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Understanding earthquake communication to improve preparedness and resilience

Michèle Marti



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Understanding earthquake communication to improve preparedness and resilience

A thesis submitted to attain the degree of
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(Dr. sc. ETH Zurich)

presented by
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2020

To those who have inspired, motivated, and supported me.

With a special thanks to Dominik, Suzanne, and Heinz.

"Without explicit analyses, though, there is no assurance that such advice is worth following. Widely accepted 'best practices' can still be terrible if they've been unthinkingly copied from one source to the next."

(Fischhoff 2011, p. 522).

SUMMARY

Earthquakes, the unpredictable threat from deep underground, are equally fascinating and frightening. While their destructive force was once attributed to the anger of the gods, their causal mechanisms in the Earth's interior are now well understood. The human race is mostly affected by earthquakes because we have missed to design our living environments accordingly. Insufficiently reinforced buildings and infrastructures combined with a mostly ill-prepared population explain why earthquakes are - despite being rare - the deadliest and most expensive among all natural hazards. Over the last decades, this has not changed despite a significant gain in knowledge with respect to the occurrence of earthquakes, their impact, and measures to mitigate their consequences.

Structural measures have dominated the prevention efforts of recent years. Based on elaborate seismic hazard assessments, construction standards have been established allowing for increased protection of growing populations in hazardous areas. However, to fulfill their purpose they need to be implemented - a premise which is often not met due to ignorance, lack of resources or corruption. Complementary, non-structural measures are needed to improve earthquake preparedness. For both types of measures, technical and scientific knowledge needs to be made available to those who can take actions. Hence, this thesis investigates how communication can contribute to improve earthquake preparedness and resilience.

Various factors influence communication activities in this particular field. They can be mainly assigned to one of the following domains: recipient, message, and institutional resources. Currently, the precise mode of action of these factors is only poorly understood, even though considerable resources are invested worldwide to provide information on natural hazards. There is an enormous deficit of empirical evidence, therefore most communication activities are based unthinkingly on previous efforts, intuition or anecdotal evidence. Thus, this thesis fills in some meaningful research gaps and points out future research priorities.

One such research gap concerns the effectiveness of frames. Frames emphasize certain aspects of a message and are a popular means to prompt preparedness for natural hazards or health issues. Although their successfulness has been proven many times, unclear or unexpected framing effects have also been documented. The study conducted in the framework of this thesis demonstrates for the first time that mood combined with the level of perceived risk influences the impact of gain and loss frames in a natural hazard context. According to the results of an online experiment, these three factors influence homeowners' willingness to take precautionary measures for earthquakes only in specific combinations. In consequence, a sophisticated design of communication measures is required to ensure that frames have a positive effect on the willingness to act.

Hazard maps are another popular but not well-studied means aimed at strengthening earthquake preparedness. Mainly designed for professionals, they are used likewise to inform the public about the threat earthquakes pose in a certain area. According to previous studies, non-experts in particular are assumed to have difficulties to draw adequate conclusions from studying such maps and associated information. Based on a current, real-world example, the second study examined how well the public as well as architects and engineers not specializing in seismic retrofitting understand the outreach products associated with the updated seismic hazard model for Switzerland. The results illustrate that carefully designed products are capable of transmitting key aspects of the model. However, as soon as best practices in visual design, text editing or presentation are disregarded, the comprehensibility of the information provided decreases. Even when confronted with well-designed products, non-experts in the field are challenged when requested to answer advanced assignments.

The two studies conducted suggest that existing evidence in the natural hazard domain as well as in related areas is often ignored when designing communication measures to enhance earthquake preparedness and resilience. In other cases, previous efforts or best practices in related fields are adopted without verification. The third study, analyzing documented and evaluated earthquake preparedness campaigns, confirms this observation. There is a disturbing lack of knowledge and empirical evidence to base future communication measures on. An opinion paper discusses this deficit and provides recommendations on how to best design future earthquake preparedness campaigns. The recommendations include plans for regular, long-term communication efforts, consideration of the context, selection of suitable communication channels, evaluation of communication measures, as well as conduction of further research. In addition, sufficient resources are needed, in particular to strengthen and maintain communication skills within institutions.

The first two studies of this thesis prove the potential to design effective communication measures so as to promote earthquake preparedness and resilience based on well-adapted, established knowledge. Communication is presumed to be effective when is allows its recipients to make informed decisions. To this aim, the information provided has to be accessible and understandable. Notably, this is where major research gaps persist as the third study particularly highlights.

Technical and scientific knowledge is advancing rapidly and allows for increasingly improved models and predictions. At the same time, the translation into information and products that allow non-experts in the field to derive measures is falling further and further behind. It is therefore essential to consider communication as an integral part of risk management and to develop it in-step with technical and scientific advancements. Thereby, the influence of new technologies as well as changing user needs and emerging formats must be particularly taken into account. Any resulting communication measures should therefore be based on a clear strategy taking into account best practices and be rigorously evaluated for suitability.

Communication is an indispensable means to promote prevention and resilience in the field of earthquakes and other natural hazards. This thesis illustrates the complexity of the task. While it does not offer a magic formula for successful communication, it does however provide a number of recommendations and approaches on how to best achieve this with the optimal interaction of message, recipient, and institutional resources.

ZUSAMMENFASSUNG

Erdbeben, die unvorhersehbare Kraft aus dem Untergrund, faszinieren und beängstigen gleichermassen. Während ihre zerstörerische Gewalt früher auf die Wut der Götter zurückgeführt wurde, sind ihre ursächlichen Mechanismen im Erdinnern heute gut bekannt. Uns Menschen treffen sie vor allem, weil wir unsere selbsterbaute Lebensumwelt mangelhaft auf sie ausgerichtet haben. Ungenügend verstärkte Gebäude und Infrastrukturen sowie eine grösstenteils schlecht vorbereitete Bevölkerung begründen, weshalb Erdbeben trotz ihrer Seltenheit die tödlichste und kostspieligste Naturgefahr sind. Daran vermochte auch der rapide Wissenszuwachs der letzten Jahrzehnte in Bezug darauf nichts ändern, wie Erdbeben entstehen und sich auswirken sowie mögliche Massnahmen, um ihre Folgen einzudämmen.

Bauliche Massnahmen prägten die Präventionsbemühungen der letzten Jahre. Die Etablierung von Baunormen ausgehend von elaborierten seismischen Gefährdungsabschätzungen leistet einen wesentlichen Beitrag, um die wachsende Bevölkerung in gefährdeten Gebieten besser zu schützen. Sie erreichen ihr Ziel jedoch nur, wenn sie tatsächlich umgesetzt werden, was Unwissen, mangelnde Ressourcen oder Korruption oft verhindern. Ergänzend und unterstützend benötigt es nicht-strukturelle Massnahmen, um den Schutz vor Erdbeben zu verbessern. In beiden Fällen ist eine Vermittlung von technischen und naturwissenschaftlichen Grundlagen erforderlich, um das bestehende Wissen jenen zugänglich zu machen, die Massnahmen ergreifen können. Diese Dissertation untersuchte, welchen Beitrag die Kommunikation leisten kann, um die Erdbebenprävention zu verbessern und die Resilienz zu erhöhen.

Verschiedene Faktoren beeinflussen die Kommunikation in diesem Umfeld. Sie lassen sich massgeblich den Bereichen Empfänger, Botschaft und institutionelle Ressourcen zuordnen. In einem komplexen Zusammenspiel bestimmen diese Faktoren den Erfolg von Kommunikationsmassnahmen. Ihre genaue Wirkungsweise ist aktuell wenig verstanden, obwohl weltweit beträchtliche Mittel eingesetzt werden, um über Naturgefahren zu informieren. Es besteht ein grosses Defizit an empirischen Grundlagen: die meisten Kommunikationsaktivitäten beruhen unreflektiert auf bisherigen Bemühungen, Intuition oder anekdotischer Evidenz. Die vorliegende Arbeit schliesst einige bedeutsame Forschungslücken und zeigt künftige Forschungsschwerpunkte auf.

Eine dieser Lücken betrifft die Wirkungsweise von sogenannten Frames. Frames betonen bestimmte Aspekte einer Botschaft und werden häufig verwendet, um präventive Verhaltensweisen im Naturgefahren- oder Gesundheitsbereich zu vermitteln. Ihre Wirksamkeit wurde zwar vielfach belegt, es traten aber auch immer wieder unklare oder unerwartete Framingeffekte auf. Zum ersten Mal für den Naturgefahrenbereich weist die im Rahmen dieser Dissertation durchgeführte Studie nach, dass die Stimmung und die Höhe des wahrgenommenen Risikos einen Einfluss darauf haben, wie Gewinn- und Verlustframes wirken. In einem online Experiment zeigte sich, dass diese drei Faktoren nur in spezifischen Kombinationen die Bereitschaft von HauseigentümerInnen erhöhen, präventive Massnahmen für Erdbeben zu tätigen. Es bedarf somit einer ausgeklügelten Gestaltung von Kommunikationsbotschaften, damit sich Frames positiv auf die Handlungsbereitschaft auswirken.

Erdbebengefährdungskarten sind eine weitere beliebte und wenig untersuchte Kommunikationsmassnahme, die mit dem Ziel eingesetzt wird, die Erdbebenvorsorge zu stärken. Hauptsächlich für Fachpersonen entworfen, werden die Karten gleichermassen verwendet, um die Bevölkerung über die Gefahr von Erdbeben in einem bestimmten Gebiet zu informieren. Bisherige Studien weisen darauf hin, dass insbesondere Laien Mühe bekunden, die richtigen Schlüsse aus dem Studium solcher Karten sowie den dazugehörigen Informationen zu ziehen. Anhand eines realen, aktuellen Beispiels untersuchte die zweite Studie, wie gut die Empfänger und dabei insbesondere die Bevölkerung sowie Architekten und Ingenieure ohne Spezialisierung in diesem Gebiet die aktualisierten Produkte des Schweizerischen Gefährdungsmodells verstehen. Die Resultate belegen, dass sorgfältig gestaltete Produkte in der Lage sind, zentrale

Inhalte zu übermitteln. Sobald aber beste Praktiken der visuellen Gestaltung, der Textredaktion oder der Präsentation der Inhalte missachtet werden, sinkt ihre Verständlichkeit. Es zeigt sich zudem, dass nicht spezialisierte Empfängergruppen auch bei gut gestalteten Produkten herausgefordert sind, wenn sie mit komplexeren Fragestellungen konfrontiert werden.

Die beiden Studien legen nahe, dass bestehende Evidenz aus dem Naturgefahrenbereich sowie verwandten Gebieten in der Gestaltung von Kommunikationsmassnahmen zur Stärkung der Erdbebenprävention und Resilienz oft nicht berücksichtigt oder ungeprüft übernommen wird. Dies bestätigt die dritte Studie, in der dokumentierte und evaluierte Erdbebenpräventionskampagnen untersucht wurden. Sie weist auf ein erschreckendes Defizit an Wissen und Empirik diesbezüglich hin. Ein Meinungsbeitrag diskutiert diesen Mangel und präsentiert Empfehlungen, wie Erdbebenpräventionskampagnen künftig ausgestaltet werden sollten. Diese umfassen eine stete, langfristige Kommunikationsplanung, die Berücksichtigung des Kontexts, die Wahl geeigneter Kommunikationskanäle, die Evaluation von Kommunikationsmassnahmen und weiterführende Forschungsarbeiten. Zusätzlich benötigt es ausreichend Ressourcen, um insbesondere die Kommunikationsfähigkeiten innerhalb von Institutionen zu stärken und zu pflegen.

Die vorliegende Dissertation belegt anhand der zwei ersten Studien das Potential, basierend auf einer geschickten Adaption von bestehenden Kenntnissen wirkungsvolle Kommunikationsmassnahmen zu entwickeln, um die Erdbebenprävention und Resilienz zu fördern. Als wirkungsvoll wird Kommunikation betrachtet, wenn sie ihren Empfängern erlaubt, informierte Entscheidungen zu treffen. Dies setzt voraus, dass die zur Verfügung gestellten Produkte zugänglich und verständlich sind. Insbesondere die dritte Studie weist jedoch darauf hin, dass diesbezüglich weiterhin grosser Forschungsbedarf besteht.

Die technischen und naturwissenschaftlichen Kenntnisse entwickeln sich rasant weiter und ermöglichen immer bessere Modelle und Vorhersagen. Gleichzeitig gerät der Transfer in Informationen und Produkte, die es nicht spezialisierten Empfängergruppen erlauben Massnahmen abzuleiten, immer weiter ins Hintertreffen. Aus diesem Grund ist es essentiell, Kommunikation als integralen Bestandteil des Risikomanagements zu betrachten und sie im Gleichschritt mit dem technischen und wissenschaftlichen Erkenntnisgewinn weiterzuentwickeln. Dabei gilt es insbesondere den Einfluss neuer Technologien sowie sich verändernder Nutzerbedürfnisse und aufkommender Formate zu beachten. Daraus hervorgehende Kommunikationsmassnahmen sollten auf einer klaren Strategie beruhen, bewährte Praktiken berücksichtigen und rigoros auf ihre Eignung geprüft werden.

Kommunikation ist ein unverzichtbares Mittel, um die Prävention und Resilienz im Bereich Erdbeben sowie für andere Naturgefahren zu fördern. Die vorliegende Arbeit verdeutlicht die Komplexität dieser Aufgabe. Sie bietet zwar keine magische Formel für erfolgreiche Kommunikation, aber eine Reihe von Empfehlungen und Vorgehensweisen, wie sie im optimalen Zusammenspiel von Botschaft, Empfänger und institutionellen Ressourcen gelingen kann.

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1. EARTHQUAKE COMMUNICATION MATTERS

Over the last decades, the understanding of the relevant processes and potential impacts of natural hazards has significantly increased. Sophisticated models, a bigger amount of observations and data as well as high computing power allow for ever more precise hazard assessments. However, reported losses from natural hazards have steadily increased. From 1997 to 2018 natural hazards claimed 1.8 million casualties; 4.4 billion people were injured, lost their homes or had to relocate (Wallemacq and House 2018). Every year, on average, 250 to 300 billion US$ of economic losses have to be expected (UNIDSR 2015). Despite their rareness, earthquakes account for the majority of these losses and are the deadliest among all natural hazards (Wallemacq and House 2018). Currently, earthquakes cannot be predicted nor prevented.

One can now argue that technical progress is indeed very efficient, but cannot keep up with the growth of population and assets in seismic areas. With 2.7 billion people, however, living in places in which earthquakes that cause at least slight damage have to be expected on a regular basis (Pesaresi et al. 2017), this is certainly part of the explanation. Another is that not all of those technical and scientific advancements are informing practice. The high impact of such disasters in terms of casualties, economic losses, social disruptions, demographical changes, or even political conflicts raises questions of how people respond to earthquakes (Lindell and Hwang 2008).

Improved seismic hazard assessments allow to define reliable building codes enabling earthquake-resistant constructions. Buildings and infrastructures designed accordingly pose the most efficient protection and limit earthquake related damage. As a matter of fact, even when such codes are in force their implementation is often impeded. Lacking resources, corruption, outdated standards, missing regulations and control mechanism, as well as insufficient awareness are just some of the reasons (Day 2012). In addition, even with enforced, solid regulations in place, events can exceed designated standards. Damage also often occurs to older buildings and infrastructures established before any building codes have been implemented and which have not been retrofitted since. Some of the resulting preparedness gaps can be approached with non-structural measures. They have recently gained attention to enhance the capability of a society to prepare for and cope with natural hazards. The world bank rates such interventions as particularly cost-efficient (Kelman 2013).

Communication is key to make hazard information accessible to a wider audience. It should allow for informed decision taking. To sustainably enhance earthquake preparedness, structural and non-structural measures need to be linked, carefully coordinated, and implemented. To this end, not only knowledgeable experts are required but also engaged members of a society. For example, house owners can only insist in applying building codes when they are aware of their existence and know about the seismic hazard in their area. Individual knowledge and engagement is even more important for non-structural measures. In most parts of the world, earthquake losses are underinsured (OECD 2018). Without basic information it is impossible to judge whether such an insurance is worth the expenditure or not. The same is true for the adoption of other measures such as knowing how to behave during an earthquake or put together an emergency kit.

The scientific and technical knowledge to base informed decisions for earthquake preparedness on is available and steadily growing; but how to translate it into something people can act on? This is where my thesis sets in. As a practitioner, I am challenged to seek answers to this question on a daily basis. This thesis shall thus depict the current state of the art in earthquake preparedness communication and contribute to an enhanced understanding of particular aspects in the field. It aims to contribute to improved information strategies targeting non-experts since without their support preparedness levels will not rise. "The social production of risk information itself needs to be transformed, with a shift in focus from the production of

risk information per se towards information that is understandable and actionable by different kinds of users: in other words, risk knowledge" (UNIDSR 2015, p xviii).

Up to now, empirical evidence on natural hazard communication and its impact is very limited (Khan et al. 2017; Nathe 2000). Current approaches and common practices are generally neither theory driven nor evaluated. Gathering empirical evidence and forming best practices in communicating natural hazards is therefore the main goal of this thesis.

2. EARTHQUAKES, SEISMIC HAZARD, AND RISK

Deep under our feet, the Earth is constantly moving. Tectonic plates attempt to pass each other, collide and thereby build up tensions. Earthquakes are the sudden release of stress along such tectonic faults. The discharged energy travels to the surface in the form of seismic waves. As stated before, there is currently no method to predict when a bigger amount of built-up stress will be released. However, based on historical information, recorded earthquakes, geology, and wave propagation models, seismic hazard can be defined. Seismic hazard describes how often an earthquake causing a defined amount of shaking has to be expected in a specific location. Based on these so-called horizontal acceleration values design codes are established (Swiss Seismological Service 2018b).

Design codes determine for a certain time period the amount of horizontal acceleration a building or infrastructure has to withstand without collapsing. They do not prevent structures from getting damaged or guarantee their functionality, they aim at protecting lives (Bachmann and Duvernay 2013). Critical infrastructures such as dams, hospitals, or nuclear power plants are designed to resist stronger horizontal accelerations than common housing. Such acceleration values are expected less frequently. Therefore, normal buildings usually have to resist horizontal acceleration values expected at their location once within 475 years whereas hospitals are designed for values estimated every 2,500 years (Swiss Seismological Service 2018b).

Seismic hazard does not take into account the local subsoil nor the vulnerability of buildings and infrastructures despite the fact that both critically influence potential consequences. They are included in seismic risk which considers seismic hazard, local soil conditions, vulnerability of buildings and infrastructures as well as values potentially affected. Seismic risk is the most comprehensive parameter to base precautionary measures on. However, the relevant data to determine seismic risk for a bigger area or a country is only rarely available (Robinson et al. 2018). Elaborate studies would be necessary for which resources are currently lacking in most places. For example, to map the local subsoil in detail, microzonation is needed (Parvez and Rosset 2014). To assess the vulnerability of buildings, construction plans have to be studied and assessed.

In consequence, the most reliable information currently available to base any mitigation measures on is seismic hazard. Of course, seismic hazard assessments vary in their quality and level of detail, but a primary evaluation is available for almost every country. Despite its relevance to improve resilience, seismic hazard is, in particular for non-experts, a difficult concept to comprehend and to apply. It starts with ground acceleration values being in the focus of seismic hazard outputs, a measure most people have never heard of. It continues with the representation of those values on maps, the most prominent output of seismic hazard models, which are often misunderstood (Hagemeier-Klose and Wagner 2009; Kjellgren 2013; Perry et al. 2016; Severtson and Vatovec 2012). In addition, seismic hazard models are associated with different kinds of uncertainties and provide conditional probabilities, both factors being known to challenge comprehensibility (Bostrom, Anselin, and Farris 2008; Gigerenzer and Edwards 2003).

Because of its current prevalence and importance, this thesis focuses mainly on communicating seismic hazard and the challenges associated with it. Although this thesis makes a clear distinction between seismic hazard and risk communication, the two terms are commonly exchangeable and used equivalently.

3. CHALLENGES IN SEISMIC HAZARD COMMUNICATION

In order to be able to take informed decisions, people need to have access to balanced, accessible, and comprehensible information. As highlighted above, such information is not necessarily available and may be difficult to compile. Seismic hazard communication, which aims at supporting people to take precautionary measures, has to accomplish the following: first, people need to understand how they could be affected, second they have to learn about suitable measures, and third they require resources to become engaged (Paton 2018). What sounds like an easy procedure is full of obstacles. In consequence, most people living in seismic active areas do nothing or only little to prepare for earthquakes (Solberg, Rossetto, and Joffe 2010).

Traditionally, hazard communication efforts follow a top-down approach. In a natural hazard context they are synonymous to public education and public awareness building (Khan et al. 2017). The prevalence of one-way over discursive communication is mostly owed to its range and efficiency. One-way communication allows to address a very diverse audience with a single approach. Two-way communication is, in return, more costly, demanding for targeted products, correspondent resources at an institutional level, and the willingness of recipients to enter a dialogue (Maidl and Buchecker 2015). Despite the prevalence of one-way communication approaches, it is a common fallacy that providing information will simply trigger the desired outcome (Perez-Fuentes, Verrucci, and Joffe 2016; Verrucci et al. 2016). Often communication activities are based on the misleading assumption that people are not sufficiently informed and therefore unprepared (Perez-Fuentes and Joffe 2015). Despite its potential to raise awareness, passive information unfortunately hardly shapes preparedness (Becker et al. 2013).

In addition, a variety of factors influence how seismic hazard information is processed, understood, and interpreted. The key challenges in raising earthquake preparedness with the support of communication measures can be attributed to peculiarities of the recipients, the message, and the resources available on an institutional level. Inadequately designed communication measures can lead to misunderstandings, deficient interpretations, and loss of public trust (Scolobig et al. 2015). Seismic hazard communication, no matter how well-designed, will not be able to eliminate these challenges but must by necessity acknowledge and address them. Up to now, the evidence in this field is scarce at best (Gaspar-Escribano and Iturrioz 2011; Maidl and Buchecker 2015; Mileti et al. 2004; Mileti and Darlington 1995; Mileti and Fitzpatrick 1992; Nathe 2000; Perry et al. 2016). In the following, an overview is provided of known challenges that mirror the complexity of enhancing earthquake preparedness and reflect the current state of research.

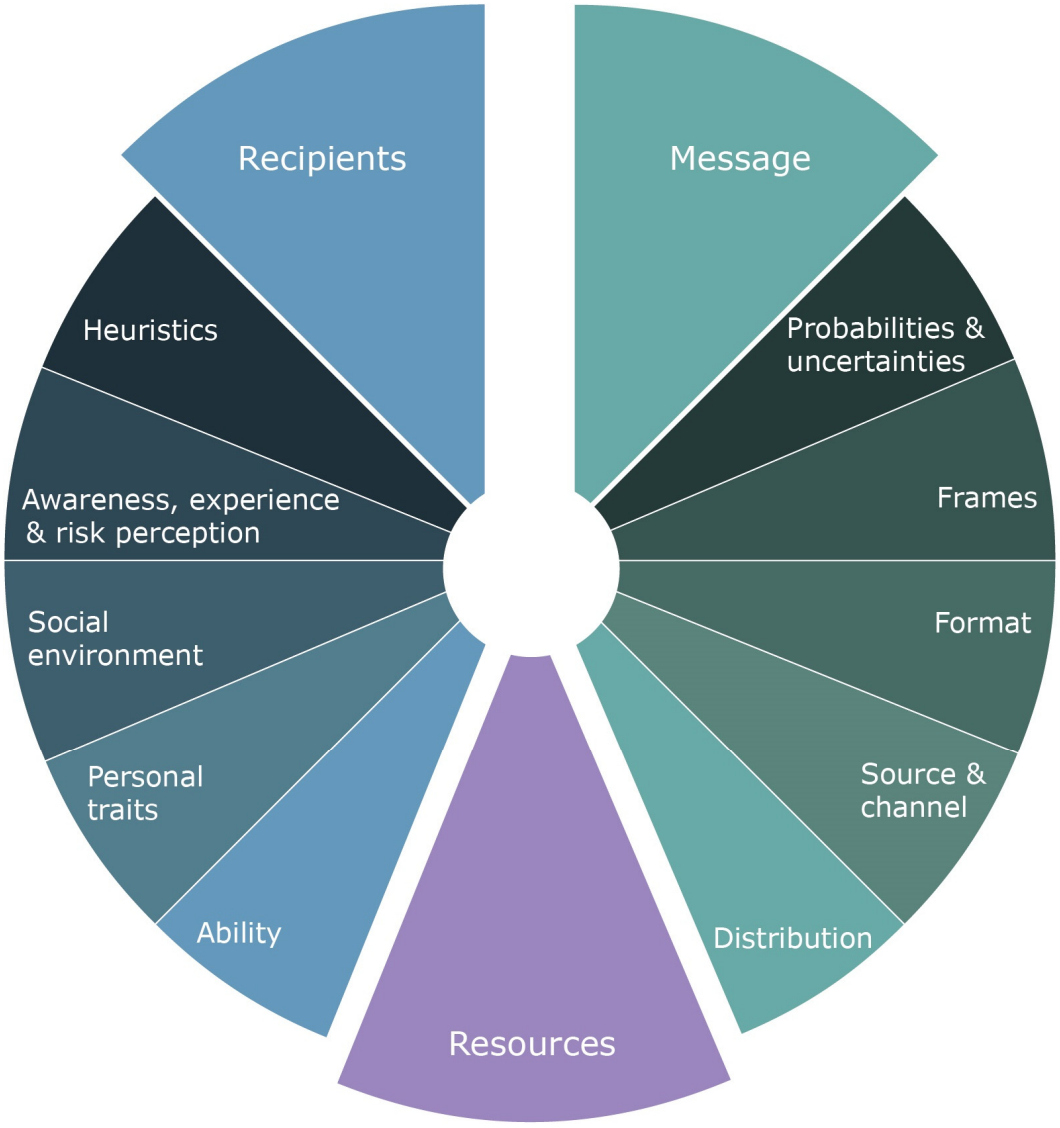


Figure 1: Color-coded domains of key challenges (recipients, message, and resources) including relevant factors when designing communication measures aimed at improving earthquake preparedness and resilience.

3.1 Recipients

Recipients are challenged in various ways when seeking for and processing hazard information. They rarely base decisions solely on information provided by institutions or media. Personal experiences, beliefs, goals, skills, needs, feelings, values or their social environment influence their decision taking (Leshner et al. 2017; McIvor and Paton 2007). "While it is probably the case that people learn how to prepare from the media, information alone is rarely sufficient to change behavior" (Heller et al. 2005, p. 416).

3.1.1 Heuristics

There is a number of heuristics impeding people from acting on information. Many persons are for example convinced that a disaster is more likely to harm others and are therefore subject to an optimistic bias (Solberg et al. 2010). As a result, individuals may not receive, misinterpret or simply ignore preparedness information (Tierney, Lindell, and Perry 2001). The same is true for those affected by a confirmation bias, deterring them from processing information that contradicts established beliefs (Perry et al. 2016). To estimate the likelihood of an event, people often rely on personal experiences. In consequence, such availability biases lead to an underestimation of rare disasters and people may have too much confidence in the precautionary measures taken as they have never been tested (Eiser et al. 2012).

3.1.2 Awareness, experience, and risk perception

People need to belief that an earthquake could affect them (Becker et al., 2013). This is certainly the case for those already having experienced one, but earthquake experience does not necessarily lead to enhanced preparedness. Whereas it increases salience, the influence of experience on preparedness is ambiguous. Many people do not take any actions despite knowing that earthquakes pose a serious threat. The previously mentioned optimistic bias as well as fatalism are possible explanations. Another is the tendency to delegate preparedness actions to response organizations (Ruggiero and Vos 2015). Hazard awareness and positive attitudes towards an intended outcome make it more likely that precautionary actions are taken (McIvor and Paton 2007). Furthermore, risk perception is often cited as having a considerable impact on preparedness (Mileti and Fitzpatrick 1992; Ronan and Johnston 2005). However, the effect is not uniform suggesting that other factors influence its explanatory power (Solberg et al. 2010). In any case, bridging the gap between attitudes and behavior remains challenging (Kollmuss and Agyeman 2010; Perez-Fuentes and Joffe 2015; Sheeran 2002; Wood et al. 2012).

3.1.3 Personal traits

Everyone is unique and therefore approaches seismic hazard information differently. Important personal traits in this context are self-efficacy, trust in others, anxiety, fear, knowledge, outcome expectations, and critical awareness (Doyle et al. 2018; Kim and Kang 2010; Paton 2003; Prati et al. 2013). Furthermore, gender, age, education, income, home ownership, race, the family situation or numeracy skills have shown to influence the processing of hazard information and the implementation of precautionary measures (Lindell et al. 2015; Lindell and Perry 2000; Peters 2008; Solberg et al. 2010; Thompson, Lindsay, and Gaillard 2015). Preparedness increases for example with age, but only up to a certain point and then drops again (Nukpezah and Soujaa 2018). Numeracy skills and therewith the ability to understand and solve mathematical tasks positively correlates with the interpretation of risk information (Peters 2008). The way people respond to hazard information not only depends on constant personal traits and rationales but also on transient affective states (Eiser et al. 2012; Keller, Siegrist, and Gutscher 2006; Slovic et al. 2004). In addition, in a crisis situation people's capacity to process information is very limited (Wein et al. 2016).

3.1.4 Social environment

People receive and process information within a social context. Observing others taking actions has a positive influence on preparing for low-probability, high-impact events (Perez-Fuentes and Joffe 2015). Talking with friends and family about preparedness can amplify the positive effects (Heller et al. 2005). Moreover, social expectations play an important role: the likelihood of taking precautionary measures for earthquakes increases within a social context that advocates such behavior (Eiser et al. 2012; McIvor and Paton 2007). The social environment also shapes the way information is received and interpreted. When designing communication measures current beliefs and associations must thus be take into account (Khan et al. 2017).

3.1.5 Ability

For being able to take decisions and implement protective actions, recipients need particular resources including the capacity, skills, and financial means to implement precautionary measures. First, information needs to be acquired and conclusions drawn. Second, after having made a plan, implementing the measures chosen requires inevitably some skills and mostly funds. For example, when one decides to attach its shelfs to the wall, a minimum level of craftsmanship is needed as well as a small amount of money for the equipment. More cost-intensive is the retrofitting of existing structures, whereas the application of seismic building codes for new buildings only accounts for about one percent of the total expenditures. In this sense, capacity, implementation skills, and

financial means are interdependent and lacking one or more of these resources will impede the implementation of precautionary measures. Financial incentives granted by insurances when taking actions or governmental support can be effective to enhance preparedness as long as recipients are willing to receive assistance (Bouwer et al. 2013).

3.2 Message

The way recipients process information does not only depend on personal attributes, but is also influenced by the message design. Adequate hazard communication needs to be selective. From the usually big amount of available information a meaningful selection has to be made based on users' needs and interests as well as on the communication goals. Spoiling recipients with unnecessary content leads to denial (Fischhoff 2011) and access to more complete information does not necessarily enhance understanding or prompt better choices (Peters et al. 2007). Besides selecting the most appropriate content its composition and presentation is essential.

Before starting any communication activity, the following points should be clarified. What is the goal of the communication? Who are the recipients? And what do they want and need? Furthermore, a message has to be appropriate for different preparedness stages ranging from encouraging people's motivation to prepare, to forming intentions, to supporting their engagement (Finnis 2004). Based on such an analysis, the design process must affect the format of a message, its content, presentation, source, channel, and distribution.

3.2.1 Probabilities and uncertainties

Probabilities and uncertainties are an inherent element of natural hazard communication and complicate its processing since users - regardless of their expertise- struggle to correctly interpret conditional probabilities, relative probabilities, and single event probabilities (Gigerenzer and Edwards 2003). To make matters worse, people are not necessarily interested in sophisticated probability assessments and usually prefer to decide based on binary schemes e.g. likely / unlikely (Mileti et al. 2004). Another challenge lies in the small probabilities characteristic for seismic hazard. Values close to zero are common and generally assessed as negligible by non-experts. On this account, despite being small, the chance of an event to happen has to be highlighted. To this aim, data can be aggregated to depict for example the chances for an event to occur within a lifetime and not within a single year only. Using frequencies instead of probabilities, offering comparisons with the background probability level or visualizing data offer additional workarounds (Gigerenzer and Edwards 2003). When it comes to communicating uncertainties, restraint is called for. The different forms of uncertainties related to seismic hazard assessments are irrelevant to non-experts. Meaningful are only those uncertainties which significantly influence the magnitude of a risk or its management (Kasperson 2014). One needs to first understand the relevance of different uncertainties for decision taking and then only disclose and elaborate the uncertain aspects relevant for decision takers (Doyle et al. 2019).

3.2.2 Frames

Besides genuine difficulties in processing probabilities and uncertainties the way numerical information is described has an impact on message interpretation and subsequent behavior. Frames emphasize certain aspects of a message. Levin, Schneider, and Gaeth (1998) differentiate between three frame types: (1) Risky choice framing describes the tendency of people to seek a riskier behavior if losses are emphasized and to act risk-averse when confronted with potential gains of the same action. (2) Goal framing aims at promoting a specific effect by either pointing out the benefits of a certain behavior or the negative consequences in case of disregard. (3) Attribute framing is related to consumer decisions or ratings. For example, the quality of beef labeled as 25 percent fat is rated lower than for beef described as 75

percent lean. Relevant is an attribute of the selection presented and not the outcome of a decision. Framing effects have shown to be variable, they are influenced by cognitive processes, personal traits, and affective states (Druckman and McDermott 2008; Keller, Lipkus, and Rimer 2003; Rothman et al. 2006).

3.2.3 Format

Different formats are used and eligible to portray hazard information. The range spans from passive information distribution to highly interactive formats. Whenever possible, explorative and interactive information access is preferable over passive distribution because it increases engagement (Becker et al. 2013; Mileti et al. 2004). The success of a specific format is not universal; it depends on how well it is designed and fits particular users' needs. In a natural hazard context, formats are usually designed to suit the largest common denominator of a very heterogeneous audience. Consequently, they may violate the requirements of minorities, disabled persons, or those speaking another language (Mileti et al. 2004).

3.2.4 Source and channel

According to a representative Swiss study, the most preferred sources to access hazard related information are websites from authorities and experts as well as the personal environment. The working environment and local associations come next. With respect to their needs in a crisis situation, participants wished most to receive behavioral recommendation presented succinctly and in a well-arranged fashion. In addition, about half of the participants would like to access recommendations on how to best protect themselves, online maps depicting local hazards or a preprogrammed form to establish an emergency plan. Many wished to have access to all relevant information. The most popular channel to retrieve preparedness information are websites followed by printed brochures, specific trainings at schools, regular updates in media, and dedicated apps. In an emergency situation, radio is most preferred to receive important information followed by sirens, TV, location based apps, public screens, public announcements, and websites. Only a third of the participants selected social media as a channel to access emergency related information (Maduz et al. 2018).

Other surveys confirm the picture drawn by this particular study. Most people still prefer traditional channels such as TV, internet, or newspapers over social media to retrieve information about disaster preparedness (Becker et al. 2016; Blakley and Chen 2009). Up to now, social media plays an insignificant role, even though a slight shift towards more popularity can be observed (Becker et al. 2016). Presumably, age is an important factor affecting channel preferences. After having received a letter informing about the flood risk in a particular area, only one third of the participants checked the promoted online information. Especially older people accessed it even more rarely (Maidl and Buchecker 2015).

3.2.5 Distribution

Earthquake prevention related information is better received when distributed repeatedly by different, trusted sources and through various channels (Becker et al. 2013; Mileti et al. 2004; Paton, Smith, and Johnston 2005). Repetition is important because single interventions hardly ever initiate a long-lasting impact (Shenhar et al. 2015; Tanaka 2005). The rareness of earthquakes further requests for regularity because such events tend to be forgotten (GeoHazards International 2018). Distributing the same message via different sources brings mainly two advantages: First, multiple channels address different audiences and thus increase the reach of a message. Whereas some prefer to read the newspaper others favor to watch TV. Second, different sources promoting the same content enhance exposure. By necessity, these sources need to be trusted. In particular for rare events, non-experts have no choice but to base on their hazard assessment on the information experts provide (Fischhoff 2011). Content from untrusted sources triggers additional information seeking and may lead to denial (Mayhorn

and McLaughlin 2014). In any case, recipients have to be motivated to receive and process hazard information (Lipkus 2007). Their willingness depends not only on its distributions, but also on the content and people's personal constitution.

3.3 Institutional resources

Earthquake preparedness comes with a price for both, those intended to take actions as previously described and for those promoting it. Even sound message design converging with aware and willing recipients may not lead to improved preparedness. The resources needed are manifold, interconnected, and assigned to different areas.

Evolving technical and scientific knowledge, societal contexts, political circumstances, institutional mandates, user needs, distribution channels, and message formats calls for constant innovation. In consequence, there is an infinite request to develop new communication material which then has to prove its effectiveness. Despite this obvious need for evaluation, it is currently quite uncommon to test natural hazard communication products and collect empirical evidence to prove its usefulness (Perez-Fuentes et al. 2016). Besides a lack of awareness, the main reasons for this deficit is a shortage of resources to support interdisciplinary collaboration, hire qualified personnel, and allocate necessary funds. To make matters worse, the impact of communication measures can be difficult to assess and evaluations also pose the threat of uncovering failure (Besson 2018). Therefore, institutions often refrain from conducting them to in the first place.

As mentioned before, trained professionals are essential to design effective hazard communication. In many cases, the development of hazard communication products is not supported by communication professionals (GeoHazards International 2018). In addition, many scientists being at the foreground to explain seismic hazard lack professional training to engage with media, authorities, and the public (Stewart, Ickert, and Lacassin 2017). Institutions also need dedicated funds for being able to respond adequately to different requests and to serve the different audiences and communication channels. For example, social media channels have to be monitored continuously and competently (Bruns and Burgess 2014). In many countries, this includes language skills and resources for translations (Mayhorn and McLaughlin 2014). To professionalize institutional communication, human and financial resources are required together with the willingness to collaborate inter-disciplinarily. Besides scientists and communication specialists, the later may involve IT developers, designers, engineers or psychologists.

Institutions may also support preparedness actions financially. To this end, however, they need to allocate dedicated funds (Egbelakin et al. 2011).

4. KNOWLEDGE GAPS AND RESEARCH QUESTIONS

The factors potentially influencing communication measures aiming at supporting informed decision taking and improved hazard preparedness are manifold. Characteristics of the recipient, the message as well as the institutional resources available determine the outcome of communicative efforts in a complex interplay. Although many individual factors are known, empirical evidence is often lacking or ambiguous, thus not allowing to specify the nature of their impact or the way they interact with each other. As a consequence, designing effective communication measures becomes very demanding.

There is a genuine lack of empirically evaluated and tested approaches aiming at increasing preparedness (Levac, Toal-Sullivan, and O'Sullivan 2012). In addition, the small amount of evaluations conducted is often deficient due to, for example, small samples or lacking baseline measurements (Johnson et al. 2014). In consequence, disaster preparedness is currently mainly based on unthinking previous efforts, intuition, and anecdotal experiences (Wood et al. 2012). Without evidence, approaches that seem meaningful still might be entirely misleading (Fischhoff 2011). Constantly low preparedness levels suggest shortcomings in transferring improved hazard knowledge gained through increasingly sophisticated scientific and technical assessments into actions. Besides other risk management tools, communication plays a critical role in promoting and supporting preparedness activities. The countless efforts undertaken to enhance disaster preparedness through information campaigns proves a recognition of its significance. The more surprises the little knowledge available and the low importance of evaluating previous campaigns. Although risk information is created and shared continuously, it remains unclear to which extend it is received and if it has the potential to alter perceptions and awareness (UNISDR 2006). In particular with respect to earthquakes, the natural hazard claiming the majority of victims, such a deficit is remarkable.

This thesis contributes profound evidence and sheds light on some of the most relevant research gaps. Split into three studies, each addresses one of the three domains of key challenges in designing communication measures aiming at improving earthquake preparedness and resilience (see Figure 1). Although each study focuses on one particular domain of key challenges, the characteristics of recipients, message design, and resource availability are assessed comprehensively, reflecting real communication settings as much as possible. The results shall contribute to expand the knowledge of seismic hazard communication and support the formation of best practices. In the future, improved hazard communication shall be qualified to take up its indispensable role as part of a holistic risk management enhancing earthquake preparedness and resilience. The following research question represents the main interest of this thesis:

How to design and compile communication measures improving earthquake preparedness and resilience?

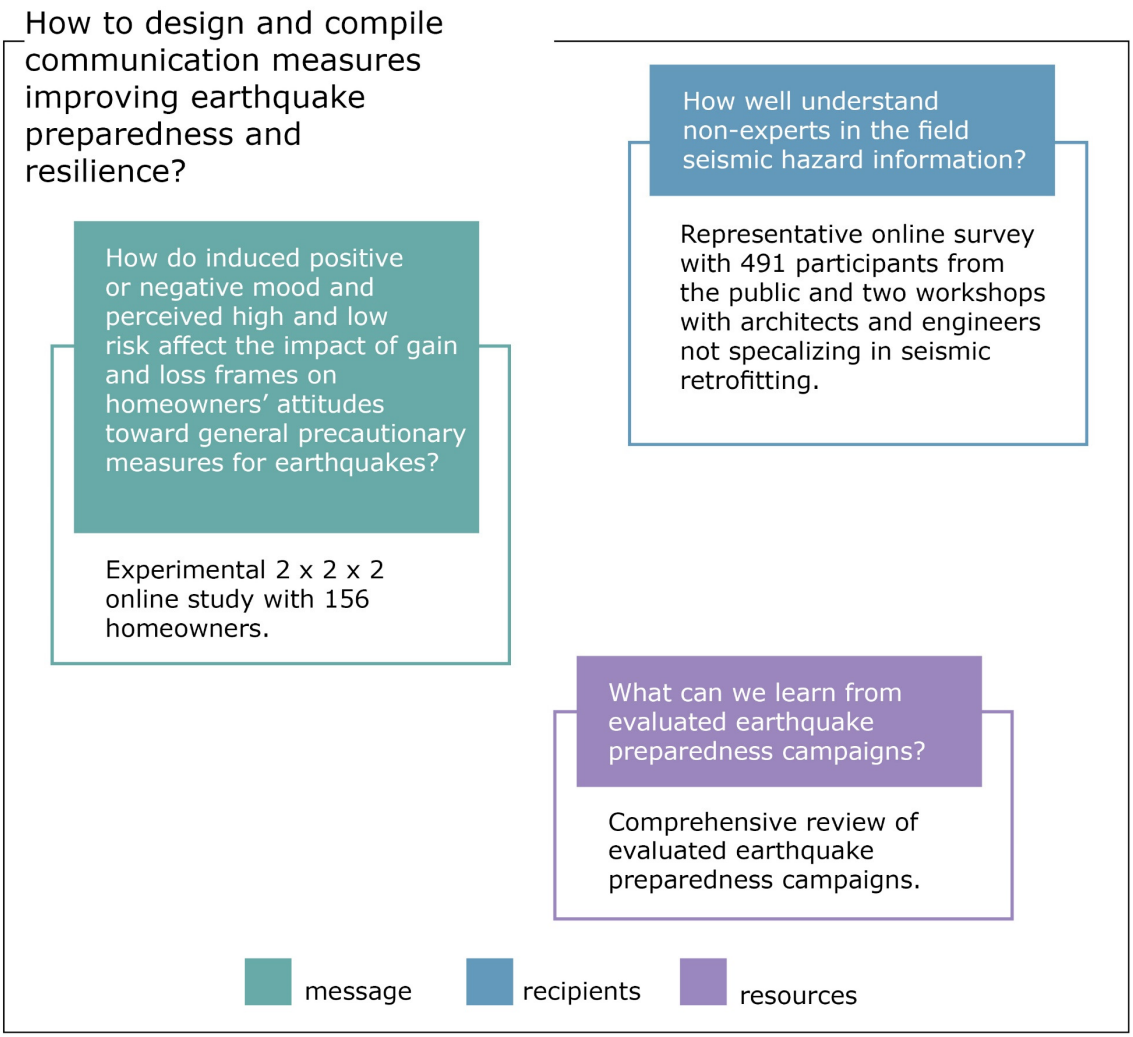


Figure 2: Overview of the research questions and design of the three studies conducted. The three key challenges upon designing communication measures aiming at improving earthquake preparedness and resilience are color-coded.

The first two studies set a spotlight on widely used but never fully evaluated practices in seismic hazard communication.

One such poorly evaluated element in a natural hazard context are framing effects. Clearly an attribute of the message, one of the three domains of key challenges in preparedness and resilience related communications. Frames shape the content of a message by emphasizing a specific attribute. In a natural hazard context, frames have shown to affect people's risk perception, information needs, and intentions to take precautionary measures (Henrich, McClure, and Crozier 2015; McClure, White, and Sibley 2009; Terpstra et al. 2014). Despite being well documented framing effects are ambiguous and sometimes contradictory (Leshner et al. 2017). Only recently, evidence has been found that affective states influence framing effects and the willingness to take precautionary (health) measures (Chang 2007; Keller et al. 2003). These studies also revealed that risk perception plays a significant role in this context. For the first time in the context of natural hazards, the interaction of mood, perceived risk, and gain or loss frames on attitudes to prepare for earthquakes is being analyzed. The study not only contributes empirical evidence on the effectiveness of frames in a natural hazard context, but also advances the understanding on how mood, risk perception and frames interact.

Even more prominently used and equally badly evaluated are seismic hazard maps and the information enclosed. They are currently the most prominent output of seismic hazard assessments conducted by seismological services around the world. Nevertheless, up to now there is hardly any empirical evidence documenting the impact these maps have on attitudes and risk related decisions (Bostrom et al. 2008). Because their development is biased to the needs

of primary users (Perry et al. 2016), non-experts in the field often struggle to interpret them correctly (Hagemeier-Klose and Wagner 2009; Kjellgren 2013; Perry et al. 2016; Severtson and Vatovec 2012). This study focuses on the recipient, another key challenge. Based on a real case, the second study examines how well seismic hazard maps are understood and interpreted by such non-experts, thus setting the baseline for an improved seismic hazard communication when using maps.

The literature reviewed in the context of the first two studies showed how appallingly scanty the evidence is to base sound hazard communication on. For this reason, the third paper takes a closer look at evaluated earthquake campaigns with the goal to deduce lessons learned. In addition, it discusses potentials to improve future communication in the field.

5. COMMUNICATING EARTHQUAKE PREPAREDNESS

The influence of induced mood, perceived risk and gain or loss frames on homeowners' attitudes towards general precautionary measures for earthquakes

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Abstract

Despite global efforts to reduce seismic risk, actual preparedness levels remain universally low. Although, earthquake- resistant building design is the most efficient way to decrease potential losses, its application is not a legal requirement across all earthquake-prone countries and even if, often not strictly enforced. Risk communication encouraging homeowners to take precautionary measures is therefore an important means to enhance a country's earthquake resilience. Our study illustrates that specific interactions of mood, perceived risk and frame type significantly affect homeowners' attitudes towards general precautionary measures for earthquakes. The interdependencies of the variables mood, risk information and frame type were tested in an experimental 2 x 2 x 2 design (N = 156). Only in combination and not on their own, these variables effectively influence attitudes towards general precautionary measures for earthquakes. The control variables gender, "trait anxiety" index and alteration of perceived risk adjust the effect. Overall, the group with the strongest attitudes towards general precautionary actions for earthquakes are homeowners with induced negative mood, who process high risk information and gain-framed messages. However, the conditions comprising induced negative mood, low risk information and loss-frame and induced positive mood, low risk information and gain-framed messages both also significantly influence homeowners' attitudes towards general precautionary measures for earthquakes. These results mostly confirm previous findings in the field of health communication. For practitioners, our study emphasizes that carefully compiled communication measures are a powerful means to encourage precautionary attitudes among homeowners, especially for those with an elevated perceived risk.

5.1 Introduction

Earthquakes pose a major threat for many countries. In the last 25 years, six of the ten natural disasters causing the most fatalities worldwide were earthquakes (Munich RE 2015a). The same holds true for overall financial losses (Munich RE 2015b). Earthquakes rank first, accounting for 36 % of the average annual losses caused by natural hazards (UNIDSR 2015). The high potential impact of such disasters in terms of casualties and economic losses as well as social impacts, demographical changes or even political conflicts raises questions of how people respond to natural hazards (Lindell and Hwang 2008).

How threatening earthquakes are for specific countries defines their seismic risk. This depends on the seismic hazard of their territory, the vulnerability of infrastructure, the local subsoil and the affected assets (Swiss Seismological Service 2018a). Among the countries with the highest seismic risk are Turkey, Pakistan, Iran as well as India and China. The main reason for their elevated vulnerability is a combination of high seismic hazard with poor building design (Crowley and Elliott 2012), as earthquake-resistant construction offers the best protection against the consequences of serious seismic activity (Swiss Seismological Service 2018a). "The lax, deficient or absent building codes and laws within developing countries

results in an elevated number of fatalities for any given size of earthquake when compared, for example, with that for California or Japan" (Crowley and Elliott 2012). In places where the application of seismic building codes is mandatory, further regular updates to these codes, stringent implementation and enforcement are important (Day 2012). Because even in regions where such instruments are in place many homeowners refuse retrofitting measures due to their perception of earthquake risks, lacking trust in retrofitting techniques or insufficient support of authorities (Egbelakin et al. 2011). Even though, seismic adjustment has improved for example in the US over time, most people only engage very selectivity (Ronan and Johnston 2005). As Heller et al. (21) reveals most people, who state to have taken precautionary measures, were in possession of items associated to general emergency preparedness. A considerable smaller amount of households implemented earthquake-specific measurements including structured support (bolding house to the ground).

Switzerland has a low to moderate seismic hazard but a high seismic risk due to very high-value and dense but vulnerable buildings and infrastructures (Swiss Seismological Service 2018a). In Switzerland, earthquakes are the natural hazard with the largest damage potential and the fourth biggest overall risk for the country (Hohl et al. 2015). Although Switzerland introduced earthquake building codes in 1989, their application is only an explicit legal requirement in some parts of the country. The absence of legal requirements and enforcement discourages people from taking appropriate measures (Kenny 2007) and is a major reason why many buildings in Switzerland are not sufficiently protected (Federal Office for the Environment 2014).

An effective way to establish seismic building design is by setting up and enforcing a legal framework determining the mandatory application of seismic building codes for major renovations and new buildings. In addition, financial incentives might be beneficial in supporting legal frameworks concerning retrofitting measures, as interviews with owners in New Zealand revealed (Egbelakin, Wilkinson, and Ingham 2014). In countries with a weak regulatory framework regarding seismic building codes, addressing current and future homeowners directly is a promising way to improve earthquake resilience. Resilience defines the capability of a community to deal with hazards (Crowley and Elliott 2012). Risk communication is an important means of promoting precautionary measures to minimize negative effects of natural hazards. To maximize the desired outcome, it is crucial to understand the effects of risk information on recipients and consider interactions with perceived risk (Kung and Chen 2012; Terpstra et al. 2014; Visschers et al. 2007) or affective state (Keller 2011; Keller et al. 2006; Xie et al. 2011).

Due to the low public awareness of earthquake hazard in Switzerland (Buchecker, Maidl, and Wiederkehr 2016), communication measures addressing homeowners' precautionary attitudes face serious challenges. Even in countries with higher seismic hazard, programs to increase homeowners' willingness to take precautionary measures illustrate that the actual level of preparedness remains universally low (Becker et al. 2013; Egbelakin et al. 2011; Heller et al. 2005). This study focuses on aspects affecting Swiss homeowners' attitudes towards general precautionary measures for earthquakes. We investigate how mood, perceived risk and gain or loss frames influence their attitudes. We first review existing studies on the interactions of frames, risk perception and mood for preparedness to derive our research questions and hypotheses.

5.2 Theoretical background

Risk communication can lead to more accurate beliefs about seismic hazard, a bigger tendency towards precautionary measures (Whitney, Lindell, and Nguyen 2004), and a higher level of preparedness (McClure and Sibley 2011). An important prerequisite is to raise awareness of earthquake risk and influence person's attitudes towards a certain behavior. Attitudes depend on the intended positive or negative outcome of a promoted behavior. Generally speaking, a

greater salience of positive attitude towards precautionary measures makes it more likely that such actions will be taken. Besides attitudes, social expectations play an important role: the likelihood of taking precautionary measures for earthquakes increases within a social context that advocates such behavior (McIvor and Paton 2007). Other good predictors of preventive actions are "behavioral intentions, perceived self-efficacy, collective efficacy, empowerment, perceived outcome expectancy, critical awareness", and community aspects like a sense of community, participation in community activities and trust in authorities (Perez-Fuentes and Joffe 2015). However, in general, bridging the gap between attitudes and behavior is challenging (Kollmuss and Agyeman 2010; Perez-Fuentes and Joffe 2015; Sheeran 2002; Wood et al. 2012).

In the context of natural hazards, studies document the influence of frames on information need (Terpstra et al. 2014) and intentions towards taking precautionary measures (McClure et al. 2009). Frames emphasize certain aspects of a message and thereby influence how information is processed. Framing effects "occur when (often small) changes in the presentation of an issue or an event produce (sometimes large) changes of opinion" (Chong and Druckman 2007). McClure, White and Sibley (2009) analyzed the influence of positive and negative frames on the intention to prepare for earthquakes. They showed that people were more willing to take precautionary measures if the outcome was framed negatively. Combined with specific actions, the perceived importance of precautionary measures was stronger when the negatively framed outcome was paired with a positive action frame. In a follow-up study two years later, the authors substantiated this result. Again, the outcome frame only influenced judgements about the general importance of precautionary actions, whereas for survival actions the interaction between the outcome and the action frame was relevant. In contrast to their first study, the combination of a negative outcome with a negative action (being poorly prepared) was most successful (McClure and Sibley 2011). These so-called loss frames are used to stress negative consequences of not adopting a behavior, whereas gain frames emphasize the benefits of adopting a specific behavior (Salovey, Schneider, and Apanovitch 2002). Thereby, both frames carry the same message despite a different emphasis (Chong and Druckman 2007). According to prospect theory (Tversky and Kahneman 1986), people tend to seek riskier behavior if faced with a loss frame but act more risk-aversely in response to a gain-framed message. Based on this premise, the effect of gain- or loss-framed messages should depend on the perceived valence of the recommended behavior (risk averse or seeking). A risk seeking behavior is defined by an expected negative outcome and a risk averse behavior by an expected positive outcome (Rothman et al. 2006).

While the occurrence of framing effects is well documented in social and political decision-making (Druckman and McDermott 2008), the findings are not always consistent (Rothman et al. 2006; Rothman and Salovey 1997). One reason is the affective state of persons processing framed information (Druckman and McDermott 2008). According to hedonic contingency theory, people in a positive mood tend to act more strongly in response to gain-framed messages compared to loss-framed information, as they want to maintain their positive mood. People in a negative mood, by contrast, have no preference; therefore, framing effects are less strong. "When current mood is positive, scrutinizing the hedonic consequences of behaviors is rewarded and ignoring the hedonic consequences of possible action is punished; when current mood is negative, however, both scrutinizing and ignoring hedonic consequences are typically rewarded" (Wegener and Petty 1994). Compared to specific emotions, moods are less conscious and manageable, last longer and may have a more widespread and potentially insidious impact on reasoning and decision-taking (Eich et al. 2002; Forgas 2001).

Besides frames and the affective state, risk perception has proved to be an important variable influencing the adoption of seismic hazard adjustments, both on its own and in combination with other variables (Kunreuther 2002; Lindell and Perry 2000; Mileti and Fitzpatrick 1992; Ronan and Johnston 2005). In a meta-analysis of 23 articles, Lindell and Perry (2000) found in the majority a significant correlation between perceived risk and seismic adjustment. A

recent study (Solberg et al. 2010) reviewing the correlation between perceived risk and seismic adjustment draws the conclusion of a less strong relationship. The discrepancy in the strength of the influence of perceived risk is explained by numerous moderators like personal context, age, gender, trust or fatalisms.

However, it is not only on their own but also in combination that these variables influence preparedness levels. People in a positive mood act risk-aversely in situations where the perceived risk is high. If the risk is perceived as low, they act risk-prone (Nygren 1998; Robert J. Hockey, A. John Maule, Pe 2000). People in a negative mood tend to behave in the opposite way, as a study by Yuen and Lee (2003) indicates. The authors point out that there are only a few studies looking at people's behavior in a negative mood, whereas positive mood effects are relatively well documented. Regarding the influence of perceived risk on framing effects, Rothman and Salovey (1997) revealed that the behavior motivated by the frame is only adopted if it is perceived as appropriate. In the context of flood hazard communication, Terpstra et al. (2014) demonstrated that risk frames resulted in a higher information need and were moderated by attributes like risk perception and negative affect.

Despite numerous indications, only a few studies have addressed the influence of positive and negative affects regarding framing effects in the light of consequential losses (Keller et al. 2003). In an experimental study in the field of health communication, Keller, Lipkus and Rimer (2003) tested how the affective state of participants influences the effectiveness of loss- and gain-framed messages. The results show that for participants with an induced positive mood, loss-framed messages are more persuasive, whereas for participants in a negative mood gain-framed messages are more effective. Furthermore, people in a positive mood perceived the risk of undertaking a mammography as higher than people in a negative mood and estimated the costs of such a behavior as lower when receiving loss-framed instead of gain-framed information. Although this is not specifically mentioned, decisions on mammography screenings are situated in a high risk context as they are potentially life-threatening. Chang (2001) drew similar conclusions in an earlier experimental study about travel medicine: he finds that in high risk situations people with a positive mood respond better to loss-framed messages and people in a negative mood to gain-framed messages. Both studies illustrate a moderating influence of the affective state and the perceived risk on the impact of gain- and loss-framed messages.

These findings seem to contradict the aforementioned hedonic contingency theory. However, this is only the case in situations with perceived high risk, when people in a positive mood seek to adhere to their affective state in the longer term. According to Hullett (2005), maintaining positive mood over a longer period of time proves to be especially desirable in cases with a high degree of self-relevance. The degree of self-relevance is defined by the personal implications a piece of information might trigger. In the case of health-related issues, possible negative effects provoked by not adopting a certain behavior might be high. The authors presume that people in a positive mood therefore accept a short impairment of their mood, caused by receiving a loss frame, in order to maintain their mood in the long term. The hedonic contingency theory only applies if people in a good mood do not value the long-term maintenance of their affective state (Keller et al. 2003).

5.3 Research questions and hypotheses

Many studies address the single influence of frames and perceived risk on attitudes and behavioral intentions towards precautionary measures. Only a few have analyzed the interaction of these variables with positive and especially negative affective state (e.g. 18,35,36,50). More specifically, even fewer studies, and none in the field of natural hazards, describe how these three variables interact (Chang 2007; Keller et al. 2003). Our study aims to fill these gaps by examining the influence of induced mood (positive and negative) and perceived risk (high and low) on the impact of gain and loss frames on the attitudes of Swiss homeowners

towards general precautionary measures for earthquakes. Attitudes are a strong precursor of future actions as they depend on the expected positive or negative outcome of an advertised behavior. Positive attitudes towards a certain behavior enhance the chance of related actions to be taken (Heller et al. 2005). We thus formulate the following research question:

How do induced positive or negative mood and perceived high and low risk affect the impact of gain and loss frames on homeowners' attitudes towards general precautionary measures for earthquakes?

More specifically, we want to test the following hypotheses:

Hypothesis 1

People with induced positive mood are in case of perceived high risk more favorable than people with induced negative mood towards precautionary measures for earthquakes if receiving loss- instead of gain-framed messages.

People in a positive mood tend to be more in favor for precautionary measures, in a situation with perceived high risk and self-relevance, when receiving a loss-framed instead of a gain-framed message. A short period of impaired mood, caused by loss frames, is accepted for the sake of long-term mood stabilization (Keller et al. 2003). The hedonic contingency theory only applies for people in a positive mood if faced with a low perceived risk (Dillard and Nabi 2006; Handley et al. 2004; Keller et al. 2003; Wegener and Petty 1994). Therefore, loss-framed messages presumably have a stronger impact on attitudes towards precautionary measures for earthquakes among homeowners with induced positive mood who are exposed to high risk information.

Hypothesis 2

People with induced positive mood are in case of perceived low risk more favorable than people with induced negative mood towards precautionary measures for earthquakes if receiving gain- instead of loss-framed messages.

In case of induced positive mood and perceived low risk, gain-framed messages have shown to be more effective than loss-framed messages (Chang 2007). These findings are in line with hedonic contingency and mood maintenance theory, which predicates that people seek to maintain positive affective states (Day 2012; Keller et al. 2003; Wegener and Petty 1994). People do not have any incentive to regulate their mood in the long term if risk is perceived as low instead of high, as discussed previously. Gain-framed messages are therefore assumed to have a stronger impact compared to loss-framed messages on homeowners' attitudes towards general precautionary measures for earthquakes, if participants are in the condition with induced positive mood.

Hypothesis 3

People with induced negative mood are in case of perceived high risk more favorable than people with induced positive mood towards precautionary measures for earthquakes if receiving gain- instead of loss-framed messages.

Only a few studies have discussed the influence of negative mood in combination with perceived risk towards the persuasive power of framed messages (Chang 2007; Keller et al. 2003). For people with perceived high risk and negative mood, gain-framed messages proved to be more persuasive than loss-framed messages (Chang 2007). The mood repair theory explains this effect (Handley et al. 2004; Keller et al. 2003), stating that people in a negative mood constantly aspire to improve their affective state. This contradicts the hedonic contingency theory, which supposes that people in negative moods should be indifferent towards the frame presented (Keller et al. 2003). Unlike people in a good mood, people in a bad mood are not willing to consider their long-term affective state (Hullett 2005). For homeowners with

induced negative mood receiving high risk information, gain-framed instead of loss-framed messages are expected to have a bigger impact on attitudes towards general precautionary measures for earthquakes.

For participants in a negative mood and high risk condition, Chang (2001) found gain-framed messages to be more persuasive, which is reflected in hypothesis 3. However, there were no significant framing effects for participants in a negative mood and low risk condition, a result that is not further discussed in the study. This raises the question of which frame type (if any) proves more persuasive in case of perceived low risk and negative mood. This leads to the following research question:

Research Question

Which frame type has a bigger impact on the attitudes of homeowners towards general precautionary measures for earthquakes in case of perceived low risk and negative mood?

Table I shows the expected interdependencies of mood, risk information and frame type. For each condition, the assumed impact on homeowners' attitudes towards general precautionary measures for earthquakes is shown. A high impact is only anticipated if mood, risk information and frame type collude in one of the eight ways illustrated in Table I. Thus, significant impacts are only expected subsequent to three-way interactions. Main effects and two-way interactions would not meet the expectations.

Hypothesis & research question	Mood	Perceived risk	Frame type	Impact on attitudes	Number of participants
H1	Positive mood	High risk	Gain frame	Low	23
			Loss frame	High	19
H2		Low risk	Gain frame	High	21
			Loss frame	Low	20
H3	Negative mood	High risk	Loss frame	Low	19
			Gain frame	High	21
?		*Low risk*	*Loss frame*	*High*	17
			Gain frame	*Low*	16

Table I: Expected impact of interdependencies of manipulated mood, perceived risk, and frame type on attitudes of homeowners towards general precautionary measures for earthquakes. Highlighted are conditions with suspected high impact on attitudes (N = 156).

5.4 Method

5.4.1 Sample collection and procedures

Our study focuses on Swiss homeowners, as they have the ability to contribute significantly to improving the earthquake safety of buildings, thereby diminishing potential losses. The Swiss Homeowners Union helped to recruit homeowners for the study by sending a link to an online questionnaire to 3,000 of their members living in the German-speaking part of Switzerland. Due to a low return rate of 2.5 %, the random sample had to be extended to a snowball sample, including homeowners not necessarily belonging to the Swiss Homeowners Union. Participants were randomly assigned to one of the eight experimental conditions. Of the 558 people who participated overall, 200 completed the questionnaire. As successful manipulation of the various aspects requires the experiment to have been completed with concentration and a lack of distraction, participants needing more than twice as long as the average (> 64.4 minutes, N = 10) or half as long as the average (<16.1 minutes, N = 25) were excluded. Also excluded were those who were renting at the time and had no intention of owning a home within the next ten years (N = 7). In total, 156 participants (42 female, 107

male, 7 not specified) were included in the study, mostly living in the German-speaking part of Switzerland and with an average age of 52.62 (see Table I).

5.4.2 Mood, frame type and risk manipulation

In a series of five online experiments, texts with emotional pictures proved to be the only effective method of provoking a positive and negative mood alteration (Göritz and Moser 2006). To reproduce these effects for our study, funny quotes from schoolchildren's essays were presented, annotated with positive pictures (e.g. of smiling kids) and cartoons to enhance participants' mood. To induce negative mood, we used an article about a young father whose apparently harmless case of flu led to heart failure and who subsequently died from a long-awaited and badly-needed heart transplant. In order to enhance the desired outcome, participants in the positive mood condition were asked to think of similar funny personal experiences in the past and participants in the negative mood condition of a similarly sad incident.

Different effect sizes in past studies indicate that it is harder to induce positive mood (Westermann et al. 1996). To offset this, participants in the positive mood condition also had to reply to a set of questions and were given very positive feedback, regardless of their actual responses. To avoid demand effects, participants were not asked to try to achieve a certain mood (Westermann et al. 1996).

Subsequent to the mood manipulation, participants were randomly assigned to one of four journal articles where low and high risk information was combined with gain and loss frames. The text described the current situation regarding earthquake preparedness of buildings in Switzerland and informed homeowners about what they could do to improve their building's resistance. In every text version, the same sentences were modified to emphasize the condition tested. In the case of risk information, the likelihood of occurrence and the damage potential were altered. With regard to frame types, the gain-framed condition emphasized the advantages associated with taking precautionary measures for earthquakes, whereas the loss-framed condition stressed the potential losses of not taking any action.

5.4.3 Procedure and measurements

An online experiment was chosen to make it easier for the main target group, homeowners, to take part. Following the mood manipulation, an initial set of questions measured participants' mood. Participants noted their current mood on a five-point Likert scale (from 1 "I fully agree" to 5 "I fully disagree"). The first positive mood factor (positive mood 1) was based on eight items (amused, satisfied, relaxed, merry, pleasant, happy, cheerful)[1], resulting in a Cronbach α of 0.94 (see Table II). The negative mood factor (negative mood 1) consisted of three items (sad, sorrowful, anxious) and had a Cronbach α of 0.77. Participants then read one of the four journal articles including frame type and risk information. This was followed by a second measurement of their mood. The reliability analyses of the second mood factors were based on the same items used for the first mood factors and resulted in a Cronbach's α of 0.94 for the positive mood (positive mood 2) and a Cronbach α of 0.77 for the negative mood factor (negative mood 2).

Next, the frame type and the perceived risk were measured. To question the frame type, participants were asked to rate whether the text mainly emphasized gains or losses, on a ten-point Likert scale (from 1 "only losses are emphasized" to 10 "only gains are emphasized").

[1] All items and text used for the experiment have been translated by the authors from German to English for this publication.

Perceived risk was measured using the following eight items compiled in an index with a Cronbach α of 0.75:

- Switzerland has a high earthquake hazard.
- If an earthquake hits Switzerland, major damage is to be expected.
- I don't think that a major earthquake will occur in Switzerland in the near future.
- I believe earthquakes do not pose a major threat to me.
- I am afraid that the apartment/house I am living in might be destroyed.
- I feel protected against earthquakes at my place of work.
- I feel personally affected by the earthquake hazard in Switzerland.
- Switzerland would recover fast in the aftermath of a major earthquake.

Homeowners' attitudes towards general precautionary measures for earthquakes were questioned with the following items measured on a five-point Likert scale:

- New buildings should be built according to SIA standards[2].
- It is reasonable to introduce mandatory national earthquake insurance.
- Cantons[3] should do more to improve earthquake resistance.
- The earthquake resistance of existing buildings should be tested as a matter of course.
- Every Swiss should know how to behave in case of an earthquake.
- The Swiss Confederation should invest more in earthquake resistance.
- Homeowners should invest more to protect the public from earthquake-related risks.
- Existing buildings not meeting SIA standards need to be retrofitted.
- Schools should place more emphasis on the earthquake risk in Switzerland.

The items were compiled in an index with a Cronbach α of 0.90. Attitudes about governmental initiatives are very relevant in Switzerland, as the political system offers its citizens extensive rights to shape governmental actions. Most measures questioned would be up for public vote in a referendum.

Afterwards, participants were questioned about alterations to their risk perception, also using a five-point Likert scale. The index compiled exhibited a Cronbach α of 0.75 and was based on the following items:

- I now rate the earthquake risk in Switzerland more highly than before reading the article.
- I was not aware that earthquakes pose a serious threat to Switzerland.
- I am inclined to believe that a major earthquake will occur in Switzerland in the near future.
- Before, I would have assumed the damage caused by a major earthquake to be smaller.
- Now, after reading the article, I personally feel more affected by the earthquake hazard in Switzerland.

The questionnaire ended with a set of demographical questions and some potential moderators such as trait anxiety (measured according to (Kemper, Brähler, and Zenger 2013)) and supposed living conditions within ten years. The seven items measuring trait anxiety were compiled in an index with a Cronbach α of 0.64.

At the end, participants were debriefed about the purposes of the study and the text amendments. Participants in the negative mood conditions were shown a selection of the best funny kid quotes in order to neutralize their affective state.

[2] SIA standards set out the latest building design requirements in Switzerland.

[3] Switzerland is divided into 26 cantons. Cantons are an independent and sovereign entity with their own constitution, parliament, government and courts. The regulatory framework for construction standards is mostly defined by the cantonal authorities.

Variable	Number of items	Cronbach α	M	SD	N
Positive mood 1	7	0.94	27.08	8.44	156
Negative mood 1	3	0.77	12.45	2.93	152
Positive mood 2	8	0.95	27.83	7.23	155
Negative mood 2	3	0.77	12.64	2.48	154
Perceived risk	8	0.75	19.63	5.36	145
Attitudes	9	0.90	28.79	8.52	154
Alteration of perceived risk	5	0.75	10.05	4.11	154
Trait anxiety	7	0.64	13.39	4.50	152

Table II: Overview of measurement variables.

5.4.4 Analysis

The interdependencies of the variables mood, risk and frame type depicted in Table I were tested in an experimental 2 x 2 x 2 design. SPSS was used to analyze the data.

Three univariate analyses of variance were conducted to test the mood, risk information and frame type manipulation. For each manipulation test analysis, the respective condition (positive or negative mood, high or low risk information, gain or loss frame) figured as an independent variable. The factors positive and negative mood 1 and 2, the index of perceived risk and the frame type measurement figured as dependent variables.

Next, a univariate analysis of variance was performed to test whether the manipulation of mood, risk information and frame type had had in combination a significant influence on the attitudes of Swiss homeowners towards general precautionary measures for earthquakes. The manipulation conditions (positive or negative mood, high or low risk information, gain or loss frame) were used as independent variables and the attitudes index as a dependent variable. In addition, the following control variables were included in the analysis, as previous studies mentioned them as potential moderators of framing and mood effects: gender (Byrnes, James P.; Miller 1999; Druckman and McDermott 2008; Levin et al. 2002; Taylor, Keefe, and Jensen 2007) and trait anxiety (Heller et al. 2005; Keller et al. 2003). Additionally, the index compiled for risk perception alterations was included to assess the study's influence on the generally low earthquake risk awareness of Swiss people (Buchecker et al. 2016). To complete the hypothesis testing, a series of post-hoc tests was conducted to analyze the extent to which the eight manipulation conditions depicted in Table I differ from each other.

5.5 Results

5.5.1 Manipulation checks

Table III shows that the mood manipulation is successful for both measurements, before (first mood measurement, factors positive and negative mood 1) and after reading the text (second mood measurement, factors positive and negative mood 2) with the manipulated frame type and risk information.

Condition	Factor	M	SD	F	p	η^2
Positive mood	Positive mood 1	0.50	0.71	F (37.50, 0.76) = 49.15	0.000	0.242
	Negative mood 1	-0.52	1.03			
Negative mood	Positive mood 1	-0.56	0.56	F (56.23, 0.64) = 87.66	0.000	0.363
	Negative mood 1	0.64	1.01			
Positive mood	Positive mood 2	0.27	0.94	F (12.56, 0.92) = 13.58	0.000	0.082
	Negative mood 2	-0.30	0.98			
Negative mood	Positive mood 2	-0.30	0.88	F (16.05, 0.90) = 17.81	0.000	0.104
	Negative mood 2	0.34	1.02			

Table III: Mood manipulation check (N = 156 for first mood measurement and N = 154 for second mood measurement).

Equally effective was the risk manipulation: the text with the low risk information results in a lower perceived risk among participants (M = 2.28, SD = 0.62) compared to those who received the high risk information (M = 2.63, SD = 0.71), F (4.74, 0.44) = 10.70, p = 0.001, η^2 = 0.066. Despite significant results, both conditions result in relatively low levels of perceived risk, which points to the limited earthquake awareness among Swiss homeowners. Regarding the manipulation of the frame type, participants receiving the gain-framed text significantly state that the gains of taking precautionary measures for earthquakes are emphasized compared to the losses (M = 5.99, SD = 2.22). For participants in the loss-framed condition, the contrary is true (M = 4.19, SD = 2.37), F (124.32, 5.25) = 23.67, p = 0.000, η^2 =0.135. According to these results, the manipulation checks are successful and provide the basic requirement to test the hypotheses.

5.5.2 Influences on attitudes

As depicted in Table IV: attitudes towards general precautionary measures for earthquakes are significantly moderated by the three-way interaction of mood, perceived risk and frame type as well as by the "alteration of risk perception" index. Additionally, the mood manipulation tends to significantly influence attitudes.

Independent variables	F	p	η^2
Mood manipulation	F (3.01, 0.78) = 3.873	0.051	0.027
Frame type manipulation	F (0.16, 0.78) = 0.199	0.656	0.001
Risk manipulation	F (3. 06E-8, 0.78) = 0.000	1.000	0.000
Alteration of perceived risk	F (5.72, 0.78) = 7.361	0.007	0.050
Trait anxiety	F (0.45, 0.78) = 0.582	0.447	0.004
Gender	F (0.63, 0.78) = 0.805	0.371	0.006
Mood manipulation* frame type manipulation	F (0.27, 0.78) = 0.347	0.557	0.002
Mood manipulation * risk manipulation	F (0.73, 0.78) = 0.937	0.335	0.007
Frame type manipulation * risk manipulation	F(1.05, 0.78) = 1.347	0.248	0.009
Mood manipulation* risk manipulation* frame type manipulation	F (3.62, 0.78) = 4.657	0.033	0.032

Table IV: Univariate analysis of variance with the attitudes index as a dependent variable and mood, risk and frame type manipulation as independent variables, including the following control variables: trait anxiety index, alteration of perceived risk index and gender (N = 152).

The results confirm the assumptions that only in combination do the independent variables mood, perceived risk and frame type significantly influence attitudes of Swiss homeowners regarding general precautionary measures for earthquakes. The control variables gender, trait anxiety index and alteration of perceived risk adjust the effect. Among these control variables only the index of perceived risk alteration significantly influences the dependent variable on its own.

A closer look at the influence of the perceived risk alteration index reveals that participants undergoing big shifts in their perceived risk are more in favor for general precautionary measures: $F(17.76, 0.62) = 28.61$, $p = 0.000$, $\eta^2 = 0.275$.

5.5.3 Test of hypotheses

Figure 3 illustrates the influence of mood, low and high risk information and frame type on attitudes towards general precautionary measures for earthquakes.

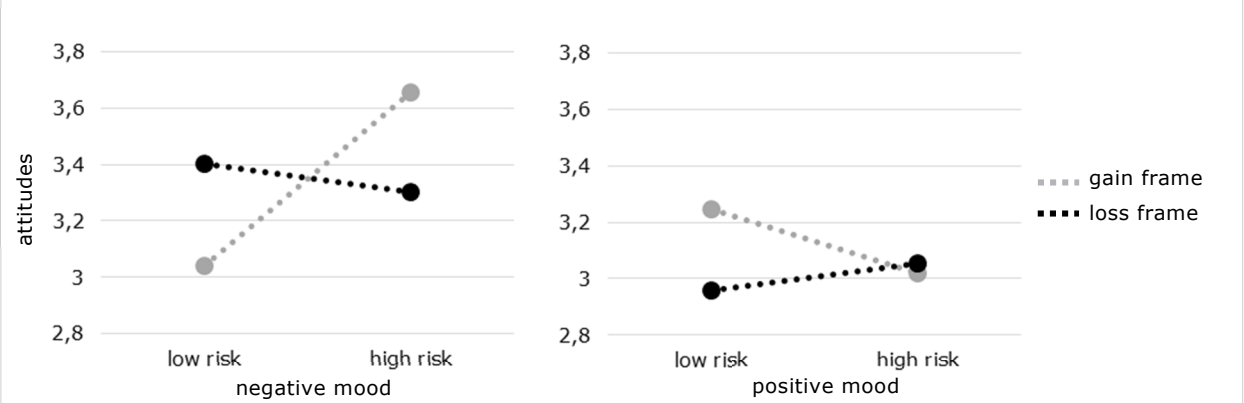


Figure 3: Impact of high and low risk information, frame type and mood on attitudes towards general precautionary measures for earthquakes (gain frame N = 80, loss frame N = 72).

According to hypothesis 1, participants with induced positive mood are more strongly influenced by loss frames than gain frames when receiving high risk information. The post-hoc test refutes this assumption: the gain ($M = 3.02$, $SD = 0.26$) and the loss frame condition do not differ significantly ($M = 3.05$, $SD = 0.24$), $p = 1$.

Hypothesis 2 is confirmed: for participants with induced positive mood, the gain-framed messages ($M = 3.24$, $SD = 0.21$) are significantly more persuasive than the loss-framed messages ($M = 2.96$, $SD = 0.23$) $p = 0.033$ in the low risk condition.

Hypothesis 3, which assumes that participants with induced negative mood after reading high risk information are more supportive for taking precautionary measures for earthquakes if receiving a gain ($M = 3.66$, $SD = 0.25$) instead of a loss frame ($M = 3.30$, $SD = 0.22$), $p = 0.002$, is confirmed.

Our analysis shows that loss frames ($M = 3.40$, $SD = 0.14$) are more persuasive than gain frames ($M = 3.04$, $SD = 0.19$) $p = 0.006$ for participants who have received low risk information.

The condition with induced negative mood, perceived high risk and gain frame emerged, with one exception, as the most persuasive condition (highlighted in Table V). This condition does not significantly differ from the one with induced negative mood, perceived low risk and loss frame.

Mood manipulation	Risk manipulation	Frame type manipulation	M	SD	p
Positive mood	High risk	Gain frame	3.02	0.26	.000
		Loss frame	3.05	0.24	.000
	Low risk	Gain frame	3.24	0.21	.000
		Loss frame	2.96	0.22	.000
Negative mood	High risk	Loss frame	3.30	0.22	.002
		Gain frame	3.66	0.25	-
	Low risk	*Loss frame*	3.30	0.22	.120
		Gain frame	3.04	0.19	.000

Table V: Post-hoc test comparing the condition negative mood, high perceived risk, gain frame with every other condition (N = 152). Highlighted is the most persuasive condition.

5.6 Discussion

Our study illustrates that specific interactions of mood, perceived risk and frame type significantly affect Swiss homeowners' attitudes towards general precautionary measures for earthquakes. Only in combination and not on their own, these variables effectively moderate attitudes. The control variables gender, trait anxiety index and alteration of perceived risk adjust the effect. The results largely confirm the evidence of previous health-related studies (Chang 2007; Keller et al. 2003).

Participants with induced negative mood advocate in a high risk condition precautionary measures if receiving gain- instead of loss-framed messages. This is in line with previous studies in the field and theoretically based on mood repair theory (Handley et al. 2004; Keller et al. 2003). Loss-framed messages are more persuasive for participants in a negative mood when exposed to low risk information. Only a few studies (Chang 2007; Keller et al. 2003), and none in the field of natural hazards, have examined the influence of negative mood in combination with frames and perceived risk. While our study provides significant results for the negative mood and low risk condition in line with trends of previous results (Chang 2007), a theoretical foundation is still lacking and needs to be developed.

For participants with induced positive mood, our study confirms former findings along with the hedonic contingency theory for those exposed to low risk information (Dillard and Nabi 2006; Handley et al. 2004; Keller et al. 2003; Wegener and Petty 1994). These individuals are significantly favoring general precautionary measures for earthquakes if receiving gain-framed instead of loss-framed messages. The results for participants with induced positive mood receiving high risk information are not significant. Their attitudes towards precautionary measures for earthquakes are equally strong, irrespective of the frame type they received, which contradicts previous findings (Chang 2007; Keller et al. 2003).

According to studies in the field of health communication, people in positive mood and high risk conditions are more willing to act when receiving loss instead of gain frames, because they want to enhance their mood over a longer period. This seems not to be the case in relation to precautionary measures for earthquakes. In contrast to health-related precautionary measures, preventive actions for earthquakes might not have the same degree of self-relevance. However, people only aspire to maintain positive mood over a longer period of time if dealing with issues with a high degree of self-relevance (Hullett 2005). The overall low level of perceived earthquake risk among participants of this study is one aspect indicating a low level of self-relevance. Another is the dependent variable used: participants might not necessarily associate general precautionary measures for earthquakes with personal, self-relevant actions. Although, Swiss people have comparably extensive political rights to influence gov-

ernmental actions regarding earthquake preparedness. Analyzing personal actions (e.g. buying emergency food supplies) instead of general precautionary measures might lead to an increase in homeowners' self-relevance and amplify the effect.

5.6.1 Contribution to theory and research

Previous studies in the field of natural hazards highlighted the influence of one or two of the three independent variables analyzed in the course of this study (Kunreuther 2002; Lindell and Perry 2000; McClure et al. 2009; Mileti and Fitzpatrick 1992; Ronan and Johnston 2005; Terpstra et al. 2014). However, none of these studies examined whether and how these three variables interact to influence attitudes or behavioral intentions, even though framing effects were known to be inconsistent (Rothman et al. 2006; Rothman and Salovey 1997). By contrast, health-related studies showed that all three variables have to be taken into account as they jointly moderate attitudes and behavioral intentions (Chang 2007; Keller et al. 2003). Our study replicates these findings in the field of natural hazards, targeting Swiss homeowners' attitudes towards precautionary measures for earthquakes.

Our study illustrates that incorporating the interaction of mood, perceived risk and frame type is not only crucial for health information but valid for communicating precautionary measures for earthquakes too and might be valuable for communicating other risks. We further demonstrated that it is possible to strengthen homeowners' attitudes towards precautionary measures, despite the low level of earthquake awareness in Switzerland. To further examine the observed effects, attitudes with a higher degree of self-relevance as well as behavioral intentions should be studied. In addition, long-term studies observing how attitudes influence real actions would be advantageous as attitudes are only one step towards actual actions and enhanced resilience.

One of the big challenges of this study was the mood manipulation, as only a few studies have successfully manipulated positive and negative mood in an online environment. We used an irrelevant mood manipulation to prevent additional interaction effects and successfully managed to induce the desired mood. We adapted proven methods from previous studies to alter mood and were able to replicate the intended effects (Göritz and Moser 2006).

5.6.2 Limitations and future research

The findings of this study are limited to attitudes of homeowners in a country with moderate earthquake hazard and low risk awareness. Our analysis revealed that the alteration of perceived risk is the only significant moderator of the three-way interaction between mood, perceived risk and frame type. A closer look at the influence of this control variable shows that people with a shift towards a higher perceived earthquake risk tend to be more favorable towards precautionary measures. Whereas a review study does not find any significant correlation between perceived risk and behavioral intentions (Solberg et al. 2010), others are consistent with this result (Lindell and Perry 2000). A possible explanation for our result lies in the nature of the measurement. Whereas we were questioning attitudes towards general precautionary measures, Solberg et al. (2010) referred to very specific actions such as having stocked water supplies. To further analyze the role of perceived risk alteration, a pre-measurement of perceived risk should be conducted in addition to the self-assessment following completion of the experiment. In addition, it would be worth measure behavioral intentions of Swiss homeowners, as mentioned before. Nevertheless, our results indicate a crucial role of perceived risk in communicating precautionary measures for earthquakes and lead to the assumption that increased perceived risk might provoke stronger preparedness levels.

As well as perceived risk, financial incentives to take precautionary measures, and the social environment should also be taken into account. That was not the case in this study, but other studies have found that this factors might increases the likelihood of precautionary measures

being taken (Egbelakin et al. 2014; McIvor and Paton 2007). Speaking of the social environment, our results are limited to Swiss homeowners mainly living in the German-speaking part of Switzerland and are therefore probably not valid for the whole population of the country and/or other groups of people. However, previous studies offer no evidence for varying effects among different target groups, as diverse sample types were used.

The results might differ if real information material from a trustworthy source were used, rather than material compiled for the purposes of the study. This might impact the perceived self-relevance of taking precautionary measures.

5.6.3 Conclusion and practical implications

Skillful designed messages incorporating mood, perceived risk and frame type are an effective way to influence homeowners' attitudes towards general precautionary measures for earthquakes. The condition entailing negative mood, high perceived risk and gain-framed messages proved most effective (see Table V). It combines a threatening message with uplifting information on how to diminish the risk. In practice, there are ethical concerns about inducing negative mood. Applying a relevant instead of an irrelevant mood manipulation might address these concerns. Using examples of homeowners who recovered (positive mood) or suffered (negative mood) in the aftermath of an earthquake might provoke similar effects on mood as the irrelevant manipulation used in our study. Otherwise, precautionary messages including gain or loss frames and the risk information could be placed in a suitable media environment (Yan, Dillard, and Shen 2010) (e.g. sad or funny story or commercial break of a sad movie).

Although the condition combining negative mood with high risk information and gain-framed messages proved the most successful, the positive mood condition with low risk information and gain-framed messages also significantly influenced homeowners' attitudes towards general precautionary measures for earthquakes. Practitioners might operate likewise with negative or positive mood provided their choice is adequately combined with high or low risk information and the suitable frame type. In other words, information material promoting precautionary measures for earthquakes and other hazards needs to be carefully compiled. Only in certain combinations do mood, perceived risk and frame type have significant persuasive effects. Just focusing on positive or negative mood, high or low risk or gain- or loss-framed messages will not result in enhanced precautionary activities in most cases.

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Appendix A

A.1 Mood Manipulation

A total of 29 sentences from real children's essays were used to induce positive mood. Here are some examples:

- The Muslims' Bible is called the Kodak.
- The pope lives in the vacuum.
- In our country, men are only allowed to marry one woman. This is called monotony.
- Life insurance is the money you receive after surviving a fatal accident.
- All fish lay eggs. Russian fish even lay caviar.
- Earthworms can't bite because they have a tail at both ends.
- Gravity affects everyone. This is particularly true in autumn when the trees lose their leaves.
- After shaving my brother uses after-sheep. It smells terrible.

To emphasize the mood manipulation, two pictures of smiling boys and two comics were presented.

The negative mood manipulation was based on a personal story and included some especially sad sentences like the following:

- It is extremely hard for me to understand why this is happing to me. It feels like I am abandoning my family. Instead, it is my heart that is failing.
- 31 years old, too young to die, as we say. His wife Ursula cannot accept the unbelievable and is not willing to understand or accept what happened. Besides her grief, she has no idea how to pay off the debts that accumulated during her husband's illness. Instead of the bright future she was expecting after the heart transplant she only sees a big black hole.

Two sad pictures of a family holding hands and a landing stage leading into a grey, infinite background were used to emphasize the feelings evoked in the text.

A.2 Perceived Risk and Frame Type Manipulation

The basic text structure was altered in various places to emphasize the specific risk or frame type condition. Some examples are given in the following:

High risk	**Low risk**
The next strong earthquake is overdue.	The next earthquake is impending.
There are huge gaps regarding earthquake safety in Switzerland, even though the time is ripe for the next one.	There are some gaps regarding earthquake safety in Switzerland, which might be explained by the long absence of major earthquakes.
Massive backlog among private homeowners.	Some backlog among private homeowners.

Gain frame	**Loss frame**
Homeowners taking responsibility for earthquake safety only creates benefits.	Homeowners not taking responsibility for earthquake safety only creates losses.
Homeowners and cantonal authorities can achieve safety benefits.	Homeowners and cantonal authorities risk the loss of lives.
Supporting precautionary measures is an opportunity for voters to improve inadequate earthquake safety and thereby save lives.	Voters not supporting the opportunity to take precautionary measures will directly endanger lives.

6. DIFFICULTIES IN EXPLAINING COMPLEX ISSUES WITH MAPS

Evaluating seismic hazard communication – the Swiss case

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Abstract

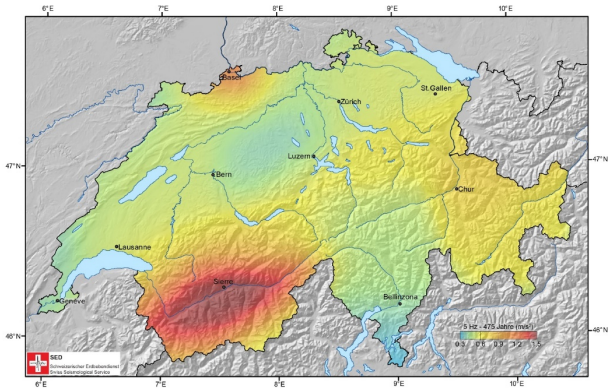
A total of 2.7 billion people live in areas where earthquakes causing at least slight damage have to be expected regularly. Providing information can potentially save lives and improve the resilience of a society. Maps are an established way to illustrate natural hazards. Despite being mainly tailored to the requirements of professional users, they are often the only accessible information to help the public in deciding about mitigation measures. There is evidence that hazard maps are frequently misconceived. Visual and textual characteristics as well as the manner of presentation have been shown to influence their comprehensibility. Using a real case reflecting current practices, the material to communicate the updated seismic hazard model for Switzerland was analyzed in a representative online survey of the population (N = 491) and in two workshops involving architects and engineers not specializing in seismic retrofitting (N = 23). Although many best-practice recommendations have been followed, the understanding of seismic hazard information remains challenging. Whereas most participants were able to distinguish hazardous from less hazardous areas, correctly interpreting detailed results and identifying the most suitable set of information for answering a given question proved demanding. We suggest scrutinizing current natural-hazard communication strategies, empirically testing new products, and exploring alternatives to raise awareness and enhance preparedness.

6.1 Introduction

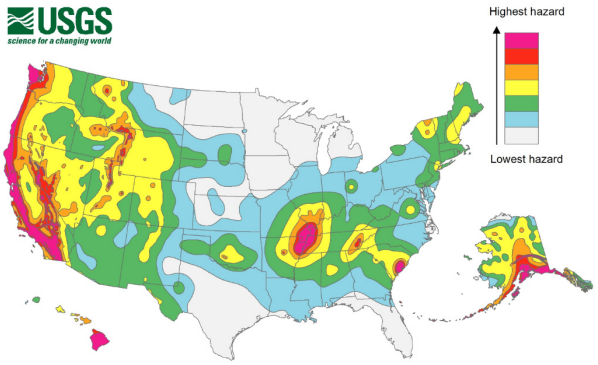
Many of the 2.7 billion people living in areas where earthquakes causing at least slight damage have to be expected regularly[4] (Pesaresi et al. 2017) are unaware of this threat or underestimate it. Earthquake hazard is invisible as the processes of relevance occur deep underground. In addition, earthquakes are characterized as low-probability, high-impact events allowing for no warning. Currently, seismic hazard maps are the most commonly used means of visualizing and communicating this danger (see a selection in Figure 4) (Bostrom et al. 2008; Gaspar-Escribano and Iturrioz 2011; Kunz and Hurni 2011).

[4] The global seismic hazard map (EMMI-GSHAP) defines areas as hazardous if there is a 10 % chance of exceedance in 50 years for earthquakes with a minimal intensity of V on the Mercalli scale.

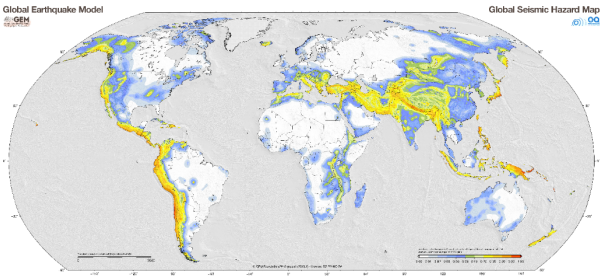
a) Switzerland, 2014



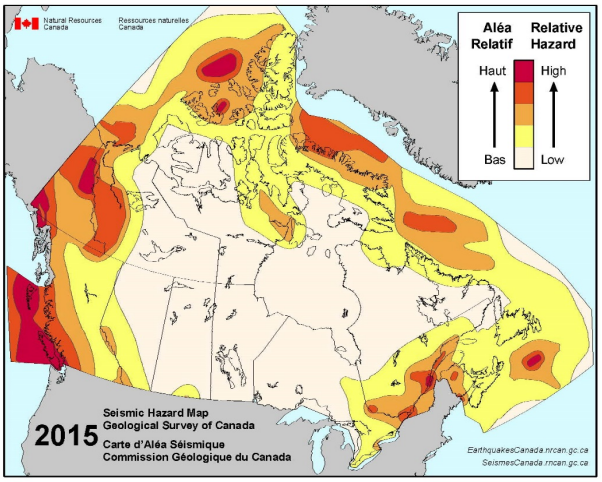
b) USA



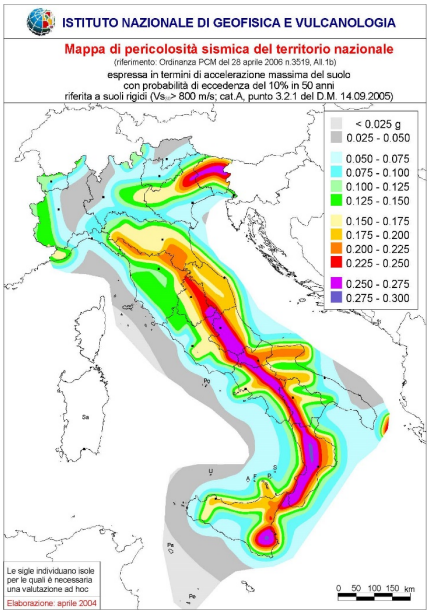
c) Global Earthquake Model



d) Canada



e) Italy



f) New Zealand

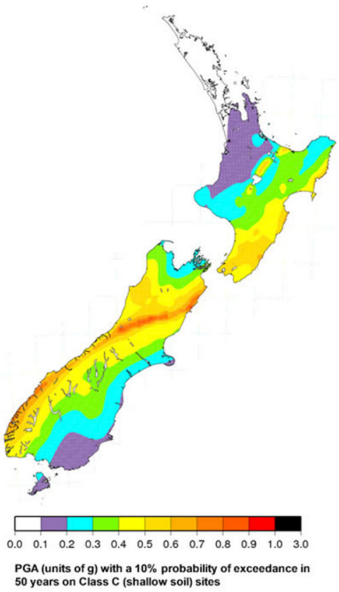


Figure 4: Selection of national seismic hazard maps: (a) Swiss seismic hazard map (Swiss Seismological Service, 2018; www.seismo.ethz.ch/knowledge/seismic-hazard-switzerland/) (b) US seismic hazard map (United States Geological Survey, 2018; https://earthquake.usgs.gov/hazards/hazmaps/) (c) Global Earthquake Model (GEM) Seismic Hazard Map (version 2018.1 - December 2018) (Pagani et al., 2018; www.globalquakemodel.org/gem) (d) Simplified seismic hazard map for Canada (the provinces and territories; Natural Resources Canada, 2018, www.earthquakescanada.ca/hazard-alea/simphaz-en.php) (e) Pericolosità sismica di riferimento per il territorio nazionale (Istituto Nazionale di Geofisica e Vulcanologia, 2018; http://zonesismiche.mi.ingv.it/), and (f) The 2010 National Seismic Hazard Model for New Zealand (Institute of Geological and Nuclear Sciences Limited, 2018; www.gns.cri.nz/Home/Our-Science/Natural-Hazards/Earthquakes/Earthquake-Forecast-and-Hazard-Modelling/2010-National-Seismic-Hazard-Model).

Knowing and understanding seismic hazard is a major step towards loss reduction (Gaspar-Escribano and Iturrioz 2011; Shaw, Kobayashi, and Kobayashi 2004). An earthquake-resistant building design, based on seismic hazard values (Perry et al. 2016), is the most efficient means of reducing seismic risk and generally implemented by professionals. This is not only valid for new constructions, but also when conducting renovations at older facilities. However, even when strict building codes are in place, their application is often deficient or impeded (Day 2012). For example, in Switzerland the enforcement of building codes depends in many parts of the country exclusively on non-specialized engineers and architects or knowledgeable building owners. The information provided in the framework of the national seismic hazard map is their principle source for understanding the seismic hazard of a given area. This also applies for homeowners, who need to make a decision about getting earthquake insurance. This is not exclusively the case for Switzerland, earthquake damage is underinsured worldwide (OECD 2018). In addition, building codes only set a minimal standard which can easily be exceeded by a specific event. Therefore, individual preparedness is essential.

Even though natural-hazard maps are mainly tailored to the needs of primary users (Perry et al. 2016), they are used in their unaltered form to communicate with other recipients (Thompson et al. 2015). In consequence, recent publications indicate that they often fail to transmit their content (Meyer et al. 2012). Non-experts in the field, in particular, often struggle to interpret the maps correctly (Hagemeier-Klose and Wagner 2009; Kjellgren 2013; Perry et al. 2016; Severtson and Vatovec 2012). This is fundamental, because as stated above, improving resilience requires not only knowledgeable experts, but also politicians, authorities, and informed members of society to support precautionary actions.

Identifying and providing seismic hazard values are a primary responsibility of seismological services around the world. Earthquake hazard describes how often a certain horizontal acceleration caused by an earthquake has to be anticipated at a specific location (Swiss Seismological Service 2018b). The access statistics of the website of the seismological service (www.seismo.ethz.ch) demonstrate for Switzerland that seismic hazard information is highly requested: the respective pages dedicated to non-professionals are among the most popular. For professionals, there is a separate portal where also hazard spectra and curves can be accessed (www.efehr.org). In addition, the media often asks to reprint the seismic hazard map for a return period of 475 years.

The main users or recipients of seismic hazard maps can be broken down into three groups (Meyer et al. 2012): (1) experts, mainly seismologists, geologists, and specialized civil engineers, who use seismic hazard maps on a regular basis for professional purposes; (2) other professionals, like architects, engineers not specializing in seismic retrofitting, and emergency and disaster managers, who only deal occasionally with seismic hazard maps; and (3) the public, who are confronted by authorities or media with seismic hazard maps or seek advice before purchasing a house or getting insurance. They are usually unfamiliar with many of the maps' components.

Previous studies evaluating maps for risk management purposes mainly focused on directly-involved stakeholders and authorities (Dransch, Rotzoll, and Poser 2010). The few studies that analyzed the public's needs regarding hazard maps did so either by questioning experts or by mostly relying on a small sample (Hagemeier-Klose and Wagner 2009; Kjellgren 2013; Meyer et al. 2012; Thompson et al. 2015). The understanding of seismic hazard by non-experts in the field and the public has thus been neglected. The challenge lies not only in making accurate information available but also in presenting it in understandable ways (Peters, Bostrom, and Cutter 2008). Publishing hazard maps online is seen as an important option for providing hazard information to the public (Hagemeier-Klose and Wagner 2009; Kostelnick et al. 2013).

With respect to flood maps, Meyer et al. (2012) recommend implementing a less complex map design for the public in contrast to primary users. Different requirements and expectations are also emphasized by Hagemeier-Klose and Wagner (2009), who stress that when presenting flood maps, technical terms should be avoided and "emotional empathy" created. With regard to volcanic hazard maps, accurate data classification, meaningful application of color schemes, and textual elements are emphasized as being important for user engagement and the interpretation of map content (Thompson et al. 2015). Overall, there is a serious lack of empirically tested knowledge on how to design (seismic) hazard maps, especially when addressing the public.

For the first time, we study how well seismic hazard maps, as the most prominent output of any model, are able to inform non-experts. Thus, we focus on the general public as well as on architects and engineers not specializing in seismic retrofitting. They are both indispensable in improving earthquake resilience, but neither are currently of specific relevance for the producers of most seismic hazard maps nor the focus of the research about maps to communicate natural hazards. Our study is based on a real-world case, analyzing the seismic hazard maps and aligned information provided by the Swiss Seismological Service (SED) at ETH Zurich.

This case was chosen as it is representative of the way results of a natural-hazard assessment are presented to a variety of users. It typically reflects the work seismological services and other natural-hazard agencies are doing around the world. By taking into account the newest findings not only in the model calculation but also in the presentation of the results, the SED has gone one step further. We analyze how well participants are able to handle the information provided as well as their competence in giving answers to specified questions. We also examine their ability to interpret statistical information and the effect of interactive access. The results will allow for deriving best practices for improving seismic hazard and natural-hazard communication worldwide.

6.2 Best practices in communicating seismic hazard

Risk communication can lead to more accurate beliefs about seismic hazard and a tendency towards taking precautionary measures (Whitney et al. 2004). As elaborated previously, maps are the means of choice to communicate seismic hazard. In the following, we discuss the factors determining how hazard maps are read, interpreted, and understood. This sets the baseline for analyzing the maps produced by the SED.

6.2.1 Visual characteristics

Visual characteristics of seismic hazard maps are mainly defined by colors, contrast, and the explanatory legend. A survey compared volcanic hazard maps with a red-yellow and a red-yellow-blue color scheme (Thompson et al. 2015). Despite indicating the same values, identical hazard levels were interpreted differently. In a red-yellow map, areas colored yellow were considered to be at risk. In contrast, in a red-yellow-blue map, areas previously colored yellow and then colored blue gave the impression of being safe. Red color schemes are, with some cultural differences, commonly associated with danger, hazard, and risk (Bostrom et al. 2008). In contrast, light colors naturally seem less alarming than dark colors (Gaspar-Escribano and Iturrioz 2011; Peters et al. 2008).

Clear colors and high contrast ratios improve the understanding of maps (Hagemeier-Klose and Wagner 2009). Contrasts are especially relevant for people with defective color vision (Kunz, Grêt-Regamey, and Hurni 2011). This is particularly important for maps with color schemes ranging from green to red (Thompson et al. 2015). Depicting certain values directly on the map instead of only mentioning them in the legend helps people with visual impairments to interpret the content correctly.

The chosen colors should allow easy distinction between data classes. The use of different color hues at each end of the scheme instead of a single hue helps. However, having too many classes diminishes users' ability to distinguish color values and decreases saturation of a specific class (Kunz and Hurni 2011). It is worth testing which intervals are most likely to be understood and categorizing the data into three to five classes (Fuchs et al. 2011; Gaspar-Escribano and Iturrioz 2011). Alternatively, unclassified maps can be used to depict continuous data. Even though users cannot distinguish small changes and might have difficulties in situating single data points in the legend, unclassified maps represent the data more accurately (Severtson and Myers 2013).

Legends are another important aspect of visuals. If users cannot clearly understand or see the legend, they will probably misunderstand the map content (Kunz and Hurni 2011). As different users have different needs, Gaspar-Escribano and Iturrioz (2011) recommend comprehensive, numerical information for professionals and qualitative legends for non-professionals. Another approach suggests combining unclassified maps with verbal legends (e.g. low to high risk), as in any case, users struggle to assign specific color hues to single data points in the legend. In contrast, isarithmic maps, which connect points of equal values with lines, are preferably combined with numerical values (Severtson and Myers 2013).

6.2.2 Textual characteristics

Descriptions support the understanding of graphics and enhance their persuasive impact (Lipkus 2007). To reach this aim, the trade-off between the completeness and the comprehensibility of information needs to be well balanced. Access to more complete information does not necessarily lead to enhanced comprehension and a better quality of choice (Peters et al. 2007). This is especially true for older persons and those with lower numeracy skills (Peters 2008). Numeracy acts as a representative for cognition (Severtson and Myers 2013) and may influence the general ability to understand graphics (Spiegelhalter, Pearson, and Short 2011). Providers should shift from an approach centered on information completeness to one that facilitates users' decision-making(Peters 2008) by emphasizing important information (Pang 2008).

In the context of seismic hazard communication, technical jargon, transmitting odds, and other statistical information is of further special relevance.

6.2.2.1 Technical vocabulary

Whenever possible, technical vocabulary should be avoided for non-experts (Hagemeier-Klose and Wagner 2009). Recent usability studies (e.g. Burningham et al., 2008) in the context of flood hazards emphasize that non-experts struggle to understand technical terms accompanying flood maps, like "return periods expressed as probabilities" (Meyer et al. 2012) or a "one hundred year flood" (Hagemeier-Klose and Wagner 2008).

6.2.2.2 Odds

Most people struggle to understand odds. What they would like to know is the likelihood of an earthquake occurring within a conceivable period (Nathe 2000). In the context of volcanic hazard, using "within" instead of "in" to describe the period helps with achieving a more balanced judgment of the distribution of the likelihood of volcanic eruptions over a given time frame (Hudson-Doyle et al. 2011). Nevertheless, the effect is only visible for longer periods and is more pronounced in likelihood judgments by non-scientists (Doyle, McClure, and Johnston 2014).

6.2.2.3 Statistical information

When it comes to statistics, it has proven especially challenging to communicate single-event probabilities, conditional probabilities, and relative risks (Gigerenzer and Edwards 2003).

Statistical judgments by experts and non-experts improve similarly if they are based on frequencies rather than probabilities (Hoffrage et al. 2000). Nevertheless, in a study on volcanic hazard, participants with relatively high numeracy skills expressed a preference for percentages only, or percentages in combination with natural frequencies (Thompson et al. 2015). Alternatively, verbal and linguistic probabilities can be used (e.g., "likely" or "certain"), even though they appear to be interpreted very differently. To minimize the risk of misinterpretation, combining verbal and numerical information is seen as the most promising approach (Bodemer and Gaissmaier 2012; Budescu et al. 2014).

Conditional probabilities pose another challenge. The standard seismic hazard map depicts a probability of exceedance of 10 percent within 50 years. Health-related studies demonstrate that such conditional probabilities are often misconceived by both physicians and patients (Bodemer and Gaissmaier 2012; Gigerenzer and Edwards 2003).

Relative risks are more difficult to understand than absolute risks (Bodemer and Gaissmaier 2012; Gigerenzer and Edwards 2003). Communicating absolute risks improves the correct understanding of a given statistical statement (Gigerenzer and Edwards 2003).

6.2.3 Manner of presentation

Experiential and interactive information generates a stronger impact on attitudes and leads to a higher level of preparedness (Becker et al. 2013; McIvor and Paton 2007). Bostrom et al. (2008) point out the potential in offering interactive visualizations to explore seismic risk information, allowing individual configurations to cover different user groups' needs. However, interactive visualizations should not be overloaded or too complex. Moreover, they should be based on clear communication goals and only offer functionalities that serve those goals (Dransch et al. 2010). In a study, natural hazard experts confirmed the usefulness of interactive hazard-mapping tools (Kunz and Hurni 2011).

Interactive map visualization facilitates the comparison of different parameters and allows for personalized settings, e.g., for transparency. Maps should enable appropriate hazard assessment and therefore make it possible to compare hazards at different times and in different areas (Dransch et al. 2010; Hagemeier-Klose and Wagner 2009). Adaptive zooming is strongly recommended. It reduces the amount of information visible at once (Kunz and Hurni 2011). The interface provided has to be user-friendly and offer access to further information (Hagemeier-Klose and Wagner 2008). An extensive review of flood maps in Europe revealed that all analyzed maps were either too simple or too complex. Many included too many functionalities and too much information, which diminished their comprehensibility (Hagemeier-Klose and Wagner 2009).

6.3 Case study and focus of research

Testing hazard products is seen as an important success factor for information-presenting strategies (Kostelnick et al. 2013; Perry et al. 2016; Peters 2008; Thompson et al. 2015). A testing campaign should determine how well the given information is understood, the extent to which the communication goals are reached, and the influence of the presented materials on actual choices (Peters et al. 2008). Our case study uses the original maps the SED provides to communicate its hazard model. In the following, we discuss their qualities with respect to the aforementioned best practices.

6.3.1 Qualities in the presentation of the Swiss seismic hazard model

Besides traditional hazard maps depicting ground acceleration values, the SED introduced two other map types: effect and magnitude maps (see Figure 5). Effect maps show the probability of a particular intensity (EMS-98) and the associated effects within a certain period. Magnitude maps illustrate how often an earthquake of, or above, a certain size is expected to occur within a specific radius and period. These maps were developed because users mostly do not ask for ground acceleration values but instead want to know how often a damaging earthquake or an earthquake with a certain magnitude has to be expected at a specific location (Wiemer et al. 2015).

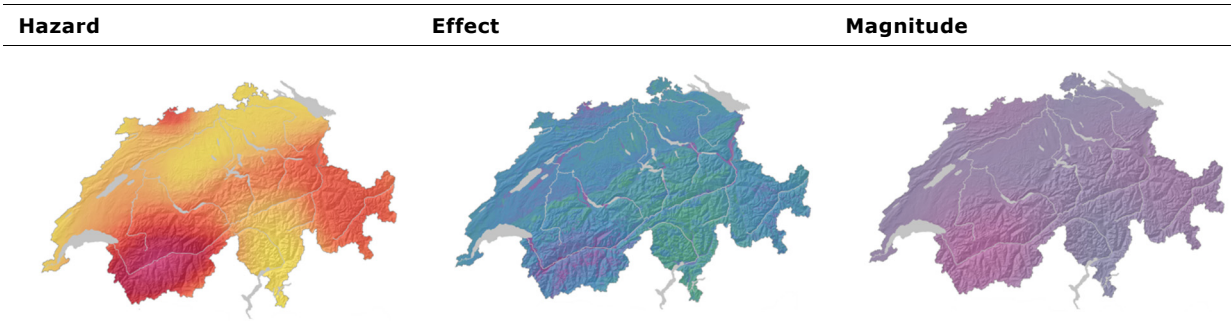


Figure 5: Comparison of the color scales of the three map types offered for the release of the updated seismic hazard model: (a) hazard map (in units of m/sec^2), (b) effect map (in units of EMS intensity) and (c) magnitude map (in units of magnitude) (Swiss Seismological Service, 2018; www.seismo.ethz.ch/knowledge/seismic-hazard-switzerland/).

To make it easier to compare maps in terms of, for example, return periods, the same color scale is used for all map variations within one of the three map types (Figure 6).

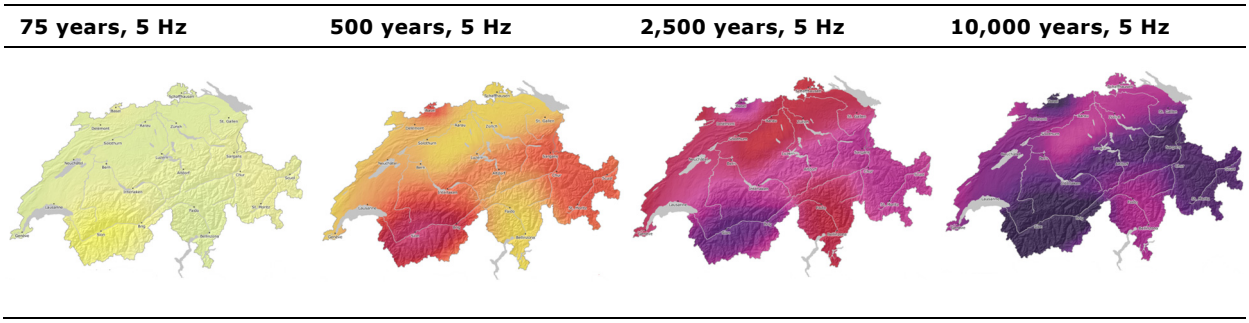


Figure 6: Same color scale for hazard maps with different return periods. From left to right are return periods of (a) 75 years, (b) 500 years, (c) 2,500 years, and (d) 10,000 years) (Swiss Seismological Service, 2018, www.seismo.ethz.ch/knowledge/seismic-hazard-switzerland/maps/hazard/).

In total, 45 maps were made accessible in an interactive web tool (Figure 7).

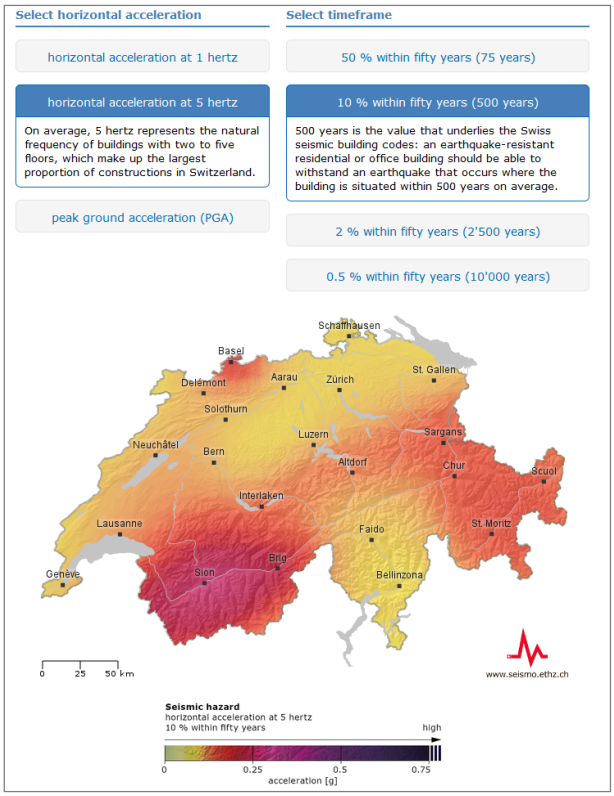


Figure 7: Screenshot of the Swiss seismic hazard model interactive web tool 2015 (Swiss Seismological Service, 2018, www.seismo.ethz.ch/knowledge/seismic-hazard-switzerland/maps/hazard/).

With regard to visual characteristics (see Section 6.2.1), darker colors are used to depict areas with higher hazard, intensity, or magnitude values, as recommended in other studies (Gaspar-Escribano and Iturrioz 2011; Peters et al. 2008). In contrast to its previous version (see Figure 4a), the seismic hazard map is mostly colored yellow-red, indicating that the whole country is potentially endangered. All maps are unclassified as they depict continuous data; this includes the downside of not allowing users to read single data points (Severtson and Myers 2013). The contrast ratios are rather low, especially in the case of the magnitude and effect maps, as a consequence of using the same color scale for all maps of a certain type. Low contrast ratios degrade the readability of the maps and also impede the understanding of the information shown (Hagemeier-Klose and Wagner 2009; Kunz et al. 2011). The legends are prominently positioned and depict numeric and qualitative information, as suggested by literature.

With respect to textual characteristics (see Section 6.2.2), the information provided follows best practice recommendations. Even though technical vocabulary has not been avoided in the legends, it is explained in accompanying text around 100 to 200 words long. In addition, every map has a caption summarizing the most important parameters. All map types depict different probabilistic information, which is not only provided in numbers but also explained[5].

The interactive tool allows different map parameters to be combined individually. However, there is no option to zoom in, select specific data points or information, or personalize the map displayed (e.g. transparency), which contradicts current best practices in the field (see Section 6.2).

5 For example, the term "probability of exceedance of 10 percent in 50 years (500 years)" used for the seismic hazard maps is explained in connection to the building codes: "Earthquake-resistant residential or office buildings in Switzerland are designed to withstand shaking that is expected to occur where the building is situated once every 500 years on average. The lifetime of a building is approximately fifty years. Within this lifetime, the probability of a residential or office building experiencing the design shaking is ten percent."

6.3.2 Research questions

Although there are various fragments contributing to best practices in the conceptualization of hazard maps and accompanying information, a comprehensive theoretical background is lacking. In addition, the few studies analyzing the conceptualization and comprehensibility of hazard maps mainly consulted primary users and usually worked with small, non-representative samples (Hagemeier-Klose and Wagner 2009; Kjellgren 2013; Meyer et al. 2012; Thompson et al. 2015). This is astonishing considering that maps are the most commonly used means of communicating hazard values to a greater audience. In the absence of alternatives, they play a particularly important role in raising the awareness of the population and in influencing decisions about precautionary measures.

To fill these research gaps, our study analyzes based on a real case, how well the public, including architects and engineers not specializing in seismic retrofitting, understand and interpret the seismic hazard information provided by the SED. Our findings will significantly depend on how well the maps are conceptualized in terms of visuals, texts, and presentation format.

We are focusing on three areas: the handling and understanding of the maps, the interpretation of statistical information, and the benefit of interactive access. In addition, we are interested in factors influencing the performance of participants in understanding and interpreting hazard information, such as numeracy skills, age, gender, or education (Peters 2008; Solberg et al. 2010; Thompson et al. 2015). Awareness and risk perception are further important precursors of future actions (Becker et al. 2013; Lindell and Perry 2000; Ronan and Johnston 2005). Because of their assumed influence, all these factors are controlled.

The most prominent output of the seismic hazard model is the seismic hazard map for a return period of 475 years. Based on the first research question, we aim to study whether people are able to correctly read and understand this particular seismic hazard map. Distinguishing hazardous from less hazardous areas requires correct interpretation of color hues, shading, and the information provided in the legend. It might also be beneficial to take into account and accurately interpret the accompanying information. In the following, the different research questions examined in this study are specified:

1. *Are participants able to distinguish regions with a higher seismic hazard from regions with a lower seismic hazard in Switzerland?*

2. *Which factors influence the understanding of seismic hazard maps?*

To execute predetermined tasks using magnitude or effect maps, participants need to derive the right conclusions based on color hues, legends, and textual information.

3. *Are participants able to choose the right magnitude or effect map for answering a given question?*

4. *Are participants able to identify and correctly interpret probability values on a magnitude or effect map to answer a given question?*

Statistics are fundamental for seismic hazard assessments and a genuine part of seismic hazard communication. They have proven to be very challenging to interpret. We therefore analyze how participants judge different statistical statements.

5. How well do participants interpret statistical information?

Based on previous findings (Peters et al. 2008), we assume that numeracy influences the interpretation of statistical information and therefore formulate the following hypothesis:

Hypothesis 1

Participants with higher numeracy skills interpret the statistical information presented more accurately.

An interactive presentation of hazard data, allowing users to answer personalized questions, is believed to support the understanding of the information provided.

Hypothesis 2

An interactive exploration of the Swiss seismic hazard model positively influences the understanding of the content provided.

6.4 Approach

A combination of quantitative and qualitative methods was chosen to best picture how people understand and interpret the maps and information offered in the context of the updated seismic hazard model for Switzerland. According to Haynes et al. (2007), quantitative methods alone fail to "capture the complexity of risk perception" in the case of volcanic hazard. When analyzing flood hazard maps, too, a combination of both approaches proved to be advantageous (Hagemeier-Klose and Wagner 2009). We conducted an online survey of the public in order to collect data and invited architects and engineers to participate in two workshops with the goal of gaining deeper insight.

6.4.1 Sample

In total, 491 members of the public answered the online survey. Random sampling based on quotas for age, gender, education, and language was carried out by a professional research company using their panel. From a total of 1042 participants, 478 were not allowed to complete the survey after having first answered sociodemographic questions. Their quota was already full. From the remaining 564, 36 were suspended because they had not completed the survey and 37 for quality reasons because they invested less than 5 minutes to fill it in. The remaining participants took an average of 12.9 minutes to complete the survey; 257 of the participants were female and 234 male, and 71.1 % filled in the German version of the online survey, while 28.3 % filled in the French version[6]. The average age of participants was 46.9 years[7] and most of them were renting a house or an apartment (66.4 %). The statistics on final examinations showed that 10.4 % had completed compulsory education, 52.1 % had gained upper-secondary-level qualifications (vocational education and training certificate), and 37.5 % had gained third-level qualifications (e.g., university degree). In sum, the sample was mostly representative of the Swiss population in terms of gender, language, and level of education.

[6] Switzerland has three official languages (German, French, and Italian) and four national languages (the aforementioned three languages and Rumantsch). The survey looked at the two groups with the most representatives among the total population: German speakers (63 %) and French speakers (22.7 %) (Bundesamt für Statisik 2015).

[7] 12.6 % of the Swiss population aged 25 to 64 have only completed compulsory education, 46.2 % hold upper-secondary-level qualifications and 41.2 % hold third-level qualifications.

Twenty-three architects and engineers participated in the two workshops, each of which lasted about two hours. The four women and 19 men were 36 years old on average and mostly worked for civil engineering companies in the German-speaking part of Switzerland. All of them had a university degree. Participants were selected using a snowball sampling approach.

6.4.2 Procedure and measurements

Both groups, the public and the architects and engineers, started by answering a standardized questionnaire (see Table VI). Detailed response options are specified in the Appendix. In the online survey, the response options were randomly reordered.

First set of standardized questions	1.	Sociodemographic questions (age, gender, education etc.)
	2.	Perceived-risk questions
	3.	Have you personally ever felt an earthquake in Switzerland?
	4.	How high would you classify seismic hazard in Switzerland?
	5.	Are there any areas with a particular seismic hazard in Switzerland?
	6.	Do you know the seismic hazard map the Swiss Seismological Service at ETH Zurich has published?
	7.	If so, where have you seen it?
	8.	Have you ever used this map to make a decision?

Table VI: First set of standardized questions. The public answered the questions online, and the workshop participants answered the questions on a handout. Translated from German to English by the authors.

Afterwards, all participants had to conduct usability tasks (see Table VII). In the online survey, the maps questioned were always on display including an explanatory legend, expect for question 12, where no map was depicted. All online participants had to reply the questions concerning the hazard map for a return period of 475 years. In the following, they were randomly assigned to answer questions either concerning the magnitude or the effect maps. For question 13 three magnitude (magnitude 5, 6, and 7) or effect (intensity IV, VII, and VIII) maps were on display. For questions 14 and 15 one map either depicting the probability for an earthquake with a magnitude of 6 or higher or an intensity of VIII within the next 100 years was shown. In total, online participants were confronted with four different maps.

Usability tasks	Hazard map	9.	Which are the regions with the highest seismic hazard?
		10.	Which town has the higher seismic hazard, Aarau or Interlaken?
		11.	Are there any areas in Switzerland without seismic hazard?
	Magnitude maps	12a.	Which map type would you choose to answer the following question? «In which two Swiss cities is an earthquake with a magnitude of 6 or higher most likely to be expected within the next 100 years?"
		13a.	Which of the three magnitude maps depicted seems most useful in answering the following question? "In which two Swiss cities is an earthquake with a magnitude of 6 or higher most likely to be expected within the next 100 years."
		14a.	Choose the pair of cities in which, according to the map shown, an earthquake with a magnitude of 6 or higher has to be expected most likely.
		15a.	How big is the probability for an earthquake with a magnitude 6 or higher to occur within the next 100 years in Bern?
	Effect maps	12b.	Which map type would you choose to answer the following question? "In which two Swiss cities is an earthquake causing severe damage most likely to be expected within the next 100 years?"
		13b.	Which of the three effect maps depicted seems most useful in answering the following question? "In which two Swiss cities is an earthquake causing severe damage most likely to be expected within the next 100 years."
		14b.	Choose the pair of cities in which, according to the map shown, an earthquake causing severe damage has to be expected most likely.
		15b.	How big is the probability for an earthquake causing severe damage to occur within the next 100 years in Bern?

Table VII: Survey section with usability tasks. The public answered the questions online, and the workshop participants noted their answers on a flip chart. The public solved the usability task as part of the online survey, and workshop participants needed to use the SED website to find their answers. Translated from German to English by the authors.

The architects and engineers were split from the beginning into two groups. In front of a big screen, they had to navigate through the website of the SED (www.seismo.ethz.ch) to find the information needed to solve the usability tasks. Again, all participants were confronted with the hazard map, but only one group at a time answered the questions concerning the magnitude or the effect maps. Four observers documented their discussions, their navigation paths on the website, and their suggested answers to the given questions. Apart from the setting, the assignment of tasks was identical.

To conclude, both groups were asked, based on given adjectives and statements, to rate the information provided. A further set of questions dealt with their understanding of statistical information, their willingness to take precautionary measures, and changes in their risk perception. Finally, they had to evaluate their numeracy skills (see Table VIII).

Second set of standardized questions	16. What is your general impression of the information you have seen? 17. How do you rate the following statements with respect to the maps you have seen before? 18. It is mentioned several times that an event is expected "within" a certain period, e.g., 50 years. What does that mean to you? 19. Assuming that there is a 60 percent probability for a damaging earthquake at your place of living within the next 50 years, how would you rate this probability? 20. Assuming that you were living in Valais, where there is an approximately 60 percent probability for a damaging event within 50 years, which measures would you take to protect yourself from such an event? 21. Which measures have you personally taken to protect yourself from the impact of an earthquake? 22. What could we improve in the presentation of the hazard model to enhance its comprehensibility? 23. Has your assessment of the earthquake hazard in Switzerland changed over the course of the survey? 24. Please assess your numeracy skills by answering the following questions. 25. Do you have additional comments about the survey?

Table VIII: Second set of standardized questions. Translated from German to English by the authors.

The following measurement parameters derive from the online survey; only there did enough people participate to allow for resilient statistical statements.

A five-point Likert scale was used to measure perceived risk (question 4), covering eight items compiled in an index with a Cronbach α of 0.753[8]. Earthquake hazard in Switzerland was classified on a five-point Likert scale (1 "very low" to 5 "very high").

In the usability section, based on a list with nine areas, we measured the number of correctly selected hazardous areas (question 9) and built a variable reflecting seismic hazard competence (see Table IX). The five areas with an elevated seismic hazard are Valais, Basel, Grisons, central Switzerland, and Saint Gallen Rhine Valley. The four areas with low to moderate seismic hazard are Jura, Tessin, the Lake Geneva region, and eastern Switzerland.

[8] "Switzerland has a high earthquake hazard." / "If an earthquake hits Switzerland, major damage is to be expected." / "I do not think that a major earthquake will occur in Switzerland in the near future." / "I believe earthquakes do not pose a major threat to me." / "I am afraid that the apartment/house I am living in might be destroyed." / "I feel protected against earthquakes at my place of work." / "I feel personally affected by the earthquake hazard in Switzerland." / "Switzerland would recover fast in the aftermath of a major earthquake."

Hazard competence	Number of correctly selected hazardous areas	Percentages	Number
Very low	0 - 1	28.9 %	142
Low	2	22.8 %	112
Medium	3	39.9 %	196
High	4 – 5	8.4 %	41

Table IX: Distribution hazard competence (N = 491).

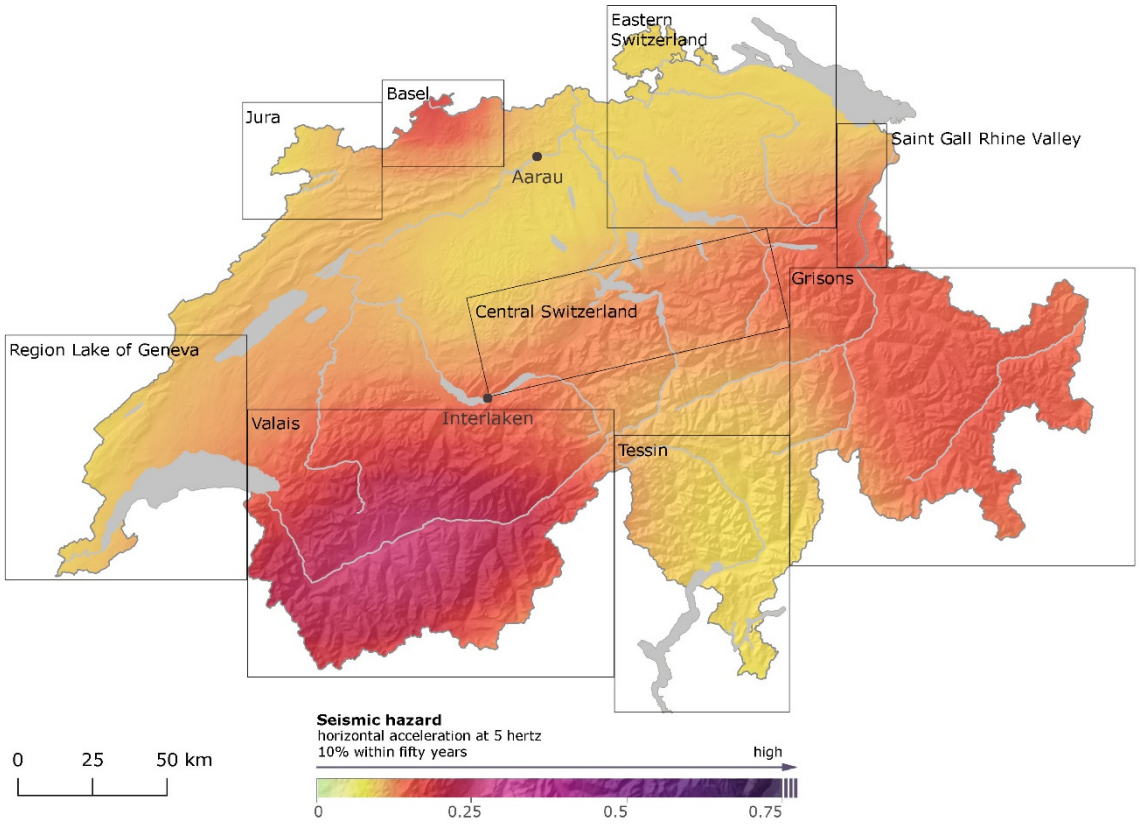


Figure 8: Seismic hazard map displaying the probability of a horizontal acceleration at 5 Hertz to be experienced with 10 % within fifty years (475 years) on rocky subsoil and the areas in question (Swiss Seismological Service, 2018, www.seismo.ethz.ch/knowledge/seismic-hazard-switzerland/maps/hazard/). The map was shown to the participants without the frames highlighting the different areas.

In the second set of standardized questions we made the following measurements: firstly, a selection of seven adjectives measuring the general impression of the information presented had to be rated on a five-point Likert scale (question 16), leading to an index with a Cronbach α of 0.790[9]. Secondly, statements regarding the coloring of the maps, the differentiation of map types and color hues, and the explanations provided had to be rated on a five-point Likert scale; no index was compiled[10] (question 17). This was followed by two questions addressing the understanding and interpretation of statistical information, also measured on a five-point Likert scale (questions 18 and 19). To conclude, participants' numeracy skills were measured

9 "attractive" / "trustworthy" / "helpful" / "instructive" / "complicated" / "nontransparent" / "confusing" /

10 "The colors chosen for the maps are cumbersome to understand the information depicted." / "The difference in content the maps display is clear." / "Color differences on the various maps are not distinct enough to read out details." / "The explanations for the individual maps are comprehensive." / "The legends (captions) are helpful to understand the maps." /

with four items[11] (Fagerlin et al. 2007) compiled in an index with a Cronbach α of 0.916 (question 24).

6.5 Results

The following results are mainly based on the online survey conducted with members of the Swiss public. Unlike the data gathered at the workshops with the architects and engineers not specializing in seismic retrofitting, the analysis of the online survey allows for resilient statistical statements. Therefore, sections 6.5.1 to 6.5.3 solely reflect the results of the online survey and section 6.5.4 describes the observations made during the workshops.

6.5.1 Understanding seismic hazard maps

Before being confronted with the seismic hazard map for a return period of 475 years, most participants (85.5 %) state that they had not seen it before. With the map displayed, the majority is able to correctly select two to five hazardous areas from a total of nine regions (see Table IX). Most often, participants recognize Valais as an area with an elevated seismic hazard, closely followed by Basel and Grisons. As areas with an objectively lower hazard than the aforementioned regions (though they are still among the most hazardous areas in Switzerland), the Saint Gallen Rhine Valley and central Switzerland are in most cases not recognized as such (see Table X). Almost all participants (93.5 %) successfully differentiate a city in a less hazardous area (Aarau) from one in a more hazardous area (Interlaken; see Figure 8). 76.4 % agree to the statement that there are not any areas without seismic hazard in Switzerland.

Areas with an elevated seismic hazard in Switzerland	**Percentages of participants selecting hazardous area**	**Other areas**	**Percentages of participants selecting other areas**
Valais	84.1 %	Tessin	9.6 %
Basel	60.9 %	Eastern Switzerland	9.4 %
Grisons	58.5 %	Jura	9.4 %
Central Switzerland	11.8 %	Geneva Region	7.5 %
Saint Gallen Rhine Valley	9.6 %		
Total selection of hazardous areas	86.25 %	Total selections of other areas	13.75 %

Table X: Participants' selection of hazardous and other areas in Switzerland (N = 491) with the map displayed. Number of selections taken is 1280.

The numeracy skills of participants and their living situation significantly influence their hazard competence. Participants with advanced numeracy skills and homeowners have a higher hazard competence (χ^2 = 19.28 (6), p = 0.004, n = 491). Those stating that there are not any areas in Switzerland without seismic hazard also have higher numeracy skills, are younger, and have a third-level qualification (χ^2 = 14.42 (4), p = 0.006, n = 491) (see Table XI).

[11] "How good are you at working with fractions?" / "How good are you at working with percentages?" / "How good are you at calculating a 15 % tip?" / "How good are you at figuring out how much a shirt will cost if it is 25 % off?"

	Index numeracy skills				
Hazard competence	M	SD			
Very low	3.66	1.07			
Low	3.75	1.03			
Medium	4.02	0.95	p = 0.003	F(487) = 4.70	η^2 = 0.03
High	4.09	0.91			
	Index numeracy skills				
Areas without seismic hazard	M	SD			
Yes	3.63	1.12	p = 0.020	F(488) = 3.93	η^2 = 0.02
No	3.93	0.97			
	Age				
Areas without seismic hazard	M	SD			
Yes	51.10	14.00	p = 0.001	F(488) = 6.64	η^2 = 0.26
No	45.51	15.17			

Table XI: Univariate analysis of variance with the numeracy skills index as dependent variable and hazard competence as independent variable as well as the numeracy skills index and age as dependent variables and the areas without seismic hazard as independent variable (N = 491).

The rating of the information provided using adjectives significantly influences participants' hazard competence as well as the choice of the city with the higher seismic hazard. Those who rate the provided information more favorably have a higher hazard competence and are more inclined to choose Interlaken instead of Aarau (see Table XII).

	Index rating of the information presented				
Hazard competence	M	SD			
Very low	3.45	0.73			
Low	3.56	0.71	p =< 0.000	F(487) = 8.46	η^2 = 0.05
Medium	3.80	0.67			
High	3.80	0.76			
City pair	M	SD			
Aarau	3.13	0.66	p = 0.009	F(489) = 6.80	η^2 = 0.01
Interlaken	3.50	0.79			

Table XII: Univariate analysis of variance with the index rating of the information presented as dependent variable and hazard competence or the city pair as independent variables (N = 491).

Gender, age, and risk perception have no significant influence on hazard competence or the ability to adequately select a city with an elevated seismic hazard or correctly assess that there are not any areas without seismic hazard in Switzerland.

In response to the first research question, the majority of participants are able to correctly distinguish regions and a city with a higher seismic hazard from regions and a city with a lower seismic hazard. Furthermore, they generally assess the whole country as potentially being in danger. However, only a few recognize central Switzerland and the Saint Gallen Rhine Valley as being among the areas with an elevated seismic hazard. With respect to the second research question, there is a series of factors influencing participants' understanding of the information provided. Numeracy skills and the rating of the information provided significantly influence participants' ability to accurately identify areas or a city with an elevated seismic hazard in Switzerland. Together with education, age, and the living situation, numeracy also significantly influences whether people are able to correctly deduce that there are not any areas without seismic hazard in Switzerland. The rating of the information provided further affects the choice of the more hazardous city.

6.5.2 Understanding magnitude and effect maps

Participants had to select the most suitable of three magnitude or effect maps for answering a given question. The results shown in Table XIII indicate that participants make the right choice more often (see highlight) when confronted with magnitude rather than effect maps.

Magnitude maps (N = 244) Map selected to answer the following question: "In which two Swiss cities is an earthquake with a magnitude of 6 or higher most likely to be expected within the next 100 years?"			**Effect maps (N = 247)** Map selected to answer the following question: "In which two Swiss cities is an earthquake causing severe damage most likely to be expected within the next 100 years?"		
Magnitude 5	Magnitude 6	Magnitude 7	Intensity VI	Intensity VII	Intensity VIII
35.2 %	56.6 %	8.2 %	12.2 %	53.8 %	34 %

Table XIII: Selection of the most suitable magnitude or effect map for answering a given question. The correct answers are highlighted.

Then, with the correct magnitude or effect map displayed, participants had to select which of four city pairs has the highest probability of experiencing a magnitude 6 event or an earthquake causing severe damage. Again, they select the correct pair more often when the magnitude map was displayed (χ^2 (3) = 56.72, p < 0.001) (see highlight in Table XIV).

	Which city pair has the highest probability for experiencing a magnitude 6 event or an earthquake causing severe damage?			
	Basel and Sion	Sion and Brig	Sion and Sargans	Brig and Sargans
Magnitude maps (N = 244)	18.4 %	71.3 %	5.8 %	4.5 %
Effect maps (N = 247)	46.2 %	39.7 %	11.3 %	2.8 %

Table XIV: Percentages of city pairs selected with maps displayed. The correct answers are highlighted.

Participants perform similarly well when asked to choose the correct probability range for the occurrence of an earthquake with a magnitude of 6 or an intensity of VIII within the next 100 years in Bern (χ2 (4) = 7.73, p = 0.147) (see highlight in Table XV).

	Probability range for the occurrence of an earthquake with a magnitude 6 or an intensity of VIII within the next 100 years in Bern				
	10 - 25 %	25 - 50 %	50 - 75 %	75 - 100 %	Not possible to depict from the map
Magnitude maps (N = 244)	64.8 %	20.9 %	6.1 %	0.4 %	7.8 %
Effect maps (N = 247)	61.9 %	18.6 %	12.2 %	1.2 %	6.1 %

Table XV: Percentages of probability ranges selected with maps displayed. The correct answers are highlighted.

With regard to the third research question, the results show that participants struggle to select the most suitable of three maps for answering a given question. Their performance, especially in the case of the magnitude maps, improves when asked to fulfill a task with the right map already displayed. With respect to the fourth research question, results are mixed. Participants increasingly choose the correct city pair with the highest probability of experiencing a certain event with the magnitude map displayed. In contrast, the probability range for a specific event in Bern is assigned equally well on the magnitude and the effect map.

6.5.3 Interpreting statistical information

Regarding the understanding of textual information describing probabilities, the statement of an event "within" a certain period of time is interpreted as intended by 73.3 % of the participants (N = 491). It can be understood as an event that has to be expected on average every 50 years, without knowing if it will happen tomorrow or in 70 years. Numeracy skills as well

as the change of perceived risk significantly influence the choice of the statement (see Table XVI).

	Numeracy				
Assessment of a verbal statement concerning an event within 50 years	M	SD			
Certain to occur before the end of 2067	3.53	1.25			
Certain to occur in 2067	3.48	0.93	$p < 0.000$	$F(478) = 7.91$	$\eta^2 = 0.46$
To be expected on average every 50 years	4.00	0.95			
I do not know	3.48	1.02			
	Change of perceived risk				
	M	SD			
Certain to occur before the end of 2067	3.50	0.99			
Certain to occur in 2067	3.32	0.67	$p < 0.001$	$F(487) = 8.44$	$\eta^2 = 0.49$
To be expected on average every 50 years	2.80	0.95			
I do not know	2.85	0.60			

Table XVI: Univariate analysis of variance with numeracy or the change of risk perception as dependent variable and the assessment of a verbal statement about an event within 50 years as independent variable (N = 491).

When asked to choose a verbal statement to assess the chance of a damaging earthquake occurring in their hometown within the next 50 years with a probability of 60 percent, 72.5 % of the participants rate such an event as quite plausible or almost certain. Participants' numeracy skills, risk perception, and change of perceived risk significantly affect their assessment (see Table XVII).

	Numeracy				
Assessment of a verbal statement concerning an earthquake in their hometown	M	SD			
Very unlikely	3.68	1.04			
Quite plausible	3.45	0.97	$p < 0.000$	$F(266) = 10.56$	$\eta^2 = 0.041$
Almost certain	4.00	0.98			
	Risk perception index				
	M	SD			
Very unlikely	2.63	0.63			
Quite plausible	2.80	0.67	$p = 0.002$	$F(488) = 6.07$	$\eta^2 = 0.024$
Almost certain	3.00	0.62			
	Change of perceived risk				
	M	SD			
Very unlikely	2.96	0.76			
Quite plausible	3.30	0.91	$p < 0.001$	$F(488) = 10.6$	$\eta^2 = 0.04$
Almost certain	3.31	0.70			

Table XVII: Univariate analysis of variance with numeracy, the risk perception index or the change of perceived risk as dependent variable and the assessment of a verbal statement concerning an earthquake in their hometown as independent variable (N = 491).

The first hypothesis is clearly confirmed, participants with higher numeracy skills interpret statistical information more accurately. In addition, risk perception and its change are important factors influencing their interpretation. Nevertheless, over two thirds of the participants interpret the statistical statements as intended. With respect to the fifth research question, we conclude that the statistical information provided is well understood.

6.5.4 Benefit of interactive access

Only the architects and engineers not specializing in seismic retrofitting worked directly with the web tool provided by the SED to solve the usability tasks.

The results of the observations made at the two workshops reveal that navigation through the website is challenging, at least in a group setting. The choice of the most suitable map type or map version for answering a given question proves very demanding for this group of participants too. Even though additional information was available in the form of descriptions, participants do not usually take much time to read it. They also mention that the amount of information and options to choose from is demanding. In addition, the interpretation of single data points or probability ranges is perceived as difficult. Participants criticize the web interface for not allowing them to zoom in or display specific values.

Despite having interactive access, the architects and engineers not specializing in seismic retrofitting do not differ from the participants filling in the online survey in their ability to understand and interpret the information provided. We therefore have to reject the second hypothesis assuming that an interactive access has a measurable positive influence on the understanding of the content provided.

6.6 Discussion

Although communication of seismic hazard in Switzerland follows many best practice recommendations, its understanding remains challenging for the public as well as for architects and engineers not specializing in seismic retrofitting. Potential for improvements can mainly be found in the following: amount of information presented, user guidance, coloring of certain maps, and design of interactive access. As such, all elements of the map conceptualization in terms of visuals, texts, and presentation are affected. Furthermore, a complex interplay of personal factors, including risk perception, its change, the rating of the information provided, numeracy skills, age, education, and living situation influence how hazard information is understood and interpreted.

Looking at the hazard map for a return period of 475 years, participants are generally able to differentiate areas and a city with an elevated seismic hazard from those with a lower seismic hazard. The majority also deduces correctly that there are not any areas in Switzerland without seismic hazard. Participants' competence in handling the maps is influenced by their numeracy skills; the rating of the information provided using adjectives; and their living situation, age, and level of education. The higher their numeracy skills and the better their rating of the information presented, the higher their hazard competence. This is in line with previous findings, highlighting numeracy as an important moderator for the handling of scientific information (Keller 2011; Peters et al. 2008; Severtson and Myers 2013) and interpreting graphics (Spiegelhalter et al. 2011). Regarding the effect of the rating, a greater ability to read the maps may have led to a more favorable assessment of the information presented. We conclude that the color hues chosen, the graduation of the coloring, and the conceptualization of the legend, all of which follow best practices (see Section 6.3.1), supported the understanding of this product. Homeowners' comparably higher hazard competence might be explained by the fact that they are more often confronted with questions on how to best protect their building. Therefore, they might have a greater interest and hence a greater capability to process relevant information. Younger participants and those with third-level qualifications more often

correctly state that there are not any areas without seismic hazard in Switzerland. It is known that preparedness increases up to a certain age and then drops again (Joffe et al. 2016). Better prepared individuals are probably also better informed or more used to interpreting available evidence. The same is true for those with a higher education.

By contrast, participants are less successful in understanding and interpreting magnitude and effect maps. These additional map types were introduced to provide an alternative to the ground acceleration values depicted in hazard maps, which are usually unfamiliar to non-primary users. However, many participants struggled to select the most suitable of three maps for answering a given question. Participants would have needed to read three sentences at the bottom of each map explaining its content to make the right choice. The comparatively short average time taken to complete the online survey and the observations made at the workshops indicate that many users did not take this information into account. It is open to speculation whether three sentences already disturb the equilibrium between completeness and comprehensibility (Peters et al. 2007) or whether the caption was just overlooked. A future study using eye tracking could shed light on this, as this method makes it possible to gain a better understanding of the elements taken into account (Keller 2011). In an eye-tracking analysis of flood maps it was observed that laypersons have difficulties in focusing on specific aspects of a map. Compared to specialists they show a rather erratic manner of exploring the content (Fuchs et al. 2011) Furthermore, whereas for the magnitude map, the magnitude value of 6 was directly mentioned in the caption[12], the term "very severe damage" had to be autonomously translated into an intensity value of VIII[13]. Since intensity values are not commonly communicated in Switzerland, people might have struggled to understand and interpret them.

When asked to pick and interpret probability values, participants tend to be more successful when magnitude maps, rather than effect maps, were displayed. However, a considerable amount of participants failed, which is mostly attributed to the color scales used (a criticism often brought up in the comment section and observed at the workshops). Coloring is a very sensitive component of map conceptualization (Thompson et al. 2015). As recommended for depicting continuous data, unclassified maps were compiled, which have the downside of impeding the readability of single data points (Severtson and Myers 2013). In sum, both map types failed to apply best practices with respect to their coloring, as the shading is not sufficient (Kunz and Hurni 2011).

The majority of participants interpret statistical information identically and as intended. Using "within" instead of "in" to describe the period for an expected event seemed to have supported the comprehensibility of the statements, as described in previous studies (Doyle et al. 2014; Hudson-Doyle et al. 2011). Two-thirds further describe a damaging event occurring in their hometown with a probability of 60 as quite plausible or almost certain. Due to the semantic similarity of these options, only the differentiation to the third option "very unlikely" is justifiable, which was only chosen by a minority. Confirming previous findings (e.g., Peters et al., 2008), participants with higher numeracy skills more often choose the indented interpretation. In addition, participants' risk perception and its change have, or at least tend to have, an effect on the interpretation of statistical information. McClure et al. (2015) also show, using the example of a potential earthquake in Wellington or Christchurch, that risk perception influences likelihood estimations.

12 "The map below shows the probability of an earthquake with a magnitude of 6 or higher, within a radius of 50 km, within one hundred years. In the case of earthquakes with a magnitude of 6, moderate to major damage is likely over a wide area. One hundred years represents the approximate life expectancy of a human being."

13 "This map shows the probability of experiencing shaking on local subsoil with an intensity VIII or higher within one hundred years. In the case of an intensity VIII, major damage and even the collapse of buildings is likely. One hundred years represents the approximate life expectancy of a human being."

The two workshops conducted with architects and engineers revealed that they are similarly challenged by the tasks assigned. Interactive access had no measurable positive effect on the comprehensibility of the Swiss seismic hazard model. Besides the similar knowledge and awareness levels of engineers and architects not specializing in seismic retrofitting, the amount of information provided and the design of the interactive access may explain the outcome. As stated in other studies, too much information is rather obstructive for transmitting knowledge (Pang 2008; Peters et al. 2007). As people only invested a little time in going through the content, even shorter texts are advisable. With respect to interactive access, workshop participants mentioned on several occasions that the tool did not meet their expectations, which were established by use of popular commercial mapping tools (e.g., Google Maps). This attitude was also documented by Perry et al. (2016). Being unable to zoom in or display specific values by clicking was seen as a major drawback and disregards best practices (Dransch et al. 2010; Hagemeier-Klose and Wagner 2009; Kunz and Hurni 2011). It prevents users from accessing information on different aggregation levels, which is recommended (Kunz et al. 2011). In any case, there is always a trade-off between providing individualized information and offering too many options (Pang 2008).

Despite some particularities of seismic hazard communication, the results of this study are transferable to any other context in which maps are used to communicate hazard to a wide range of users. The challenges observed are not limited to seismic hazard maps, but have also been observed for flood (Hagemeier-Klose and Wagner 2009; Kjellgren 2013) or volcanic hazard (Thompson et al. 2015) maps and therefore apply to any other (natural) hazard. However, the results of this study are limited to Switzerland, a country with a moderate seismic hazard, and a population with low earthquake awareness.

The real-world setting introduces some limitations as, for example, the material tested already existed. Due to the complexity of updating a hazard model, the data needed for communication materials usually only become available very shortly before the actual release. In addition, the development of communication materials is technically challenging and very resource intensive. However, the study design mirrors adequately the setting in which seismic hazard is communicated not only by the SED but also by many agencies around the world (see Figure 4). Therefore, it allows for practical insight beyond theoretical considerations or lab experiments.

6.7 Conclusions and practical implications

Seismic hazard maps are the most frequently used output of complex assessments to inform the public about this threat. Knowing and understanding the seismic hazard of a particular area are a requirement for being able to make informed preparedness decisions. Despite the importance of professionals in advancing seismic hazard mitigation through building codes, a knowledgeable public is needed to enforce existing regulations and to fill in reaming preparedness gaps, for example by getting insurance or fixing movable items. We tested based on a real-world case if non-experts understand current approaches of presenting seismic hazard information.

The most frequently requested map of the Swiss seismic hazard model, the one for a return period of 475 years, follows best practices and confirms its usefulness. The map seems to reach its aims by adequately informing non-experts and allowing them to distinguish hazardous from less hazardous areas. We conclude that despite the evidence that many hazard maps are not interpreted correctly (Hagemeier-Klose and Wagner 2009; Kjellgren 2013; Perry et al. 2016; Severtson and Vatovec 2012), when designed very carefully, they have the potential to also inform non-experts in the respective area.

Conversely, the disregard of best practices leads to the weak comprehensibility of magnitude and especially effect maps. Mainly the coloring, the impossibility of reading or accessing single data points, and the assumed unfamiliarity with intensity values impair their understanding. Improving the coloring over a wide range of values without using unappealing colors or color combinations is very challenging. An alternative would be to classify the data (e.g. in five classes) and thus greatly simplify the map design. Further, the needs of people with visual impairments should be taken into account, an aspect not specifically evaluated and considered in the framework of this study. It is also difficult to further educate people about intensity values without increasing the amount of information. By contrast, access to single data points could be implemented easily in an interactive tool allowing users to zoom in and click.

To conclude, the newly introduced map types, magnitude and effect, currently do not fulfill their intended purpose (see Section 6.3.1). They are not offering users a worthwhile alternative to complex ground acceleration values depicted in seismic hazard maps. Despite the assumed value of magnitude and effect maps for a better understanding of the strength and impact an earthquake might have at a specific location, they are less requested and almost never shared by the media. We attribute this mainly to the poor implementation as well as to the unfamiliarity with intensity values. In addition, habit may play a role. Previously, only hazard maps were published, and people might refer to what looks familiar to them without reflecting that another product could be more suitable.

Finding the most appropriate information for answering questions relating to earthquake hazard has proven to be very demanding. Textual information was often not taken into account. This is a very challenging condition for the design of successful communication measures. The most obvious solution would be to improve the texts themselves, namely their positioning and appearance, while another would be to enhance user guidance. Instead of offering all possible options at once, specific, frequently asked questions could be answered by displaying the most suitable map automatically. As an alternative, local scenarios (Perry et al. 2016) could be used to help people realize that such a threat is real and might impact their lives (Mileti et al. 2004; Nathe 2000). As a result, the total of 45 maps would only be accessible in a next step for users wishing to conduct more in-depth investigations.

The deficient performance of magnitude and effect maps in particular raises the question as to whether maps are the most eligible means of communicating hazard information. A doubt supported by the findings of Dobson et al. (2018) in the context of flood hazard information is the following: in direct comparison with tables and graphics, maps lead to the least accurate decisions. This indicates that despite their extensive use, there might be other, more adequate, and more user-friendly means of processing the information. Infographics are currently trending as a way to communicate complex issues. They aspire to graphically represent data for a lay audience. In spite of their assumed potential, there is currently only limited experimental evidence on their impact (Spiegelhalter et al. 2011). A recent analysis showed that infographics were well received but rated as being less trustworthy (McMahon, Stauffacher, and Knutti 2016). Nevertheless, future studies exploring the potential of infographics to communicate seismic hazard could be beneficial.

Besides the characteristics of the information presented, users' personal traits, experiences, and perceptions influence how well they understand and interpret seismic hazard information. Risk perception and its change have proven to be of relevance, conforming previous findings: familiarity with a specific hazard is the very first step towards precautionary intentions and actions (Whitney et al. 2004). Moreover, the effect of the change of perceived risk demonstrates that informing people is pertinent and can have an impact. However, the interplay between the information provided and personal characteristics is very complex. Since every member of a society is needed to strengthen earthquake resilience, the understanding of a regional seismic hazard is crucial for all of society. We strongly recommend assessing actual user needs and taking them into account when developing future products to inform about

seismic hazard. An option would be to co-produce seismic hazard information material with relevant users. In any case, seismological services will continue to struggle to meet all users' needs when offering hazard information.

Through our representative study analyzing the way seismic hazard information is currently presented we set the baseline for improved hazard communication. Our study shows that applying or disregarding best practices in visualization, editing, and presentation significantly impacts the comprehensibility of seismic hazard information. We further discuss numerous possibilities for improvements like revising the coloring, classifying data, amending textual information, reducing complexity, implementing scenarios, improving mapping tools, or using infographics. However, whether these amendments meet users' needs and actually lead to an improved understanding and interpretation of seismic hazard information has to be tested first.

Due to the similarity in communicating other hazard assessments, we are convinced that our results are transferable to any other (natural) hazard context, where maps play a central role in making the results of an assessment accessible to a variety of users. We therefore strongly suggest evaluating current natural hazard communication strategies and empirically testing updated or new products. We also encourage exploring new ways in presenting and communicating seismic hazard to raise awareness and to trigger protective actions. Such efforts would be of particular benefit to the public and non-specialist professionals, who may strongly support precautionary actions.

Appendix B

The Table B1 depicts the detailed response options and procedure.

	Public	**Architects and engineers**
	Online	Handout
First set of standardized questions	1. Sociodemographic questions – Age – Gender – Living situation (tenant, home owner, other) – Level of completed education – Canton of living – Profession 2. Perceived-risk questions – Switzerland has a high earthquake hazard. – If an earthquake hits Switzerland, major damage is to be expected. – I do not think that a major earthquake will occur in Switzerland in the near future. – I believe earthquakes do not pose a major threat to me. – I am afraid that the apartment/house I am living in might be destroyed. – I feel protected against earthquakes at my place of work. – I feel personally affected by the earthquake hazard in Switzerland. – Switzerland would recover fast in the aftermath of a major earthquake. 3. Have you personally ever felt an earthquake in Switzerland? – Yes – No 4. How high would you classify seismic hazard in Switzerland? – 1 very low – … – 5 very high 5. Are there any areas with a particular seismic hazard in Switzerland? – Open section 6. Do you know the seismic hazard map the Swiss Seismological Service at ETH Zurich has published? – Yes – No 7. If so, where have you seen it? – In a printed newspaper – On the internet – In a brochure – On the website of the Swiss Seismological Service – Other 8. Have you ever used this map to make a decision? – No – Yes, when buying a house – Yes, to base on a decision about insurances – Yes, as part of my work – Other	

		Online	Workshop
Usability tasks	Hazard map	9. Which are the regions with the highest seismic hazard? – Jura – Valais – Grisons – Central Switzerland – Tessin – Basel – Lake of Geneva Region – Eastern Switzerland – Saint Gall Rhine Valley 10. Which town has the higher seismic hazard, Aarau or Interlaken? 11. Are there any areas in Switzerland without seismic hazard? – Yes – No	
	Magnitude maps	12a. Which map type would you choose to answer the following question? «In which two Swiss cities is an earthquake with a magnitude of 6 or higher most likely to be expected within the next 100 years?" – The *effects maps* focusing on potential consequences of an earthquake. – The *hazard maps* depicting how often specific horizontal accelerations hit a building. – The *magnitude maps* showing how often earthquakes with a specific magnitude occur. 13a. Which of the three magnitude maps depicted seems most useful in answering the following question? In which two Swiss cities is an earthquake with a magnitude of 6 or higher most likely to be expected within the next 100 years. – The map shows the probability of an earthquake with a magnitude of 5 or higher, within a radius of 30 km, within fifty years. In the case of earthquakes with a magnitude of 6, moderate to major damage is likely over a wide area. The lifetime of the load-bearing structure of an average building is approximately fifty years. – The map shows the probability of an earthquake with a magnitude of 6 or higher, within a radius of 50 km, within fifty years. In the case of earthquakes with a magnitude of 6, moderate to major damage is likely over a wide area. The lifetime of the load-bearing structure of an average building is approximately fifty years. – The map shows the probability of an earthquake with a magnitude of 5 or higher, within a radius of 50 km, within fifty years. In the case of earthquakes with a magnitude of 6, moderate to major damage is likely over a wide area. The lifetime of the load-bearing structure of an average building is approximately fifty years. 14a. Choose the pair of cities in which, according to the map shown, an earthquake with a magnitude of 6 or higher has to be expected most likely. – Brig & Sargans – Sion & Sargans – Basel & Sion – Sion & Brig 15a. How big is the probability for an earthquake with a magnitude of 6 or higher to occur within the next 100 years in Bern? – 10 – 25 % – 25 – 50 % – 50 – 75 % – 75 – 100 % – Not possible to depict from the map	

		Online	Workshop
	Effect maps	12b. Which map type would you choose to answer the following question: "In which two Swiss cities is an earthquake causing severe damage most likely to be expected within the next 100 years?" – The *effects maps* focusing on potential consequences of an earthquake. – The *hazard maps* depicting how often specific horizontal accelerations hit a building. – The *magnitude maps* showing how often earthquakes with a specific magnitude occur. 13b. Which of the three effect maps depicted seems most useful in answering the following question? In which two Swiss cities is an earthquake causing severe damage most likely to be expected within the next 100 years. – The map shows the probability of experiencing shaking on local subsoil with an intensity IV or higher within hundred years. In the case of an intensity IV, generally no damage is likely, although the earthquakes will still be felt across a wide area. One hundred years represents the approximate life expectancy of a human being. – The map shows the probability of experiencing shaking on local subsoil with an intensity VII or higher within hundred years. In the case of an intensity VII, damage to buildings is likely. One hundred years represents the approximate life expectancy of a human being. – The map below shows the probability of experiencing shaking on local subsoil with an intensity VIII or higher within hundred years. In the case of an intensity VIII, major damage and even the collapse of buildings is likely. One hundred years represents the approximate life expectancy of a human being. 14b. Choose the pair of cities in which, according to the map shown, an earthquake causing severe damage has to be expected most likely. – Brig & Sargans – Sion & Sargans – Basel & Sion – Sion & Brig 15b. How big is the probability for an earthquake causing severe damage to occur within the next 100 years in Bern? – 10 – 25 % – 25 – 50 % – 50 – 75 % – 75 – 100 % – Not possible to depict from the map

	Online	Handout
Second set of standardized questions	16. What is your general impression of the information you have seen? – attractive – trustworthy – helpful – instructive – complicated – nontransparent – confusing 17. How do you rate the following statements with respect to the maps you have seen before? – The colors chosen for the maps are cumbersome to understand the information depicted. – The difference in content the maps display is clear. – Color differences on the various maps are not distinct enough to read out details. – The explanations for the individual maps are comprehensive. – The legends (captions) are helpful to understand the maps. 18. It is mentioned several times that an event is expected "within" a certain period, e.g., 50 years. What does that mean to you? – Such an earthquake will certainly occur until 2067. If not the period of 50 years has exceeded. – In 50 years, in 2067, such an earthquake has to be expected to occur. – On average, at least one such earthquake occurs over period of 50 years. It can happen tomorrow or in 70 years. – I do not know. 19. Assuming that there is a 60 percent probability for a damaging earthquake at your place of living within the next 50 years, how would you rate this probability? – A damaging earthquake in the near future is very unlikely to occur at my place of living. – Within the next 50 years it is almost certain that a damaging earthquake occurs. – Within the next 50 years it is quite plausible that a damaging earthquake occurs. 20. Assuming that you were living in Valais, where there is an approximately 60 percent probability for a damaging event within 50 years, which measures would you take to protect yourself from such an event? – None – Earthquake-resistant construction – Contracting an earthquake insurance – Allocating an emergency food supply – Knowing what to do in case of an earthquake – Securing items inside a building e.g. shelfs – Other 21. Which measures have you personally taken to protect yourself from the impact of an earthquake? – None – Earthquake-resistant construction – Contracting an earthquake insurance – Allocating an emergency food supply – Knowing what to do in case of an earthquake – Securing items inside a building e.g. shelfs – Other 22. What could we improve in the presentation of the hazard model to enhance its comprehensibility? 23. Has your assessment of the earthquake hazard in Switzerland changed in the course of the survey? – 1 I assess the earthquake hazard now lower – … – 5 I asses the earthquake hazard now higher 24. Please assess your numeracy skills by answering the following questions. – How good are you at working with fractions? – How good are you at working with percentages? – How good are you at calculating a 15 % tip? – How good are you at figuring out how much a shirt will cost if it is 25 % off? 25. Do you have additional comments about the survey?	

Table B1. Detailed response options and procedure.

7. ANECDOTAL EVIDENCE IS AN INSUFFICIENT BASIS FOR DESIGNING EARTHQUAKE PREPAREDNESS CAMPAIGNS

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Abstract

Improving societal resilience to natural hazards is extremely challenging. Long-term preparedness can only be enhanced by skillfully interlinking a wide range of measures. This general truth applies all the more to earthquakes, which are low-probability, but high-impact events. Over the last few decades, advancements in construction, informed by sophisticated seismic hazard and risk assessments, have greatly contributed towards saving lives and preventing economic losses. At the same time, however, individual preparedness levels have not changed, remaining universally low. Communication campaigns are the favored approach for translating available knowledge about preparedness into information on which individuals can act to enhance resilience. Based on a comprehensive review of evaluated earthquake preparedness campaigns, we find a disturbing lack of empirical evidence supporting their effectiveness. Such campaigns are typically based solely on intuition and anecdotal evidence, despite the fact that they are often very costly and prominent. We argue that conducting risk mitigation and awareness campaigns without proven measures to assess their impact is totally inadequate. Reliable evaluations are essential for designing future preparedness campaigns. Seismologists are urged to validate and test their earthquake forecasts and earthquake engineers the effectiveness of their building designs. Likewise, earthquake communication needs to be re-examined. To strengthen individual preparedness levels for earthquakes, future campaigns should consider and test the very latest recommendations for communicating low-probability, high-impact natural hazards. These include making continuous efforts, considering contextual aspects, choosing the most appropriate channels, evaluating campaigns, and conducting additional research. Well-trained communicators and the support of communication professionals are essential for effectively translating technical knowledge into individual actions. In addition, we recommend placing greater emphasis on community-based and on multi-hazard approaches, although further research is required to explore their actual potential.

7.1 Important but presumably often ineffective – campaigns for low-probability and high-impact hazards

Some disasters with serious consequences do not occur unexpectedly, just rarely, and hit suddenly with little or no warning. With respect to natural hazards, earthquakes share these characteristics, being the deadliest of natural hazards. Catastrophic earthquakes impact large areas and sometimes affect millions of people (Munich RE 2015a; Wallemacq and House 2018). Even with elaborate crisis management strategies in place, such events place high demands on immediate intervention. Appropriate behavior by the individuals and communities directly affected has the potential to substantially mitigate the impact and enable emergency organizations to allocate their resources in the best possible way. To achieve this objective, continuous education and awareness campaigns are critically important (Kapucu 2008).

Over the past few decades, several campaigns have been conducted aimed at improving earthquake preparedness, but their effectiveness is, at best, doubtful (Jon et al. 2016), with many studies revealing overall low levels of preparedness (Becker et al. 2013; Joffe et al. 2013; Meyer and Kunreuther 2017; Paton 2003; Verrucci et al. 2016) and inappropriate behavior

when events occur (Jon et al. 2016; Lazrus et al. 2016; Lindell et al. 2015; Lutoff et al. 2016; Prati et al. 2013; Ruin et al. 2014).

There is a rich body of literature describing preparedness levels, intervention strategies and the challenges in influencing hazard preparedness (Becker et al. 2013; Comerio 2004; Eiser et al. 2012; Heller et al. 2005; Joffe et al. 2013; Morss et al. 2016; Paek et al. 2010; Paton et al. 2010; Redlener et al. 2007). Yet only a very limited number of studies has evaluated whether those efforts have proved successful (Levac et al. 2012; Nathe 2000). Most current approaches designed to improve individual preparedness for rapidly evolving low-probability, high-impact events are based on intuition or anecdotal evidence (Levac et al. 2012; Wood et al. 2012). Disaster preparedness campaigns are generally neither theory driven nor empirically tested (Wood et al. 2012). "Risk information is being generated and disseminated on a large scale, but how far it reaches and whether it changes risk perceptions and awareness levels is not well understood" (UNISDR 2006, p. 137).

Meanwhile, the importance of and need for disaster preparedness is clearly increasing, as denser, strongly interconnected and continuously growing societies are becoming more and more vulnerable (Lee, Preston, and Green 2012). No fewer than 2.7 billion people live in areas where earthquakes causing at least slight damage are expected to occur regularly (Pesaresi et al. 2017). Improved hazard assessments and probabilistic forecasts are conducted and continuously updated to better understand the relevant processes and potential impacts (Albers, Stockschläder, and Szönyi 2017; Kellens, Terpstra, and De Maeyer 2013). However, it is poorly understood whether and how these technical advancements translate into enhanced preparedness. Currently, the evidence for this is lacking, despite recognition of the fact that risk management strategies solely based on technocratic approaches neglect the social dimension of disaster mitigation (Bodoque et al. 2016; Spitalar et al. 2014).

To shed light on the effectiveness of educational preparedness campaigns based on technical advancements, this contribution first provides an overview of the factors that generally influence preparedness. Second, we summarize studies describing the factors preventing people from preparing for earthquakes and their actual responses when an event occurs. Finally, we discuss documented and evaluated earthquake campaigns addressing the general public and deduce the lessons to be learnt and provide recommendations for designing future campaigns. Our aim is to contribute to a better understanding and the improvement of public education measures aimed at enhancing societies disaster preparedness.

7.2 What prevents people from preparing for earthquakes?

Being prepared can reduce the negative consequences of a disaster and empower individuals, communities, and societies to develop strategies to cope with it (Paton 2003; Tierney et al. 2001). A range of factors explain people's reluctance to take protective measures (Verrucci et al. 2016). One of the greatest factors holding them back is the rareness of disasters during most people's lives, the effect being exacerbated for low-probability, high-impact hazards. To assess the likelihood of an event, people often rely on their personal experience. Consequently, they underestimate rare disasters underestimated and may place too much confidence in the (untested) precautionary measures taken (Eiser et al. 2012). In addition, many people are convinced that a disaster is more likely to harm others and therefore are subject of an optimistic bias (Solberg et al. 2010). As a result, individuals may not receive preparedness-related information, might misinterpret or ignore it or lack the resources needed to implement recommendations (Tierney et al. 2001). There is also a tendency to delegate preparedness actions to response organizations (Ruggiero and Vos 2015).

Another important set of factors includes sociodemographic parameters like age, education, income, gender, home ownership, parenthood and race (Doyle et al. 2018; Kim and Kang 2010; Mayhorn and McLaughlin 2014; Nukpezah and Soujaa 2018; Verrucci et al. 2016). For

example, preparedness increases with age, up to a certain point, before falling again (Joffe et al. 2016). White males, people who have been through higher education and married people were found to have comparably higher preparedness levels (Donahue, Eckel, and Wilson 2014), with women often more eager to make preparations than men (Doyle et al. 2018; Prati et al. 2013).

Psychological factors such as self-efficiency, trust in others, anxiety, knowledge, outcome expectations, experience, risk perception and critical awareness can also play a role (Doyle et al. 2018; Kim and Kang 2010; Paton 2003). Preparedness is also influenced by the societal context as well as the social capital (Levac et al. 2012). Social capital is defined as "networks and associations of human relationships based on mutual trust, common interest or particular skills" (Freitag et al. 2014, p. 326). Observing others taking action has a positive influence on preparing for low-probability, high-impact events. Moreover, receiving actionable preparedness information from multiple sources and via different channels is an important predictor of individual readiness. In short, individual preparedness is shaped by how people interpret and feel about risk, their capacity to act upon this information and actions taken by their peers (Perez-Fuentes and Joffe 2015).

7.3 What people do when an earthquake strikes

Most earthquake campaigns focus on promoting recommended behavior when an earthquake strikes, even though other individual measures, like retrofitting buildings, securing movable items and taking out insurance could be similarly – or even more – effective.

Most strong earthquakes strike without warning. When the ground starts shaking, immediate action is required and will determine how the event impacts individuals (Lindell et al. 2015). Yet the best course of action to take depends on the situation, and there are no uniform recommendations about the most appropriate way to behave (GeoHazards International 2018). Whereas people in countries with comparably high building standards are usually urged to drop, cover, and hold on, those in regions with more vulnerable infrastructure are recommended to evacuate (Shapira, Aharonson-Daniel, and Bar-Dayan 2018).

Choosing the best option depending on the current situation is particularly challenging because there is scant evidence indicating how best to react in different circumstances (GeoHazards International 2018). Most injuries and fatalities result from damage to buildings and infrastructure caused by poor construction standards (Shapira et al. 2018).

A survey conducted in California in 1997 showed that the intention to adopt recommended behavior mainly positively correlates with income, hazard experience, risk perception, and hazard intrusiveness. Intrusiveness measures the number of people who are concerned and talk about earthquakes with their peers (Lindell, Arlikatti, and Prater 2009). A majority of the participants in one Israeli study stated their intention to evacuate in the event of an earthquake, which is the recommended behavior in their country. Older or married people, families with children and people with a higher education or socioeconomic status were more likely to choose this behavior (Shapira et al. 2018).

Yet studies analyzing actual conduct reveal a different picture: When the 2012 Emilia-Romagna earthquake hit, the 1,839 participants in a study reported one or more of the following behaviors: 42 % moved to another room, 35.6 % escaped, 32.9 % waited in bed, 27.9 % went downstairs and 18.6 % got dressed. Only 29.9 % sought shelter (Prati et al. 2013) and followed the official recommendations (Protezione Civile 2019). Women and better prepared individuals behaved more appropriately than men and people with higher levels of fear (Prati et al. 2013). Similar spontaneous was observed in New Zealand and Japan, where the most common response to an earthquake was to freeze, followed by evacuating and taking cover. Younger people and higher earners in both countries were more likely to seek cover than

others (Lindell et al. 2015). Again, the most frequent action taken is contrary to official recommendations (Japan Meteorological Agency 2009; National Emergency Management Agency 2019). Another transnational study, involving participants from Japan and New Zealand, indicates people's difficulties in applying what they learned from awareness programs to a real-life event. There were no significant correlations between the actions they took and their previous experience, available earthquake information or preparedness checklists (Jon et al. 2016).

7.4 Documented and evaluated earthquake preparedness campaigns

Public preparedness campaigns aim to raise awareness, warn society, and guide public behavior, (Coppola and Maloney 2009). To this end, they deploy different communication strategies to inform a large audience how best to behave (Atkin and Rice 2013). Campaigns need to prompt positive shifts in motivating people taking precautionary measures, making them more likely to implement those actions and supporting that implementation. Generally, different types of intervention are needed to accomplish changes in all areas (Paton 2003). Current disaster responses and the factors preventing preparedness make meeting significant requirements a precondition for campaigns' success.

To find out how well existing earthquake campaigns meet these requirements, we conducted comprehensive online research using Google and Google Scholar between June and November 2018, using English and German keywords. Our analysis is based mainly on studies conducted in Western countries and published in English, so we may have missed campaign evaluations published in other languages or contexts. However, even if such studies exist, they have not been widely cited and the knowledge gained through them has unfortunately not been transferred. We cannot exclude the possibility that further evaluations have been conducted but are not publicly available.

Before presenting the lessons learnt, we will briefly describe some previous campaigns that were not only documented but also at least partially evaluated. To qualify as a campaign, different communication measures had to be applied, taking a joint approach. For example, a mere web page providing information about recommended behavior or a single leaflet were not included.

7.4.1 Print-media campaigns

An early example is the Parkfield (USA) experiment used to gather data to investigate the potential of earthquake prediction. Besides fulfilling this scientific purpose, the experiment informed the public about the 95 % chance of a magnitude 5 to 6 earthquake occurring between 1985 and 1993 (Mileti et al. 1991). In addition to reports published in the media, a brochure was distributed to the potentially affected population, informing them about the experiment, the seismic hazard in the area, earthquake prediction and precautionary measures.

A survey conducted a year after the publication of the Parkfield prediction assessed the related risk communication as effective. The main reason for its success was deemed to be the repeated distribution of the same information about the Parkfield prediction by credible sources through multiple channels, reinforcing public attitudes towards the risks. People were encouraged to seek additional information and talk about the experiment with their peers, and this proved to be an important element for enhancing protective behaviors (Mileti and Fitzpatrick 1992).

In 1990, five years after the Parkfield prediction, the public’s reaction to an updated earthquake forecast for the San Francisco Bay Area (USA) was released and studied. To inform residents, again a brochure was disseminated in different languages via the Sunday newspaper (Mileti and Darlington 1995).

Mileti and Darlington (1995) reached a similar conclusion regarding the updated earthquake forecast. The mailing of the brochure led to numerous mitigating actions. For example, compared to before the brochure's distribution, the authors noted an 18 % increase in the number of people who had made emergency plans. In particular, the campaign helped to reiterate and strengthen recommendations that were previously known, but not necessarily followed over time, e.g. having emergency equipment. The lessons learnt in the framework of these predictions set the guiding principles for future campaigns in the USA (Nathe 2000).

7.4.2 Multimedia campaigns

For the next generation of earthquake preparedness campaigns, printed material was supplemented by radio broadcasts, TV reports, online resources and/or dedicated public meetings.

Tanaka (2005) studied the impact of educational programs conducted over the years in the San Francisco Bay Area (USA) and Fukui (Japan), not analyzing any specific campaign, but rather the general impact of different efforts. The more educational resources were available, the greater was the overall earthquake preparedness observed. In Japan, the source of the information had no significant effect on its impact. In the USA, by contrast, printed material had the biggest impact on preparedness, followed by broadcasts, while educational meetings were not very popular and therefore proved less influential.

In 2011, an Israeli campaign broadcast video clips and radio ads for two weeks and made them available online. They all pictured frightening situations and featured the slogan "A strong earthquake in Israel is only a matter of time, don't let it catch you unprepared" (Shenhar et al., 2015, p. 139). The aim was to raise awareness and preparedness levels for a strong earthquake in the country. Two weeks later, when a representative sample of people were questioned, it emerged that the campaign had reached 42 % of the population. Out of this sample, 23 % (equivalent to 9 % of the total population) reported that the campaign had strongly impacted their awareness and 30 % said it had increased their knowledge. Whereas 76 % took no action after being exposed to the campaign, the remaining 24 % responded by seeking more information, calling hotlines, asking friends, preparing their families or nursery equipment, or purchasing insurance. In total, 12 % indicated they did not know what to do in the event of an earthquake (Shenhar et al. 2015).

7.4.3 Drill campaigns

A novel approach introduced in California in 2008 was the ShakeOut drill, combining multimedia earthquake preparedness campaigns with the rehearsal of recommended behavior (drop, cover, and hold on) (Adams et al. 2017). Initially planned as a one-off event, the ShakeOut drill was deemed such a success that it was subsequently repeated and expanded to other parts of California and the world (Wood 2013). Yet although nearly 30 million people had participated in such drills by 2011, and more than 66 million registered for the 2019 ShakeOut (Southern California Earthquake Center 2019), there has been no continuous, comprehensive empirical evaluation (Perez-Fuentes et al. 2016). Below, we summarize the evidence to hand focusing on a wider public from the Californian drills in 2008, 2009 and 2010 as well as on exercises conducted in New Zealand in 2012 and 2015.

All the surveys questioned people who had participated in the drills and volunteered to fill in the questionnaire, producing an extremely engaged, motivated sample. For the 2008 Californian ShakeOut, the sample was further skewed by over-representing women, white participants and people on higher incomes. Since no baseline measurement was taken before the drill, no conclusions can be drawn about the actual impact of participating (Adams et al. 2017). An aggravating factor is that so far only a very limited amount of the survey data collected in the 2009 and 2010 Californian ShakeOut drills has been analyzed due to a lack of funding.

Further limitations preventing general conclusions or proper impact assessment are inconsistencies between data collection methods, the number of skipped items, and biases due to the survey being conducted online (Wood 2013).

Overall, at least two-thirds of participants practiced the recommended behavior. In the 2008 Californian survey, these participants were more likely to recruit and support their peers and more motivated to implement other elements of their disaster plan. However, one-third still felt unprepared for a large earthquake, most of them lacking sufficient disaster supplies and having no family communication plan. Among ethnic minority groups, the poor and the sick made even fewer preparation (Blakley and Chen 2009). In New Zealand, disability, age and embarrassment were the reasons most frequently cited when people were asked why they had not practiced drop, cover and hold on. Those people who did take additional measures were more likely to do so before the drill, not afterwards (Becker et al. 2016). The Californian ShakeOuts in 2009 and 2010 motivated between 7 and 32 % of participants to take specific action, like purchasing earthquake insurance or learning how to stay safe during an earthquake. However, a considerable proportion, up to 67 % of participants, said that they had taken those actions without being influenced by ShakeOut (Wood 2013).

In 2008 in the USA, the most important media channels for learning about the drill were TV, the internet and newspapers. Information on social media channels only played an insignificant role (Blakley and Chen 2009). In 2015 in New Zealand, more participants were motivated to participate by emails, online news, and Facebook in comparison to the 2012 drill (Becker et al. 2016).

7.4.4 Lessons learnt from evaluated earthquake campaigns

There is general agreement about the widespread need for communication campaigns aiming at improving preparedness levels for low-probability, high-impact natural hazards (Bodoque et al. 2016; Gruntfest, Carsell, and Plush 2002; Shenhar et al. 2015; Tanaka 2005). The documented and evaluated earthquake preparedness campaigns considered in the context of this contribution are targeting the general public and focused on people's behavior during an earthquake and on disaster preparation in general (Adams et al. 2017; Becker et al. 2016; Blakley and Chen 2009; Mileti et al. 1991; Mileti and Darlington 1995; Mileti and Fitzpatrick 1992; Perez-Fuentes et al. 2016; Shenhar et al. 2015; Tanaka 2005; Wood 2013). No campaign was found dedicated to recommended behavior when receiving an earthquake early warning. Other aspects, like the adaptation of legislative regulations or changes in crisis management measures to enhance preparedness were not directly promoted.

Technological advances have played a formative role in the history of evaluated earthquake campaigns, which were initially mainly based on printed products before developing to include online communication, video and animation. Recent campaigns have also used social media, though so far participants have paid less attention to such channels than to more traditional information sources (Adams et al. 2017; Becker et al. 2016). Another key aspect is the introduction of practical exercises and direct involvement of the public. A cross-national study suggests that campaigns with participatory elements are probably more effective than passive campaigns (Joffe et al. 2013). Most evaluations indicate a limited impact on people's overall preparedness levels, but are at least judged for being partially successful insofar as they prompt some people to act and draw the threat to others' attention. This judgement may be biased by the samples, which are mainly based on self-reporting and over-represent white people, women, older and better-educated people, and people on high incomes. Together with the lack of a baseline measurement, these aspects severely limit the evaluations' explanatory power.

Despite the acknowledged importance of campaign evaluation, the resources to conduct them are often lacking (Perez-Fuentes et al. 2016). Besides this struggle to fund evaluations, difficulties associated with finding the time and people qualified to conduct them and with measuring campaign impact, or the fear of disclosing failure are all factors that prevent institutions from conducting evaluations. This applies generally, not only to natural hazard preparedness campaign evaluations (Besson 2018).

Nevertheless, campaign evaluation is deemed crucial for improving the effectiveness of future efforts (McNeill et al. 2016; Shenhar et al. 2015). Especially before publishing a campaign, its impact on the target audience must be evaluated (Coppola and Maloney 2009). If information material is not tested, its success will solely rely on intuition and its actual effectiveness can only be assumed. "Widely accepted 'best practices' can still be terrible if they've been unthinkingly copied from one source to the next" (Fischhoff 2011, p. 522). Evaluation is particularly important when there are doubts about the success of previous campaigns, as with earthquake preparedness.

To conclude, the few published evaluated earthquake preparedness campaigns targeting the general public provide only little empirical evidence to base on future approaches. Therefore, the following recommendations section is enriched by findings from related fields aiming at improving the design of future earthquake preparedness campaigns.

7.5 Recommendations

Disaster mitigation for low-probability, high-impact events is complex. A variety of interventions can improve a society's resilience. Recently, a tentative shift has occurred, from enforcing structural improvements to enhancing the capability of a community to prepare for and cope with natural hazards (Prior and Roth 2019). According to a World Bank study, non-structural measures for disaster reduction, like behavioral adaptation, land-use planning or warning systems tend to be the most cost-effective actions (Kelman 2013). They are also relevant when an event exceeds the limits of a given structural design (Kenzo 2012). However, in many cases structural measures are needed to enable these interventions to reach their full potential (Kelman 2013).

Communication campaigns are the preferred method for enhancing individual preparedness, and should become an integral part of every disaster management strategy in countries at risk (Wallemacq and House 2018). Current individual preparedness levels clearly highlight the potential for greater personal engagement. The question is how this can be achieved. In the following, we provide a commented set of recommendations based on the lessons learnt from evaluated earthquake preparedness campaigns supplemented by additional findings filling in persisting knowledge gaps.

7.5.1 Just providing information is not sufficient

One common fallacy is that the mere provision of (more) information will trigger the desired outcome (Verrucci et al. 2016). People may probably learn from media how to prepare, but information alone rarely triggers actual behavioral change (Heller et al. 2005, p. 416). There are no easy solutions for overcoming this challenge, but here is some guidance.

Communicate regularly and repeatedly. A single intervention hardly ever has a long-lasting impact, especially when people are not regularly confronted with a specific threat. This applies even more to low-probability, high-impact events (Shenhar et al. 2015; Tanaka 2005). Especially for threats, which occur with little or no warning, regular training is crucial (GeoHazards International 2018). Long-term campaigns are thus essential for making a difference (Nathe 2000). The need for regular communication also implies the need to establish and cultivate a trusting relationship with the potential recipients of natural hazard information. People tend

to prefer the information sources they know and use on a daily basis also in the event of a crisis (Steelman et al. 2015). Talking to friends and family about preparedness can also amplify the positive effects (Heller et al. 2005) of a campaign, so this should be actively promoted. Findings in other domains suggest that incentives can have a supportive impact on preparedness, too. To this end, users of popular applications could be reminded to check their first-aid kit or update their emergency plans and be rewarded for confirming these activities (Verrucci et al. 2016).

Consider the context. Many people find it challenging to apply a campaign's recommendations in their personal context (Morss et al. 2016; Wood 2013). Establishing situational awareness and providing practical information on how to actually implement various measures could be beneficial (Fox-Rogers et al. 2016; Lazrus et al. 2016; Shenhar et al. 2015). One study that analyzed websites featuring earthquake and fire hazard information found that only 44 % of it was actionable (Verrucci et al. 2016), though minor tweaks would suffice to increase that percentage. Another recommendation is to align communication campaigns with other intervention strategies (Shenhar et al. 2015) (see the section on multi-hazard approaches) and respect the cultural context (Solberg et al. 2010).

Choose the right channels. Our review of evaluated campaigns showed that traditional communication channels still play a significant role in disaster communication, despite growing social media use (Adams et al. 2017; Becker et al. 2013). A majority of the participants in a national study carried out in Switzerland preferred accessing preparedness information on websites, followed by printed brochures distributed to their homes (Maduz et al. 2018). Future developments need to take account of changing user behaviors and corresponding claims. To this end, the use of trusted sources to disseminate preparedness information is essential (Solberg et al. 2010).

Evaluate your campaigns. The importance of evaluating campaigns has been highlighted previously (McNeill et al. 2016; Shenhar et al. 2015). Evaluation enables us to test the efficiency of campaigns, their impact on different target groups, and the longevity of potential behavioral change. It also helps to improve future campaigns. Evaluations can also reveal how well-intentioned campaigns are being poorly received provoking negative consequences. For example, campaigns can induce affects or trigger certain emotions, like fear or anger, that influence how people perceive and respond to the information conveyed to them (Visschers et al. 2012). Campaigns may also pass on information that seems relevant to its publisher, but turns out to be of little interest to its recipients (Steelman et al. 2015). Allocating resources to evaluate campaigns can prove challenging, especially in times of budget cuts. But bearing in mind that resilience is the product of a complex interplay between different mutually supportive measures, any missing link will diminish the impact of the whole intervention. Technical and scientific advances, on their own, only impact individual preparedness behaviors to a limited extent: they first need to be translated into something that non-experts find useful. For example, the impact of a warning depends on its reliability and the number of people it reaches and how many of those are capable of drawing the right conclusions (Bouwer et al. 2013). Professionally designed and evaluated campaigns are essential for ensuring that individuals can make use of faster, more accurate warnings based on sophisticated risk assessments.

Conduct additional research. Closely connected to the points above, there is currently very little knowledge about what kind of information people want and need in a crisis situation. Exploring recipients' requirements is essential for substantially improving communication campaigns (Government Office for Science 2011). This is particularly crucial for low-probability, high-impact natural hazards (Spitalar et al. 2014). In addition, it is well known that the design of hazard information with respect to its use of text, visuals or formats significantly influences its impact (Marti et al. 2019). To this end, although campaigns should be based on empirically determined best practices, they should also include promising, pre-tested novel approaches.

Accordingly, communication measures should be advanced with as much devotion as technical developments. In short, earmarking dedicated funding for the design and evaluation of communication campaigns has to become standard practice.

7.5.2 Educating and training risk communicators

Ameliorate communication skills. Most of the fundamentals for communicating any risk posed by natural hazards stem from technical analyses drawn up by highly specialized experts (Prior and Roth 2019). Transferring and sharing their knowledge is key to effective prevention, so more effort needs to go into promoting dedicated training to support such information transfers (Morss et al. 2016; Stewart et al. 2017). This will necessitate closer interdisciplinary collaboration when designing communication measures. One study found communication professionals were only involved in one-third of cases "despite communications being rated the second-most important activity for successful message development, after technical assistance to select the most appropriate message." (GeoHazards International 2018, p. 24).

7.5.3 Community-based approaches

Make use of social capital. It is suggested that strengthening social capital has the potential to enhance preparedness levels (Kim and Kang 2010; Levac et al. 2012). Communities with social capital tend to respond faster to disasters, recover more quickly and be more resilient (Nukpezah and Soujaa 2018). They also take better collective decisions (Shaw et al. 2004). For example, seeing others take precautionary measures motivates people to take action themselves (Ronan and Johnston 2005). Especially for low-probability, high-impact events, where people tend to neglect precautionary measures, consolidated social capital could play a compensatory role (Freitag et al. 2014). Adams et al. (2017) found clusters of particularly strongly engaged respondents in the 2008 ShakeOut drill and proposed targeting the members of such groups to play prominent roles in future exercises to motivate others. Verrucci et al. (2016) suggest including information about nearby community events or actions to facilitate social cohesion.

7.5.4 Multi-hazard approaches

Team up with other preventive measures. Leveraging the shared features of different preparedness approaches is seen as a promising way of enhancing resilience. For example, evacuation procedures remain the same regardless of what prompted the evacuation (Lee et al. 2012), and the same holds true with regard to obtaining emergency supplies. Exploiting synergies could enhance preparedness levels without focusing on events that only occur rarely. Another idea to put forward would entail collating relevant information on a single, multi-hazard platform (Lee et al. 2012; Maduz et al. 2018). That would require close collaboration between different authorities, which may prove somewhat demanding. According to one study, the challenges faced in such a multi-hazard approach may include a dearth of data, different ways of assessing and describing hazards, the fear of losing standing, not knowing what users need and the difficulty of processing vast amounts of information (Månsson 2019). To date, only few platforms adopt such an approach, and further research is needed to assess how best to communicate preparedness from a multi-hazard perspective (Verrucci et al. 2016).

7.6 Conclusions

To establish effective risk management for low-probability, high-impact natural hazards, a number of interventions need to be skillfully interlinked. In recent decades, remarkable progress has been made in hazard and risk assessment, especially with regard to informing structural and technical measures. At the same time, individual preparedness levels have remained unchanged, suggesting that scientific and technical advancements have not translated into personal action. Communication campaigns are an important means for raising awareness and

motivating the general public to act. Principal process steps to adhere by institutions when designing communication campaigns based on scientific and technical advancements are visualized in a flowchart (see Figure 9).

A widely neglected step in the flowchart is the evaluation of newly developed communication measures. Despite the high number of preparedness campaigns that have been run around the world, their effectiveness has rarely been investigated. As a result, current earthquake communication campaigns are based mainly on assumptions and speculation about what might work best. In addition, as highlighted in the recommendation section, available evidence from related fields seems to be not always considered when defining goals, designing, and pre-testing communication measures. A recent example of well-intentioned misleading practice was the decision by the Californian earthquake early warning team to notify users only if strong ground shaking occurred. However, in the aftermath of the Ridgecrest earthquake, many users complained that the system had not worked properly because they had not received a message warning them about perceptible shaking (Tripathy-Lang 2019). A pre-test of the message aimed at triggering specific behavioral responses would have helped to discover and address this issue beforehand.

Any increased investment in technical progress will only continue to widen the gap between the knowledge available and individuals' abilities to use it to enhance their resilience. We therefore advocate a complete rethink: instead of being 'optional extras', communication campaigns shall become an integral part of ongoing risk management efforts. To this end, they must be allocated dedicated resources and suitable professionals. This is the only way of taking preparedness for low-probability, high-impact natural hazards like earthquakes to the next level. Nevertheless, not all scientific advancements have to or should trigger the development of a dedicated communication campaign. In the light of risk management, such an effort is only needed, when these developments are of relevance for non-experts supporting them in enhancing their preparedness levels and improving disaster response in general. In addition, to be ethically justifiable, public preparedness campaigns should be based on a societal consensus that the promoted behavior is desirable.

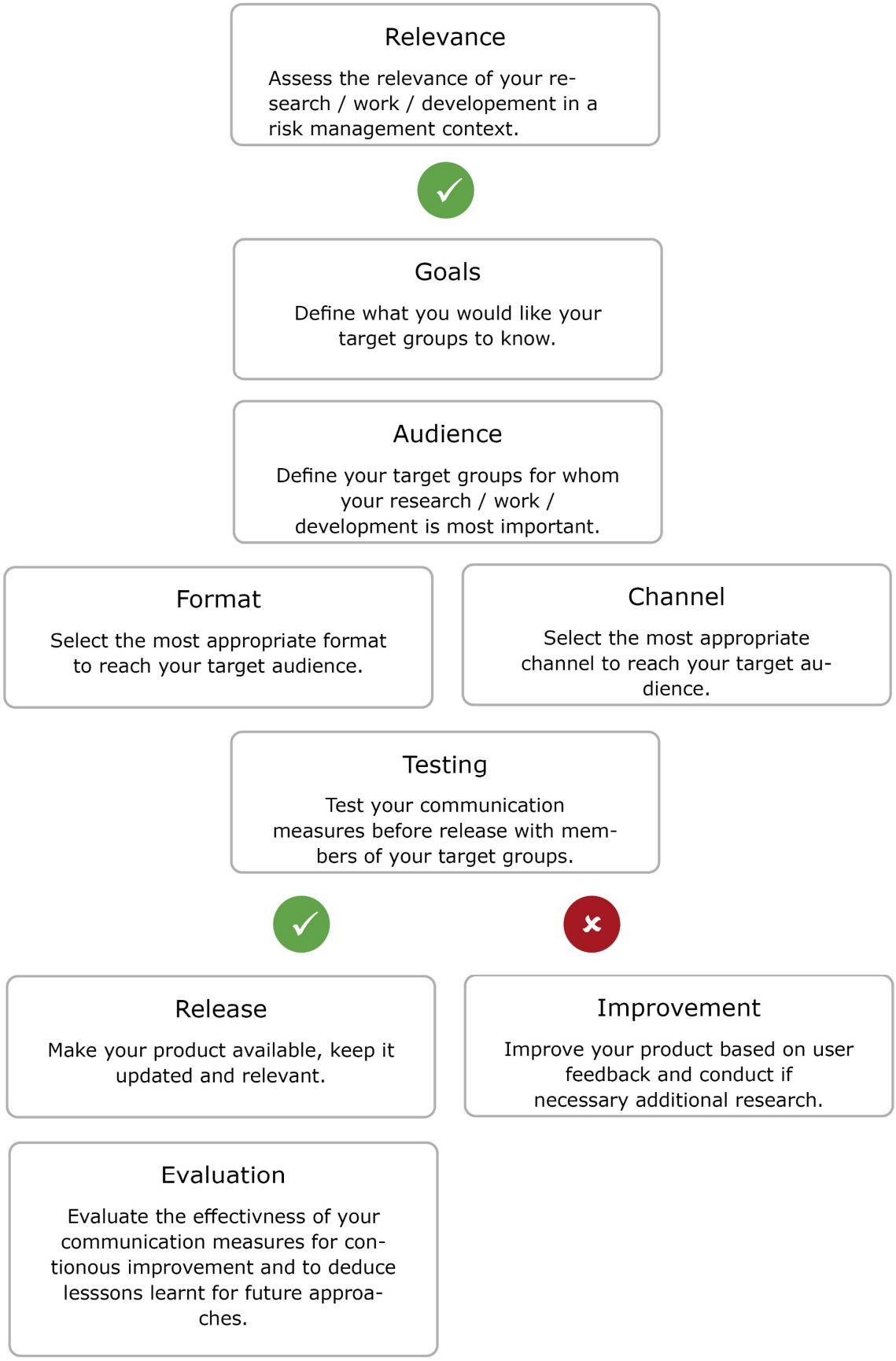


Figure 9: Flowchart visualizing principle process steps to adhere when designing communication campaigns.

8. CONCLUSIONS

8.1 Contributions of this thesis

As elaborated in Section 1, earthquake communication matters. To enhance earthquake preparedness and resilience different measures have to be skillfully interlinked. One such measure is communication. It provides the information people need so as to take informed decisions and thus supports action taking. Although the importance of communication and dissemination is widely recognized, corresponding measures are not yet a self-evident part of risk management strategies.

The three studies conducted in the framework of this thesis provide a comprehensive overview of the current state of the art in natural hazard communication and related domains. They reflect established practices and contribute empirical evidence, thus setting a baseline for elaborate communication measures to become an integral part of any risk management strategy. Despite having a focus on seismic hazard the results are transferable to any other (natural) hazard or risk communication context in which similar challenges persist.

For example, flash floods share similar characteristics with earthquakes. They are an irregular phenomenon, propagate rapidly and are therefore difficult to forecast (Morss et al. 2016; Ruin, Gaillard, and Lutoff 2007). Among the different flood types, flash floods triggered by heavy rainfall have the highest mortality rate per event (Jonkman 2005). They will additionally gain significance in the course of climate change, which leads to an aggravation of meteorological hazards including flash floods, reinforcing the importance of disaster preparedness (UNISDR 2006). In the last decades, hazard assessments for flash floods have considerably improved (Morss et al. 2016). However, the anecdotal evidence available leads to the assumption that the enhanced technical knowledge does not translate into better prepared communities. As is the case for earthquakes, people are often unaware of the threat and do not act appropriately in case of an event (Lutoff et al. 2016; Ruin et al. 2014). Whereas numerous campaigns have been undertaken to raise earthquake awareness and preparedness, the importance of communicating flash flood hazard has only recently received some attention (Bodoque et al. 2016; Gruntfest et al. 2002; Morss et al. 2016) and can benefit from the insights gained from analyzing seismic hazard communication.

The findings of this thesis highlight the multitude of factors that has to be considered when designing measures aiming at effectively informing about natural hazards. Despite their relevance, many of these factors have not yet been studied in depth in this domain. Mood is one such disregarded factor, a long lasting emotion suspected to have a comprehensive and potentially insidious impact on reasoning and decision-taking. Up to now, the impact mood or other emotions have on the processing of natural hazard information has scarcely received any attention. The in-depth analysis of these particular and other factors in the framework of this thesis helps to design future hazard and risk communication.

8.2 The results in brief

Improving earthquake preparedness and resilience is extremely challenging. The findings of this thesis do not provide a magic formula allowing to create the perfect hazard and risk communication aiming at enhancing preparedness and resilience. Nevertheless, they spotlight some frequently used, but poorly understood issues of high relevance in the field. The principal results are summarized below:

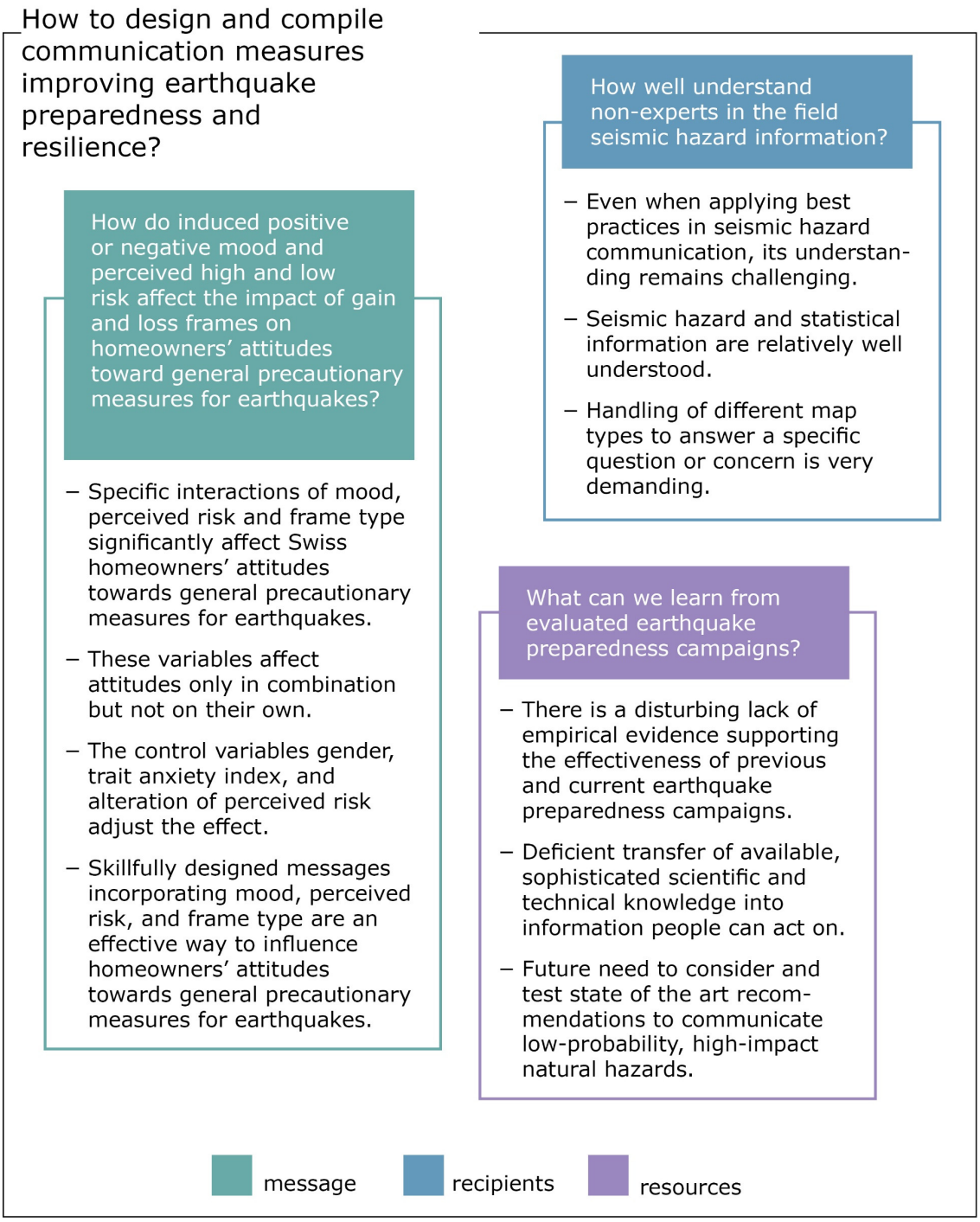


Figure 10: Overview of the main results of the studies conducted. The three domains of key challenges upon designing communication measures aiming at improving earthquake preparedness and resilience are color-coded.

An earthquake-resistant building design is the most efficient measure to prevent losses of life and finances in case of an earthquake. In many countries, homeowners thus take on a special role as they have a say when it comes to the decision to build a house accordingly or to retrofit it. Risk communication encouraging homeowners to take precautionary measures is therefore an important element to enhance a country's earthquake resilience. To highlight particular aspects of a message, such as the benefits of taking precautionary measures, frames are a common means. However, their impact is often inconsistent. Based on theoretical evidence and findings from health communication studies, the interdependencies of the variables mood, risk information, and frame type were tested in an experimental 2 x 2 x 2 design (N = 156). The results showed that specific interactions of mood, perceived risk, and frame type significantly affect homeowners' attitudes toward general precautionary measures for earthquakes thus replicating previous findings. The effect, however, only emerged when combining these

factors, which explains the frequently observed inconsistencies of framing effects. Overall, the group with the strongest attitudes towards general precautionary actions for earthquakes were homeowners with induced negative mood, who processed high risk information and gain-framed messages. To a smaller extent, both, the conditions comprising induced negative mood, low risk information, and loss-frame as well as the one with induced positive mood, low risk information, and gain-framed messages also significantly influence homeowners' attitudes towards general precautionary measures for earthquakes. The results illustrate the potential of skillfully compiled messages to influence attitudes and simultaneously highlight that small changes in the message design can make a big difference (Marti et al. 2017).

Hazard maps are the most prominent output of hazard models and often the only accessible product to help the public to decide on mitigation measures. Nevertheless, they are currently mainly tailored to the needs of professionals and frequently misconceived. Visual and textual characteristics as well as the manner of presentation influence their comprehensibility. Using a real case reflecting current practices, the material to communicate the updated seismic hazard model for Switzerland was analyzed in a representative online survey of the population (N = 491) and in two workshops involving architects and engineers not specializing in seismic retrofitting (N = 23). Important principles of the map conceptualization have been met for the seismic hazard map for a return period of 475 years, the main output of the respective hazard model. This allowed most participants to distinguish hazardous from less hazardous areas and to recognize that there is not a single region without seismic hazard in Switzerland. Equally well interpreted was the statistical information presented also following best practices in the field. In contrast, additional tests with magnitude and effect maps clearly showed that not following established guidelines decreases the comprehensibility and usefulness of products. In general, participants were challenged to identify the most suitable set of information to answer a given question (Marti et al. 2019).

Besides principles in the conceptualization of products, the two studies emphasize the significance of individual traits. In the first study, gender, trait anxiety, and the alternation of perceived risk adjusted the three-way-interaction. In the second, numeracy skills, the living situation, education, age, and again risk perception and partly its alternation had an effect. These traits add additional complexity to the understanding and subsequent designing of hazard communication. In both cases, only participating in the study altered the risk perception of participants and exhibited a positive effect. This leads to the conclusion that confronting non-experts with seismic hazard information seems beneficial to enhance preparedness as long as the products are designed well.

The first two studies show how existing evidence can be successfully applied and tested for seismic hazard communication. This then leads to the question of how well such principles are already applied in current communication campaigns for low-probability, high-impact hazards such as earthquakes. A comprehensive review of evaluated earthquake preparedness campaigns reveals that the answer is appalling. There is a disturbing lack of empirical evidence supporting the effectiveness of previous earthquake preparedness campaigns and a dearth of resilient recommendations on how to best design them. They are typically based on intuition and anecdotal evidence only. Subsequently, the study concludes with a set of recommendations geared at improving future campaigns. The most important ones are to invest in long-term efforts, consider user needs as well as the context, and to test and evaluate communication measures without fail. In addition, trained professionals willing to work inter-disciplinarily are indispensable. Furthermore, it can be advantageous to make use of synergies and to adopt novel communication forms. Despite a rich fundus of resilient evidence in other fields, the remaining research gaps for natural hazard communication are substantial.

9. OUTLOOK

9.1 Is earthquake disaster preparedness illusive?

To be reminded of a catastrophic earthquake one rarely has to look back far. Being the deadliest natural hazard and causing the second most economic losses, earthquakes pose a serious threat to many countries. Their potentially devastating impact combined with long return periods, however, heavily impede the willingness and ability of societies to take appropriate measures (Wallemacq and House 2018). In consequence, some resign even before getting started and others cut back existing efforts because they seem not to pay off. Earthquake preparedness needs endurance but can definitely be rewarded as some outstanding examples illustrate.

The predominantly low preparedness levels affirm that despite the efforts taken it appears illusive to rise them globally. Nonetheless, approaches in other fields prove this assumption wrong: Wearing seatbelts, using sun screen, or quitting smoking are successful examples of public education efforts (Nathe 2000). When it comes to earthquake preparedness, Japan is an outstanding example. The country succeeded to reach a very high level of resilience by applying strict building codes and supporting social cohesion through regular endorsement (Crowley and Elliott 2012). Considering an investment in preparedness is always based on an assessment of different aspects including finances, motivation, expected benefit, cost-value ratio, regulations, ethical aspects, or the social environment. Raising preparedness levels in a society depends on collective and individual decisions and actions. No matter the investment, it will never reach a hundred percent, but it can be significantly improved.

Having disclosed these general conditions, communication efforts dedicated to improve disaster preparedness should first and foremost allow societies to take informed decisions. To this aim, scientific evidence gained through sophisticated hazard assessments needs to become available for those who can make a difference in preparedness and resilience. Currently, the output of many hazard assessments is primarily technically driven addressing professional users. Recent findings for different natural hazards illustrate that the information available to non-experts is often misinterpreted and hence not meeting its purpose (Hagemeier-Klose and Wagner 2009; Kjellgren 2013; Morss et al. 2016; Perry et al. 2016; Severtson and Vatovec 2012).

To conclude, improving earthquake preparedness is not illusive, but it needs real dedication and advancements in many fields. Hazard and risk communication is a key element of risk management. On its own, it will hardly make a difference, but integrated in other supportive approaches it can have a significant impact (Coppola and Maloney 2009).

9.2 Designing future hazard and risk communication

After having acknowledged communication measures as an important element of disaster risk reduction, it needs to be clarified how to best reach an audience and spread the message. The focus of the following section is on novel approaches as well as on established practices which have not yet been widely applied or evaluated in a natural hazard context. Figure 11 depicts which of the three domains of key challenges is mainly addressed upon designing communication measures aiming at improving earthquake preparedness and resilience by specific interventions.

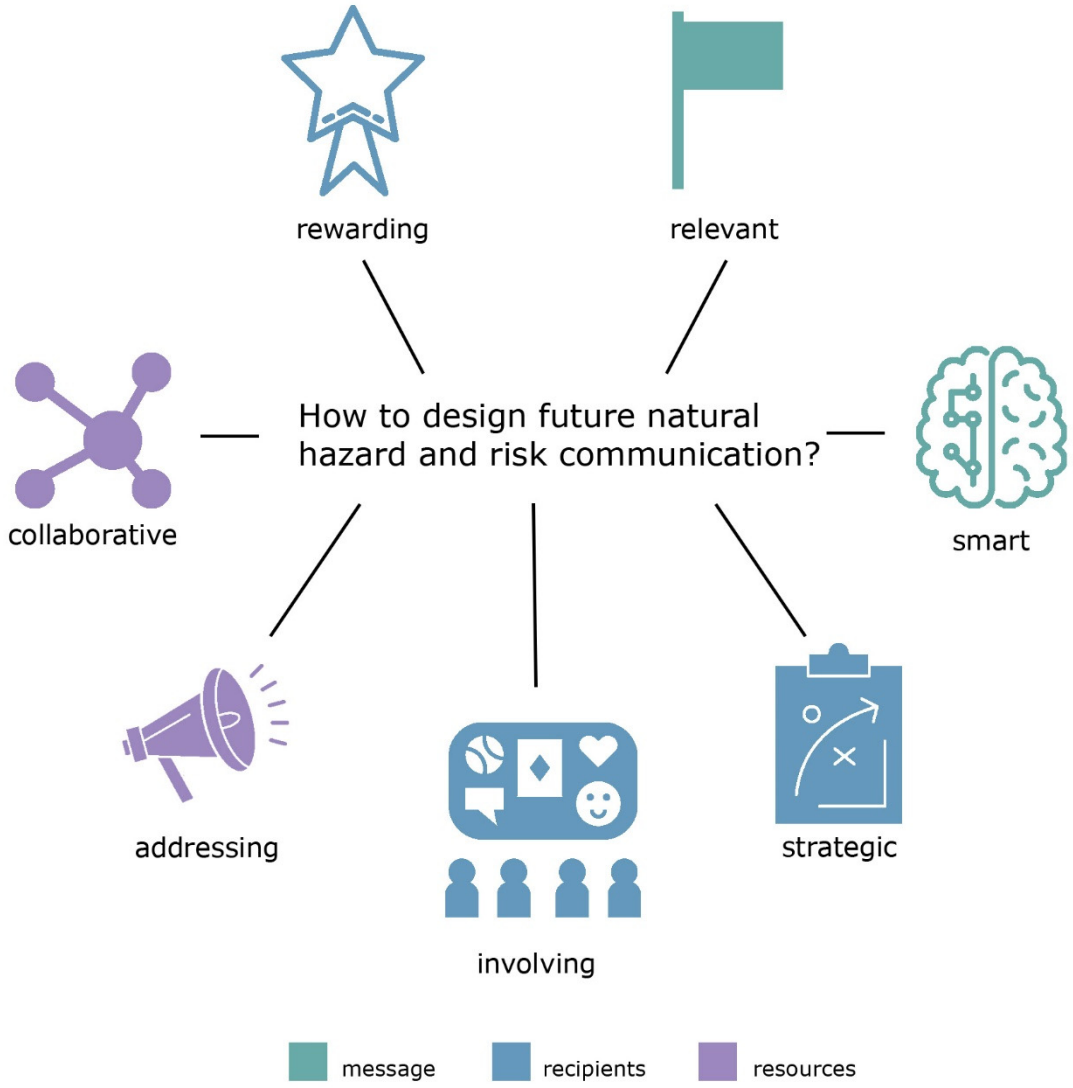


Figure 11: Representation of the elements which, according to the results of this thesis, contribute to the success of future hazard and risk communication efforts. The three domains of key challenges upon designing communication measures aiming at improving earthquake preparedness and resilience are color-coded.

9.2.1 Make it accessible and relevant

In general, people seek hazard and risk information to assess the personal relevance of a threat (Lion, Meertens, and Bot 2002). In consequence, allocating information triggering personal relevance should become a priority. This can be achieved by providing customized information based on location, needs, or expertise. Especially in the context of weather warnings, so called impact-based warnings have recently gained attention. Instead of only providing information about the weather phenomenon itself, additional information about the estimated possible impact is included. A recent study conducted in New Zealand illustrates a potential benefit of impact-based warnings compared to traditional ones. However, the results only show an effect on risk perception and not necessarily on the intention to become active and to take protective measures (Potter et al. 2018). Wood et al. (2018) call for warning messages which accurately describe the hazard or event, provide guidance, are clearly worded and specific with respect to the location as well as the time of the event.

Field et al. (2016) see a potential in using operational earthquake forecasting to enhance personal relevance and trigger protective behavior. Operational earthquake forecasting provides probabilistic information about future events. The probabilities featured are usually quite low, not exceeding a few percentages and consequently hardly motivating people to become active. Only in the aftermath of a bigger event, probabilistic aftershock forecasts may increase

up to a factor of 1'000 (Field et al. 2016). However, also in such a case actual percentage values remain comparably low. In addition, following a large earthquake people are emotionally stressed which limits their ability to process such information (Wein et al. 2016). A recent study analyzing aftershock information processing showed that besides emotions and feelings, prior knowledge, the amount of personalization, information credibility and trust in the source as well as external factors influence its understanding and interpretation (Becker et al. 2019). This results in high requirements with respect to the development of such information and respective products. Therefore, they should not be compiled ad hoc, but need to be developed and tested antecedently with relevant user groups (Becker et al. 2019; Field et al. 2016).

Donahue et al. (2014) call for communication efforts that are closely tailored to the needs and interests of different user groups. To this end, communications measures to support preparedness efforts and resilience have to be more agile and variable. Only then will they be able to satisfy the broad variety of user needs. For the development of such user-centered products dedicated resources are indispensable (Bodoque et al. 2019). Particularly for information being distributed before an event, such an approach seems absolutely feasible despite the higher demand for resources. In contrast, providing crisis information which simultaneously satisfies very different user needs is more challenging but might be achieved with the help of new technologies. To best fit user needs and enhance involvement, preparedness information, measures, and warning products can also be co-produced with future users.

Personal relevance might also increase with a more widespread availability of seismic risk information in the future. In contrast to seismic hazard, seismic risk depicts the consequences of an earthquake in a more accessible way. Instead of abstract ground acceleration values, scenarios illustrating the impact of potential events in terms of losses can be provided. Seismic risk not only tells people that there is a threat, but realistically illustrates its consequences. Currently, such seismic risk information is only available for particular areas and knowledge and experience on how to communicate it is still rare. Additional research is definitely needed to design corresponding communication measures in the best possible way.

9.2.2 Smart technologies demand for smart communication

In the field of earthquake preparedness there is a set of information that may soon become available to improve preparedness or to support adequate behavior in case of an event. Buildings, for example, can be equipped with sensors providing immediate damage information (Procopiou 2019). Also earthquake early warning systems are becoming more common offering new opportunities for individual risk reduction but likewise presenting challenges in risk communication. In general, due to the internet of things, a massive amount of potentially useful information to improve or strengthen disaster preparedness and response is becoming available (Ju 2019; Zafar et al. 2019).

As it is already the case for hazard and risk assessments, those developments move considerably faster than aligned information strategies. There is a genuine mismatch between the recognition of human behavior as an important element in disaster mitigation and the research conducted, the funding raised, and the proposals handed in to better understand it. "By and large, integrated risk assessments are lacking, and where they do exist, integration with the social and behavioural sciences is weak" (Eiser et al. 2012, p. 14).

For smart technologies to become successful, they have reach and be sophistically linked to potential users (Minges 2019). Without this connection, they remain a stand-alone solution with very limited potential. Therefore, when raising funds to develop such technologies one should always consider the next step and allocate resources to establish accessible solutions and communication tools supporting the user link. There is also a need for fundamental research to better understand how people make use of such technologies and what emotions, behaviors, and responses they trigger. This is a very important element to fill the gap between

increasingly sophisticated hazard and risk assessment through smart technologies and unaltered preparedness levels.

9.2.3 Have a strategy

Notably in a crisis situation, human resources are scarce and information needs demanding. A previously developed and tested communication strategy is eminent for enabling organizations to respond adequately. Besides defining communication goals, the needs of the audience have to be assessed. Subsequently, appropriate messages can be designed and adequate communication channels chosen (Becker et al., 2019). Having a long-term strategy is also evident when developing and conducting preparedness campaigns as behavioral change does not come overnight (Shenhar et al. 2015). In both cases, new ways for communicating natural hazards should be explored besides elaborating established formats, channels, and approaches. This relates closely to the first chapter of this section, emphasizing that users should receive the information where they are. For example, social media platforms such as Snapchat or Instagram are more popular among young people whereas Facebook is equally used by different age segments (Perrin and Anderson 2019). When designing communication measures preferences for different channels dependent on particular information needs have to be considered together with corresponding trends.

Before launching a campaign based on a sound strategy, the complexity of hazard and risk communication demands for an evaluation; no matter if totally new approaches or presumably established practices are implemented. Every use case is specific and therefore subject to a proof of concept (Spiegelhalter 2017). Often, it is also a legitimate request as most of the money spent for preparedness campaigns comes from public agencies. Nonetheless, conducting evaluations is exigent, especially in the case of participatory involvement (Lundgren and McMakin 2013).

9.2.4 Involve your audience

Recent publications rate participative approaches as very promising to enhance natural hazard preparedness (Donovan and Oppenheimer 2014; Frewer 2004). Public participation is seen as one of the most powerful means to enhance awareness and motivate people to become active (Wachinger et al. 2013). Despite its assumed relevance, involving people remains challenging (Leshner et al. 2017). The willingness to participate in social activities aiming at enhancing preparedness levels, for example, depends on the context. In a transnational study, such educational meetings were quite popular among Japanese participants whereas their American counterparts were not nearly as motivated to participate (Tanaka 2005). In contrast, when looking at the number of participants at ShakeOut drills, a large amount of a population can be motivated to take an active role. Even when considering that the numbers themselves do not necessarily reflect the success of such a participatory intervention.

Another option is to integrate a community in an iterative preparedness process. In delimitation to a top-down approach, such a procedure seems to reflect and represent the complexity of disaster mitigation more adequately (Scolobig et al. 2015). It allows the members of a community to individually shape preparedness and find solutions which are tailored to their needs (Paton 2018). Those potentially affected are offered the chance to contribute self-determinedly to the risk management (Maidl and Buchecker 2015). To this aim, adequate conditions have to be established including sufficient resources, a supportive political context, as well as an appropriate legislative framework able to dynamically respond. Long-term efforts are required to build up preparedness capabilities in local communities. Hence, real involvement and a good balance between institutional and individual responsibility has to be achieved (Scolobig et al. 2015). Social media as well as citizen science offer new potentials to involve the public more closely (Prior and Roth 2019).

Despite their potential, participatory and integrative processes are not yet at the forefront to enhance disaster preparedness. Hazard and risk communication in a natural hazard context is traditionally still top-down oriented. Whereas participatory approaches are assumed to be more effective they are also more cost-intensive. In contrast, top-down measures leave more responsibility on an institutional level but unburden the individual. Which strategy suits best depends on the aims of the communication effort as well as on the target groups. In case of an immediate crisis, top-down approaches may be more efficient. On the contrary, to develop preparedness measures, participatory or integrative processes could be more promising. Never mind the approach selected, to be legitimate needs to be designed responsibly, transparently, and accurately. And when deciding for a participatory approach, it has to be ensured that all relevant stakeholders are actually involved and not only presumed to be so.

9.2.5 Use the moment

Using the moment is not an invention, but an opportunity often missed. Just after an event, when people are still alert, aware of the threat, and interested in minimizing future damage, information ready to address these concerns can be particularly impactful. Using the so-called "window of opportunity" is a possibility to trigger engagement (Nathe 2000). "In sum, a large proportion of respondents do nothing or very little to adjust to seismic hazards, and when they do take action, it is significantly more likely to be response and recovery-related than mitigative" (Solberg et al. 2010, p. 1664). For example, many homeowners purchase an earthquake insurance after having experienced an event and cancel it if nothing has happened for several years (Kunreuther 2002). Disaster experience also enhances people's willingness to become engaged in a participatory manner (Becker et al. 2017). Having information material ready for the aftermath of an event can support communities to improve their disaster preparedness.

9.2.6 Team up

Multi-hazard platforms offer a new opportunity to distribute preparedness and disaster information (Perez-Fuentes et al. 2016). Combining relevant information for different hazards in one place has the advantage of a single access point. Some recommendations are also valid for more than one hazard (e.g. having food supplies) and can be promoted jointly. To this end, different authorities need to closely collaborate, which is not a simple task. Combining hazard information potentially also enhances complexity and thus detains access to some user groups. In addition, multi-hazard information is usually available on websites or via mobile apps, channels not equally accessed by different age groups. The "Sendai Framework for Disaster Risk Reduction" hence calls for multi-hazard approaches which are multi-sectoral and inclusive (United Nations 2015). Up to date, a growing number of platforms follow such an approach and further research is needed to assess how best to communicate preparedness from a multi-hazard perspective (Verrucci et al. 2016).

It is also important to take up a holistic perspective when thinking about natural hazard management. Often enough, communication efforts are not closely related to other activities. Using synergies between different interventions could save resources and enhance their impact. The same is true for multidisciplinary collaboration (Rickard 2019). People with different expertise, backgrounds, and experiences are advantageous to advance risk management and design effective communication measures. Of course, such cooperation, maybe even on a transdisciplinary level, brings new challenges with it (Fischhoff 2011).

An important pillar for being able to create and maintain such content and activities are trained professionals. Besides knowledgeable scientists, dedicated communication experts, managers, developers, and designers are required. A study found that communication professionals were only involved in one third of message development processes (GeoHazards International 2018), certainly a number that could be improved.

9.2.7 Reward your target groups

Not studied in the context of this thesis and generally not much discussed in the field are incentives to enhance natural hazard preparedness. Especially on an individual level, action taking could be supported by providing grants, insurance reductions, or tax savings (Eiser et al. 2012). Action taking could also be rewarded by emphasizing it on social platforms or on specific apps (Verrucci et al. 2016). Complementary, influencers could advocate preparedness measures and share them with their community. Of course, this is not only a potential for the virtual world, but also for multipliers sharing their insights within their unions or associations who merely remain in contact in the real world.

9.3 Remaining research gaps

With two examples (cf. Sections 5 and 6), this thesis demonstrates how existing evidence can be successfully applied and tested for seismic hazard communication, thus filling crucial research gaps in the field. However, as emphasized particularly in the third contribution (Section 7), the remaining research gaps are striking. In order to counter the aforementioned complexity of natural hazard communication, resilient evidence is required. Natural hazard communication is subject to continuous change triggered by technological and scientific advancements, evolving formats, changing user needs, and available evidence. This constantly generates new research questions which need to be answered. Major research potential is seen in the following areas.

9.3.1 Conceptualization and evaluation

What seems obvious, is often not a standard in the field of natural hazard communication: one needs to know its goals for being able to design effective communication measures. Many communication efforts lack or have not documented a comprehensive strategy defining their aims. Hence, it has to be assumed that best practices in other fields are often not considered (Verrucci et al. 2016). In consequence, it becomes impossible to design sound communication measures and effective evaluations. Additional research is required to better understand what institutions aim for and the processes applied to design corresponding communication measures. Based on such an advanced understanding, recommendations can be established to define optimal institutional set-ups allowing for communication measures to be implemented in the best possible way to support risk management. Currently, risk communication in a natural hazard context is too often judged as an inferior tool serving higher-ranking purposes and is thus not recognized as a discrete element of risk management (Khan et al. 2017).

Besides clear goals, solid evaluations of upcoming and existing communication measures are indispensable to improve strategic decision taking. As already emphasized previously, there is a general dearth of empirical evidence making it difficult to learn from past experiences. Standards need to be developed to conduct evaluations and to this end dedicated research efforts are required. Currently, the small number of evaluations conducted to analyze communication campaigns in a natural hazard context is usually based on small or biased samples and reflects real-world conditions only on a limited basis. More research should be conducted reflecting actual communication environments as much as possible, including field experiments, and studying large data sets (Leshner et al. 2017).

9.3.2 User needs

User behaviors change; in daily life and in crisis situations. Users are constantly exploring new channels and platforms to access preparedness and event information. To this end, trends in user behavior and platform development need to be monitored. Organizations establishing a virtual presence on upcoming channels or platforms have to understand their modus operandi and adapt their messages accordingly. Only then can trust be built in the respective community. For example, despite social media being slow in gaining relevance for hazard and risk communication, the increased use of mobile phones and apps is already a reality. Such developments cannot be ignored as they generate new claims such as mobile-friendly access. As shown in this thesis, participants have for example also very high expectations with regard to mapping tools (see Section 5). To make allowances for changing user behaviors, their media use needs to be analyzed and subsequently adequate formats must be developed and tested.

Although natural hazard information is widely available and respective warnings are commonly distributed, there is almost no evidence about the public's information expectations in an extraordinary risk situation (Government Office for Science 2011). "Curiously enough, hardly any research seems to have investigated what kind of information people desire when they are confronted with an unknown risk, although this question would seem to be particularly important in effectively communicating about risks" (Lion, Meertens, and Bot 2002, p. 765). Not knowing how people understand and interpret natural hazard information can lead to an aggravation of an already critical situation (Bean et al. 2015).

The constant flow and availability of information leads to an enormous number of competing messages, making it challenging for the recipients to process it and for authorities to reach its audience. In times of fake news, there is also a real threat of disinformation that needs to be considered and studied (Leshner et al. 2017). In particular, false aftershock predications have recently triggered social mistrust and raised anxiety. Public institutions need to develop strategies to counter such misleading campaigns in times of distress (Wein et al. 2016). Up to now, little is known about how to best guide users through the information wealth and elaborated strategies to handle disinformation.

Besides preferences for channels and formats, to be effective, preparedness information needs to be where people can and want to access it. Currently, it primarily reaches those who are already well prepared. This leads to the assumption that the others either have no access, do not receive the information they want (Donahue et al. 2014), or lack motivation to act upon it. Participatory approaches, personalization, rewards, or strengthening social capital are previously discussed options to reach currently uninvolved members of a society. However, profound evidence and established practices are missing and need to be explored first (Egbelakin et al. 2011; Levac et al. 2012; Scolobig et al. 2015). The same applies for the ethical concerns such approaches may violate and related privacy issues (Bean et al. 2015; Leshner et al. 2017; Lindsay 2011).

9.3.3 Message design

Additional research is needed to better understand how to best compile preparedness and warning messages. Besides considering user needs and adapting formats accordingly, visuals and texts play an important role in message design.

Although visuals are a common element of preparedness and event information, the effect they have on their comprehensibility and impact is only poorly understood. "Given the dearth of research on visuals such as maps for disaster communication, much more research is needed to clarify the potential impacts of visuals on publics' decision making across a variety of disaster types" (Liu et al. 2017, p. 503). Whereas this thesis meaningfully contributes to a better understanding and improved design of seismic hazard maps, the use of other, maybe

more suitable visuals such as infographics remains largely unexplored (Spiegelhalter et al. 2011).

The second contribution of this thesis clearly demonstrates that affects can play a significant role in message design. Additional investigations are essential to gain a better understanding on how affects and emotions influence information processing. Besides textual elements, the impact visuals such as maps have on emotional responses should be explored (Liu et al. 2017).

Future technological and scientific advancements will allow to allocate more comprehensive seismic hazard and risk information more rapidly. Current developments in the field of operational earthquake forecasting, earthquake early warning, or rapid loss assessments point into this direction. Despite respectable scientific and technological advancements and first implementations only little is known about their societal impact. Additional research is required to comprehend how source, channel, and message design interact to influence information reception, attitudes, credibility, or decision taking (Mayhorn and McLaughlin 2014). A better understanding is needed on how people make use of such information and what emotions, behaviors, and responses they trigger. In particular, the future availability of seismic risk models for larger areas demand for targeted and proved communication measures. Only in such cases may societies use this new resource meaningfully to improve preparedness and resilience.

Another unexplored field related to technical and scientific advancements is the personalization of messages. Future developments will allow to increasingly individualize preparedness and warning information. However, it has to be assessed to which level such a personalization is useful and enhances action taking without confusing users through varying recommendations.

Technical progress has also led to so called multi-hazard platforms, combining different hazard information about threats on a single website or mobile app. They conform to the often requested user need for a combined access to relevant information (econcept 2011). However, they also enhance complexity, as different hazards with varying characteristic have to be depicted and explained in a standardized manner. Despite their recent popularity, no research has been conducted evaluating their usefulness and effectiveness.

9.4 Do not believe in magic

There is and will never be a bullet-proof approach to enhance people's preparedness and resilience for natural hazards in general and earthquakes in particular, mainly because natural hazard preparedness is complex involving various stakeholders and measures. For example, the best behavior to adopt when the Earth starts to shake is not easy to determine, not even from a technical perspective (GeoHazards International 2018). Such insecurities additionally challenge the design and implementation of adequate communication measures.

Currently, the research on how to best translate available knowledge, including its shortcomings, into something people can act on is in a very immature state. The findings of this thesis bring light to some areas, but are limited in many other ways. To prevent a further deviation between elaborated risk and hazard assessments and poor individual disaster response, significant efforts need to be taken to better allow people to take informed decisions. Without aligned communication measures to enhance the societal response, the potential of technical advancements to further improve resilience is very limited (Maidl and Buchecker 2015).

The future of disaster risk management will bring both, new opportunities as well as challenges. Thus an integral approach linking knowledge, technology, and people has to be pursued. To this aim, dedicated resources, additional research, and a close collaboration of various professionals as well with society are required.

10. LITERATURE

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