C7. Legend items are clearly explained (e.g. High = water level could reach 3 feet here in the event of a large flood)	Legend items are explained, but not well (e.g. High = water will be deep here)	No explanation of legend items are given (e.g. High)	Brewer, 2005
C8. If data are probabilistic (if not, score = n/a), • Both percent (25%) and natural frequency (1 in 4) are used • Likelihood term is not used to describe data		Probabilistic information is provided either in percent or natural frequency and/or likelihood term used to describe data	Thompson et al., 2015
C9. Low-med-high terms are not used	Low-med-high terms are used, but clarifying information like percentages or descriptions are also included	Low-med-high terms are used without any clarifying information	Thompson et al., 2015

Table A.2 Map Updates from Hazard Map 1 to Hazard Map 2

Visual Updates	Content Updates
V1. Aerial imagery base map used	**C1. Auxiliary information present along with mapped data**
• Replaced light grey canvas with streets base map with aerial base map	• Added sidebar with auxiliary information on each hazard and how to prepare
V2. Landmarks are clearly visible to help viewer orient/locate oneself	**C2. Risk messaging included and positively framed**
• No changes made	• See C1 example
V3. Important map components are present and well-positioned on page	**C3. Maps are personalized/customizable**
• Edited and moved "Earthquake Shaking" title to a tab at top of page • Edited and moved "Projected Flood Hazard Zone" title to tab at top	• No changes made
V4. Visual Hierarchy is achieved through appropriate colors, symbols, font size, line width, and other symbolization techniques	**C4. Information appears to be accurate and up-to-date and is presented in a clear and concise manner**
• No changes made	• No changes made
V5. Appropriate color schemes are used on all data	**C5. Protective measures are included along with risk to facilitate preparedness rather than fatalism**
• Tsunami: layer changed from line to shaded region • Earthquake: changed scheme from diverging to sequential • Liquefaction: changed scheme from diverging to sequential • Flood: changed from 4 colors denoting the data source to single dark purple color	• See C1 example • Added a "How to Prepare" tab with information on what should be in a supply kit

V6. If applicable, colors match hazard color • Tsunami: color changed from pink to blue to represent water • Liquefaction: colors changed from red-orange-green to shades of brown to better match hazard • Flood: Historical flood layer was added with years indicated by different colors of blue to represent water	**C6. Jargon/specialized terms are not used in map or descriptions** • Earthquake: clarified Mercalli Intensity terms (e.g. “Very Strong” changed to “Very Strong (chimneys & plaster may fall)”) • Flooding: simplified language from four categories to a single flood hazard zone. Eliminated terms like “100-yr flood”
V7. Less than 5 color classes are used (7 or less is ideal) • Earthquake: reduced number of categories from 6 to 5	**C7. Legend items are clearly explained** • See C6 earthquake example • Volcano: “High Hazard Zone” changed to “Eruption Zone”
V8. Legend colors are matched exactly with those on map • Earthquake: Matched legend colors (HM1 did not match) • Liquefaction: Matched legend colors (HM1 did not match) • Volcano: Matched legend colors (HM1 did not match)	**C8. If data are probabilistic, then both percent (25%) and natural frequency (1 in 4) are used and likelihood term is not used to describe data** • No changes made
V9. Color-blind friendly schemes are used • All color schemes checked for colorblind friendliness • Liquefaction: colors adapted for color blind audiences (initial red-green scheme was difficult to see)	**C9. Low-med-high terms are not used** • Volcano: “High-” and “Moderate Hazard Zone” changed to “Eruption Zone” and “Lahar (volcanic debris flow) Zone,” respectively

Table A.3 Factor Analysis of Self-Report Scales

	F1	F2	F3
(SBSOD) Santa Barbara Sense of Direction Scale (Strongly Agree - Strongly Disagree)			
1. I am very good at giving directions.	.14	.66†	.20
2. I have a poor memory for where I left things.	.06	.50†	.25
3. I am very good at judging distances.	.22	.43†	.08
4. My "sense of direction" is very good.	.13	.79†	-.02
5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).	.43	.38	-.03
6. I very easily get lost in a new city.	.04	.69†	.13
7. I enjoy reading maps.	.52†	.30	-.05
8. I have trouble understanding directions.	.19	.69†	.22
9. I am very good at reading maps.	.55†	.08	.06
10. I don't remember routes very well while riding as a passenger in a car.	-.10	.72†	.20
11. I don't enjoy giving directions.	.13	.63†	-.03
12. It's not important to me to know where I am.	.15	.38†	.14
13. I usually let someone else do the navigational planning for long trips.	.24	.72†	.09
14. I can usually remember a new route after I have traveled it only once.	.20	.63†	-.19
15. I don't have a very good "mental map" of my environment.	.16	.73†	.33
(PSA) Philadelphia Spatial Ability Scale (Strongly Agree - Strongly Disagree)			
1. I am good at determining if my car fits into an available parallel parking spot.	.17	.42†	.15
2. I always know if a chair will fit through my front door before buying it.	-.01	.36	.30
3. I can easily visualize my room with a different furniture arrangement.	.11	.22	.42†
4. I enjoy putting together puzzles.	.25	.22	.47†
5. I have trouble giving someone directions, using a map that they are holding, without the ability to rotate the map to match the direction I am currently facing.	.52	.44	-.09
6. I can easily imagine what a 3D landscape would look like from a different point of view.	.54†	.28	.06
7. I have a hard time recognizing a familiar place from a satellite image.	.47	.49	.08

8. I can easily visualize the location of electrical sockets along the other side of wall in the adjoining room to my bedroom.	.47†	.17	.09
9. I am good at putting together furniture with only the use of diagrams.	.47†	.24	.03
10. I can easily recreate an origami piece after watching someone else make it.	.51†	-.14	.06
11. I can easily fold an elaborate paper airplane using a diagram.	.55†	.09	.15
12. I can visualize what the cut face of an apple would look like when the apple is cut on different planes.	.61†	.19	.18
13. I would be very good at building a model airplane, car, or train.	.65†	.10	.15
14. I could clearly imagine what a soda can would look like after it was partially crushed.	.37	.02	.55†
15. I can clearly imagine how snow would accumulate in a courtyard on a windy day.	.33†	.16	.45
16. I can clearly imagine how water flows through a rocky landscape.	.47	.10†	.34
(Allocentric View) Spatial Ability Supplementary Items: To what extent… (Not at all - Very great extent)			
1. are you good at finding your way to new places using maps?	.54†	.39	.02
2. are you good at finding shorter or faster ways to places you go frequently?	.45†	.22	-.11
3. can you tell what direction is North, South, East, or West, even if you are in an unfamiliar location?	.55†	.21	.00
4. do you like to look at maps, just because they are interesting?	.22	.41†	.05
5. When you want to go someplace unfamiliar, do you prefer to find your way by getting step-by-step directions or by looking at a map? (Prefer step by-step – Prefer map)	.48†	.33	-.08
(Metacognition) Map Comprehension Metacognition Scale (Strongly Agree - Strongly Disagree)			
1. I found it difficult to find locations on the map.	.35†	.13	.15
2. It was hard to understand what the questions were asking.	.46†	.11	-.03
3. I found it difficult to understand the map legend.	.44†	.19	-.13
4. The questions asked for information that was not available.	.32	.25	-.02
(PVA) Philadelphia Verbal Ability Scale (Not at all - Very great extent)			
1. I am good at crossword puzzles.	.10	.15	.49†
2. I am good at Scrabble.	.03	-.07	.51†
3. I often have trouble finding the right word to say.	-.16	-.06	.28
4. I would rather read a text explanation than look at a drawing or figure.	-.25	-.11	-.02

5. I have a good vocabulary.	-.27	-.09	.35
6. I spend more time reading than most people I know.	.27	-.12	.07
7. I prefer to watch TV or movies than to read for leisure.	.34†	-.09	.00
8. I can easily follow a complex verbal argument.	-.27	.23	.45†
9. I often have trouble expressing what I mean in words.	-.26	.08	.30
10. I have a good sense of language usage and write grammatically.	-.02	-.25	-.41†

Note. † denotes significant factor loading.

APPENDIX B

Survey Instrument for Chapters Three and Four

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Survey of Earthquake Preparedness in The Portland Metropolitan Area

BOISE STATE UNIVERSITY

1. **How likely do you think it is that in the next 10 years there will be an earthquake that will cause...**

	Not at all likely				Almost a certainty
a. major damage to property in your city?	①	②	③	④	⑤
b. deaths and injuries to many people in your city?	①	②	③	④	⑤
c. major damage to your home?	①	②	③	④	⑤
d. injury to you or members of your immediate family?	①	②	③	④	⑤
e. disruption to your electric, phone, and other basic services?	①	②	③	④	⑤

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2. To what extent does the possibility of an earthquake make you feel...

	Not at all				Very great extent
a. optimistic?	①	②	③	④	⑤
b. depressed?	①	②	③	④	⑤
c. nervous?	①	②	③	④	⑤
d. fearful?	①	②	③	④	⑤
e. energetic?	①	②	③	④	⑤
f. alert?	①	②	③	④	⑤

3. Which *one* of the actions below would you take if earthquake shaking begins when you are home?

① Stand in a door frame
② Drop, cover and hold on
③ Shelter in a Triangle of Life
④ Run outside away from buildings
⑤ Stay where I am until the shaking stops

4. Do you have any of the following in the place where you live?

	No	Don't have, but plan to get	Yes
a. a working portable radio with spare batteries or hand crank	①	②	③
b. at least 4 gallons of water per person in plastic containers	①	②	③
c. a two-week supply of non-perishable food for yourself and your family	①	②	③
d. at least a one-week supply of prescription medicines	①	②	③
e. fire extinguisher	①	②	③
f. flashlight and extra batteries	①	②	③
g. non-electric can opener	①	②	③
h. wrenches to operate utility shutoff valves and switches	①	②	③

5. Have you done any of the following for the place where you live?

	No	Haven't done but plan to do	Yes
a. strapped water heaters, tall furniture, and other heavy objects to building walls	①	②	③
b. installed latches to keep cabinets securely closed	①	②	③
c. developed a household earthquake emergency plan	①	②	③
d. learned where, when, and how to shut off water, gas, and electric utilities	①	②	③
e. learned the locations of nearby medical emergency centers	①	②	③
f. contacted the Red Cross or local emergency management agencies for information about earthquake hazards and emergency preparedness	①	②	③
g. attended meetings to learn about earthquake emergency preparedness	①	②	③
h. signed up for emergency alerts (e.g., public alerts, FEMA app, etc.)	①	②	③

6. To what extent would having two weeks of emergency supplies…

	Not at all				Very great extent
a. protect *persons* very effectively?	①	②	③	④	⑤
b. protect *property* very effectively?	①	②	③	④	⑤
c. also be useful for purposes other than earthquake protection?	①	②	③	④	⑤
d. cost a lot of money?	①	②	③	④	⑤
e. require specialized knowledge and skill?	①	②	③	④	⑤
f. require a lot of effort?	①	②	③	④	⑤
g. require a lot of cooperation from others?	①	②	③	④	⑤

7. To what extent would creating a family emergency plan…

	Not at all				Very great extent
a. protect *persons* very effectively?	①	②	③	④	⑤
b. protect *property* very effectively?	①	②	③	④	⑤
c. also be useful for purposes other than earthquake protection?	①	②	③	④	⑤
d. cost a lot of money?	①	②	③	④	⑤
e. require specialized knowledge and skill?	①	②	③	④	⑤
f. require a lot of effort?	①	②	③	④	⑤
g. require a lot of cooperation from others?	①	②	③	④	⑤

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8. To what extent would strapping water heaters, tall furniture, and heavy objects to the building walls…

	Not at all				Very great extent
a. protect *persons* very effectively?	1	2	3	4	5
b. protect *property* very effectively?	1	2	3	4	5
c. also be useful for purposes other than earthquake protection?	1	2	3	4	5
d. cost a lot of money?	1	2	3	4	5
e. require specialized knowledge and skill?	1	2	3	4	5
f. require a lot of effort?	1	2	3	4	5
g. require a lot of cooperation from others?	1	2	3	4	5

9. To what extent have you received or searched for information about earthquake risks and emergency preparedness actions from…

	Not at all				Very great extent
a. print media (newspapers, magazines, brochures)?	1	2	3	4	5
b. electronic media (broadcast and cable radio and TV)?	1	2	3	4	5
c. Internet (e.g., news media websites, emergency management websites)?	1	2	3	4	5
d. social media (e.g., Facebook, Twitter)?	1	2	3	4	5
e. discussions with peers (friends, relatives, neighbors, coworkers)?	1	2	3	4	5
f. meetings with community groups?	1	2	3	4	5
g. meetings with state and local emergency management authorities?	1	2	3	4	5

10. To what extent can discussions with peers (friends, relatives, coworkers) provide information about earthquake risk and emergency preparedness that is…

	Not at all				Very great extent
a. new to you?	1	2	3	4	5
b. accurate?	1	2	3	4	5
c. easy to understand?	1	2	3	4	5
d. relevant to your needs?	1	2	3	4	5

11. To what extent can meetings with local emergency managers provide information about earthquake risk and emergency preparedness that is…

	Not at all				Very great extent
a. new to you?	1	2	3	4	5
b. accurate?	1	2	3	4	5
c. easy to understand?	1	2	3	4	5
d. relevant to your needs?	1	2	3	4	5

12. To what extent can listening to live radio and watching live TV provide information about earthquake risk and emergency preparedness that is…

	Not at all				Very great extent
a. new to you?	1	2	3	4	5
b. accurate?	1	2	3	4	5
c. easy to understand?	1	2	3	4	5
d. relevant to your needs?	1	2	3	4	5

13. To what extent can viewing emergency management websites provide information that is…

	Not at all				Very great extent
a. new to you?	1	2	3	4	5
b. accurate?	1	2	3	4	5
c. easy to understand?	1	2	3	4	5
d. relevant to your needs?	1	2	3	4	5

14. To what extent can viewing earthquake hazard maps provide information that is…

	Not at all				Very great extent
a. new to you?	1	2	3	4	5
b. accurate?	1	2	3	4	5
c. easy to understand?	1	2	3	4	5
d. relevant to your needs?	1	2	3	4	5

15. To what extent has information about earthquake risk and emergency preparedness been…

	Not at all				Very great extent
a. easy to find?	1	2	3	4	5
b. easy to understand?	1	2	3	4	5
c. consistent across different sources?	1	2	3	4	5
d. realistic in its recommendations?	1	2	3	4	5
e. relevant to your needs?	1	2	3	4	5

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16. To what extent do you use each of the following devices for internet access…

	Not at all				Very great extent
a. Desktop or laptop computer?	①	②	③	④	⑤
b. Tablet computer?	①	②	③	④	⑤
c. Smartphone?	①	②	③	④	⑤

17. Have you ever experienced an earthquake that caused…

	No	Yes
a. damage to property in your city?	①	②
b. deaths and injuries to people in your city?	①	②
c. damage to your home?	①	②
d. deaths or injuries to you or members of your immediate family?	①	②
e. disruption to your electric, water, phone, and other basic services?	①	②

18. Based on your current knowledge, is your home…

	No	Unsure	Yes
a. in an area that could experience severe earthquake shaking?	①	②	③
b. in a liquefaction zone?	①	②	③

19. To what extent are you interested in receiving information about…

	Not at all				Very great extent
a. the science of earthquake hazards (e.g., causes, past history)?	①	②	③	④	⑤
b. what to do before an earthquake (i.e., how to prepare)?	①	②	③	④	⑤
c. what to do during earthquake shaking (i.e., protective actions to take)?	①	②	③	④	⑤
d. what to do after an earthquake (e.g., sanitize water, turn off utilities)?	①	②	③	④	⑤
e. how to get involved in disaster preparedness in your community?	①	②	③	④	⑤

20. What is your age? ________ years

21. What is your gender? ① Male ② Female ③ Prefer to self-describe ____________________

22. What is your marital status? ① Married ② Single ③ Divorced ④ Widowed

23. How many people in your household are: ________ less than 18 years? ________ 18–65 years? ________ over 65 years?

24. How many years have you lived in: ________ the community you live in now? ________ your current residence?

25. Do you rent or own the home where you now live? ① Rent ② Own

26. Which of the following best reflects your ethnicity?
① Caucasian ② Native American ③ African American ④ Hispanic ⑤ Asian/Pacific Islander ⑥ Mixed ⑦ Other (please specify) ____________________

27. What is your first language (you spoke as a child)?
① English ② Spanish ③ Other (please specify) ____________________

28. Which best describes your yearly household income before taxes?
① Less than $25,000 ② $25,000 - $50,000 ③ $50,001 - $75,000 ④ $75,001 - $100,000 ⑤ Over $100,000

29. Which best reflects the highest level of education that you completed?
① Elementary school (grades 1-5)
② Junior High or Middle School (grades 6-8)
③ High School (grades 9-12)
④ Some College/Trade school
⑤ College Degree (2 or 4 year degree)
⑥ Graduate Degree (Masters, Ph.D., etc.)

30. Please use the following space for additional comments regarding earthquake and disaster preparedness.

____

____

____

Thank you for participating in our survey.

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