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Communicating Hazard Location through Text and Map in Earthquake Early Warnings: A Mixed Methods Study

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Communicating Hazard Location through Text and Map in Earthquake Early Warnings: A Mixed Methods Study

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ABSTRACT

The purpose of this research was to examine the effect of presenting hazard location in different formats on key warning message outcomes—understanding, personalizing, believing, deciding, and milling. We conducted two studies using experiment and focus group methods. In the experiment, we compared a standard ShakeAlert earthquake early warning message, which merely implied location, to three enhanced messages that communicated information about the earthquake epicenter via text, map, or a combined text-and-map format. Focus groups explored reactions to warning messages accompanied by different types of maps. Overall, the standard ShakeAlert message was associated with worse message outcomes compared to messages that explicitly stated the hazard location; communicating hazard location via text was associated with better message outcomes than the map or combined text-and-map format. Although participants preferred the combination text-and-map format, the text format was associated with significantly better message outcomes. Findings revealed that providing specific hazard location information leads to improvements in message outcomes; however, the format in which the information is communicated via text is the best strategy.

KEYWORDS: *Earthquake Early Warning; Message Specificity; Wireless Emergency Alerts (WEA)*

INTRODUCTION

Earthquake early warnings (EEWs) are short. When delivered to the three U.S. states that are currently capable of issuing and receiving ShakeAlert-powered Wireless Emergency Alerts (WEA), California, Oregon, and Washington, EEWs are limited to 90 characters in length and inform message receivers that an earthquake has been detected, they should take protective action, and they should do it immediately.

Prior WEA research (Bean et al. 2015) has shown that message receivers want, and need, more information than that contained in a 90-character hazard message. For earthquakes, there is a specific desire to be alerted about the location of the earthquake epicenter, the potential intensity of the shaking, and the time by which the shaking might occur (Sutton and Wood 2021, May). Where an earthquake originates relative to the message receiver is directly related to the intensity of shaking that they might feel (strongest near the epicenter) and the length of time that may pass before they experience shaking (longer time further from the epicenter). Presenting specific location to the message receiver has the potential to increase understanding of the threat and its consequences (Liu et al. 2017), personalize the threat (Kumar et al. 2016), and possibly motivate protective action more quickly (Mileti and Sorensen 1990).

While ShakeAlert technology does not currently have the capability to communicate earthquake information with this level of specificity, that is, first determine the location of the epicenter and the anticipated shaking intensity and then deliver the information to message receivers prior to felt shaking, it may be able to do so in the future. Furthermore, some existing alerting channels already have the potential to provide this kind of content in various forms such as by determining the message receivers' location relative to the epicenter (Spooner 2021, April 28). In 2016, the Federal Communications Commission (FCC) required future WEAs to support embedded URLs with the possibility of linking to maps or geographic information systems (FCC, 2016). More recently, the FCC Communications Security, Reliability, and Interoperability Council (CSRIC) has advocated for the capability to include maps as part of warning messages (personal communication, Mike Gerber, CSRIC Chair, NOAA, 2022). Notably, one of the foremost experts on alerts and warnings, Dr. Dennis Mileti, suggested that "information enhancements" in the form of "risk personalization visualizations," such as maps, may impact protective action information behavior the most in the future (Mileti 2018). Therefore, how additional location specificity is communicated, be it in the message format, the content included, or the presentation style, the role of providing location specificity in EEWs is an important research question for the present and the future.

In this study we investigated how the inclusion of earthquake location specificity affects message perception outcomes. We manipulated the message structure to include location-specific content communicated in two formats: text and cartographic or "map." We conducted an online experiment, collected ranked preferences and open-ended explanations for rank ordering, and facilitated focus group discussions. Our research demonstrates that the inclusion of specific information about the location of the earthquake epicenter does improve message perception outcomes, but only when it is presented in a written "text" format. These findings provide insight into the effect of communicating risk via maps for imminent threat hazards. Furthermore, findings from this research can inform the design of EEW warning apps and other messaging platforms.

Literature

Prior research on warning messages has emphasized the importance of message *content*, that is, what is said, as well as *style*, or how it is said (Mileti and Sorensen 1990). Message *format*, or mode of content presentation, and message *structure* have received less attention. Message "content" refers to the information topics communicated. Research has found that messages that contain high levels of guidance (i.e., are highly instructional) result in increased knowledge and efficacy (Frisby et al. 2014). Compared to other key warning message content, the description of the hazard and the recommended protective actions have been identified as the most important drivers of warning outcomes (Bean et al. 2015, December; Wood et al. 2015, August). Message "style" refers to how content is communicated, that is, its level of certainty, consistency, completeness, and specificity. Style affects content presentation through the use of: 1) textual devices (e.g., using all-capital lettering and italics to emphasize words), 2) type of statement (declarative, imperative, interrogative, exclamatory), 3) abbreviations (acronyms and labels), and 4) design features (e.g., font type, font size, shapes, color, symbols, dynamic or static visualization) (Shen and Bigsby 2012). Message "format" or presentation mode includes presenting warning content via printed text, audio recording, graphic, or cartographic image, for example (Lindell 2020). Finally, message "structure" consists of the way in which these elements are organized and arranged (Shen and Bigsby 2012; Sutton et al. 2021).

In the risk communication and hazard warnings literature, a focus has been placed on the written text elements of mobile warnings, which has predominated efforts to improve warning design (Lindell 2018). In prioritizing written text elements, less attention has been placed on graphic, maps, or other formats of messages communicating risk information (Bostrom et al. 2008; Lindell 2020; Lindell et al. 2021). This difference in emphasis becomes increasingly important as researchers study the role of message specificity, one of the key factors identified to increase message perception outcomes that are associated with protective action behaviors (Sutton and Woods 2016). Message specificity has been described largely in reference to the style of textual message content; the *format* in which this more specific information is presented—as text, graphic, or cartographic content—has not yet been explored.

Communicating the location of a threat, the geographic area of impact, and the populations most at risk is a primary objective of a warning message. Effectively communicating such content may affect message comprehension (Liu et al. 2017) as well as perception of personal risk, thereby motivating protective action (Kumar et al. 2016). Hazard maps identify the location of the hazard and the location of impact by linking risk to geographical locations and populations in a visual format (Carpignano et al. 2009; Roth et al. 2017) and by indicating who should and should not take protective actions (Bean et al. 2015; Bonaretti and Fischer-Pressler 2021). Furthermore, the inclusion of appropriately designed maps, can improve comprehension of personal distance from a threat and the direction or movement of a threat (Cao et al. 2016; Cao et al. 2017). Absent instructional or personally orientating cues, however, viewers must infer their risk by locating their positions on the map (Jaenichen 2017). In some cases, researchers have found that message receivers experience significant challenges interpreting maps (Arlikatti et al. 2006; Lindell 2020; Zhang et al. 2004), as well as map compasses and scales (MacPherson-Krutsky et al. 2020). Furthermore, map interpretation has been used to justify decisions to disregard recommended protective actions (Wood et al. 2018), contributing to undesirable outcomes (see Bean 2019, p. 31).

Research on the textual presentation of location information in short messages is limited (Casteel and Downing 2016). Risk communicators regularly use familiar landmarks as referent points, highways, and mile markers to specify boundaries, or the names of cities, counties, and regions to generalize the area of threat. However, when Bonaretti & Fischer-Pressler (2021) studied university student responses to short messages presenting hazard location content in text format using building and street names, they found that students struggled to accurately identify the location of the emergency event. Importantly, this inability to locate themselves hindered their successful compliance with recommendations even when the intention to comply was high. Similar results were found for members of the public in response to a simulated warning for severe flooding; location information must be clearly stated and easily understood if a warning is to be effective (Smith et al. 2022).

Importantly, researchers have also found that persons under heightened stress have a limited capacity for information processing, described as information, or cognitive, overload (Misra et al. 2020; Misra and Stokols 2012). Even under the best conditions, information processing requires sufficient attention to encode, store, and retrieve relevant content (Lang 2000), which is made more difficult for those who lack the skills necessary for map reading (Jaenichen and Schandler 2017) such as interpreting colors, textures, and symbols and determining the orientation of the map to physical space. Indeed, Liu and colleagues (2017) found that the impact of maps on decision clarity, compliance, and message sharing were consistently small and lacking practical significance.

The Warning Response Model

The Warning-Response Model was initially articulated by Mileti and Sorensen in a report synthesizing early social science research on risk communication in warnings (Mileti and Sorensen 1990). The model focuses on the effect of message content, style, and social context on how individuals respond to alert and warning messages. The central notion of the framework is that messages can be designed in ways that alter individuals' perceptions of the pending threat, thereby influencing the ways in which, and how quickly, they respond.

Warning content. Mileti and Sorensen documented five key content topics appearing in the social science literature that when included in warning messages, motivate people to take timely and appropriate protective action. These five content topics, along with citations to more recent work building on the core topical areas, are: (1) the *hazard* and its expected consequences (Drabek 1999; Mallett et al. 1993; Wray et al. 2008); (2) recommended protective action *guidance* (Drabek 1999; Sorensen 1991); (3) hazard *location* (Drabek 1999; Mileti and Fitzpatrick 1992); (4) the *time* by which the public should begin taking the protective action as well as the time by which taking the protective action should be completed (Sorensen et al. 2004); and (5) the message *source* or sender (Sellnow et al. 2012; Vihalemm et al. 2012; Wray et al. 2008). Mileti later distinguished hazard *consequences* from *how protective actions reduce consequences*, and noted the importance of also including message *expiration time* (Mileti 2018). These five original elements were incorporated in the design of the U.S. Common Alerting Protocol and provided the foundation for the structure of the nation's automated WEA messages (Wood 2017). In a WEA message, however, time refers to the time the message expires (Botterell 2003).

Warning response. The Warning-Response Model focuses on individual perceptions and social interactions that occur in response to receiving a warning message (i.e., message outcomes). According to the model, when a warning message is received and attended to, individuals must *understand* the message content, *believe* the information is true, *personalize* the message by identifying as a member of the intended audience and at risk; and *decide* what course of action to take in response. To complete this process, people search for information to confirm what they understand, believe, personalize, and decide to do in response to the message in a process described as "*milling*" (Wood et al. 2018). Time spent milling can be understood as warning response delay.

Purpose

The purpose of this research was to examine the effect of varied presentation of location information on Mileti and Sorensen's warning message outcomes: understanding, personalizing, believing, deciding, and milling.

Research Questions and Hypotheses

Quantitative (experiment) and qualitative (focus group) data were used to answer the following research questions:

RQ1. *"Is the inclusion of specific hazard location information positively associated with better message perception outcomes?"*

RQ2. "What is the best format for presenting hazard location in earthquake early warnings messages—text, a map, or both?"

The experiment tested the following hypotheses:

H1. The "standard" ShakeAlert EEW message, which does not specify hazard location, will be associated with worse message outcomes than messages that include specific hazard location.

H2. Communicating hazard location in a text format will be associated with better message outcomes than communicating in a map format.

H3. Communicating hazard location via a combination of text and a map will be associated with worse message outcomes than communicating via either format alone.

GENERAL METHOD

We conducted two studies using multiple methods to investigate how the presentation of earthquake location information affects message perception outcomes. In the first study we compared a standard ShakeAlert Earthquake Early Warning message to enhanced messages that included specific information about the hazard location (i.e., earthquake epicenter). In the second study, we investigated preferences for how location information is presented. Specifically, we conducted: 1) an online experiment that tested four message conditions, which varied in *format*, and 2) two focus groups examining reactions to four messages, which varied in *style*. In the experiment, we varied the way in which location information is provided, either via text, a map, or using both formats. We also presented the messages side-by-side, and asked participants to rank order them based on their perceptions of the messages' ability to motivate warning response and to provide an explanation of their rank ordering (open-ended). In the focus groups, we varied the way in which location information is presented using

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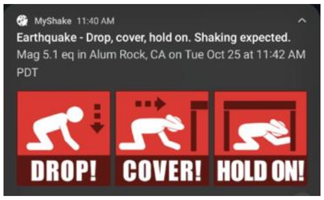
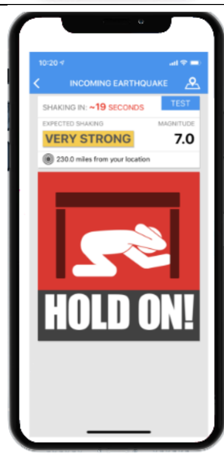
visual elements including icons, color, and animation on a map. We collected and independently analyzed both quantitative and qualitative data and then triangulated the findings. The California State University Fullerton Institutional Review Board reviewed and approved the research protocol (HSR-21-22-117, 10-25-2021).

Stimuli

As described above, prior research has identified increased message specificity as one factor that will reduce milling. Currently, location information contained in EEW messages delivered over any mobile application is broad and non-specific (see Figure 1). In the U.S. there are four primary mobile alerts: Wireless Emergency Alerts (limited to 90 characters) the QuakeAlert and MyShake apps, and the Earthquake Alerts System on Android devices. Each of these utilize the USGS ShakeAlert system for detection and notification domestically. Of these apps, three provide location information on the alert screen (QuakeAlert, MyShake, and Android), referencing the distance the message receiver is from the earthquake epicenter. Notably, Android also utilizes sensors within each phone sensors where there is no ground network of seismometers, allowing them to provide earthquake early warnings internationally. For this project, the research team endeavored to investigate the effect of specifying the earthquake location in an EEW message on message perception outcomes. While current messages delivered via WEA do not specify the location of expected shaking, as noted above, future iterations of the ShakeAlert system may make this possible.

Figure 1. Earthquake Early Warning messaging available in the U.S.

System/ Application	Screen Image	Text	Icons	Location of Impact	Magnitude	Time
Wireless Emergency Alert (WEA)		Earthquake Detected! Drop, Cover, Hold On. Protect Yourself. – USGS ShakeAlert	No	No	No	No

MyShake (UC Berkeley Seismology Lab)		Earthquake - Drop, cover, hold on. Shaking expected. Mag [X.X] eq in [city/state] on [date] at [time]	Yes	Yes	Yes	Yes
Android Earthquake Alerts System (Google)		Earthquake Estimated magnitude [X.X] XX miles away. Drop Cover Hold	Yes	Yes	Yes	No
QuakeAlert USA (Early Warning Labs)		Incoming Earthquake Shaking in [Seconds] Expected shaking [description] Magnitude [X.X] [Distance in miles] from your location.	Yes	Yes	Yes + Intensity	Yes

The research team developed the stimuli for the experiment and focus groups and the United States Geological Study (USGS) Social Science Working Group (SSWG) for the ShakeAlert Joint Committee for Communication, Education, and Outreach (JCCEO) reviewed the messages and provided feedback, which was incorporated in the final versions we tested. We selected colors in accordance with Web Content Accessibility Guidelines (WCAG) to increase accessibility by meeting a 4.5:1 contrast ratio between foreground and background colors (The World Wide Web Consortium - W3C 2008). We used an icon representing the earthquake epicenter based on images found on a seismogram, which visually represent P-wave, S-wave, and surface waves as jagged lines recording movement.

STUDY I - EXPERIMENT

Method

We conducted the online experiment via Qualtrics online software using a post-test only, between groups, design.

Sample

We recruited a volunteer sample (*N*=489) for the experiment by email via a Qualtrics online study panel. We established eligibility requirements ensuring that participants would be at least 18 years of age, speak English, and live in one of three states with ShakeAlert service (California, Oregon, or Washington); we used quotas to approximate population proportion from each state and to ensure a general balance in terms of gender and age category, with some representation across different race/ethnicity groups. Power analysis (Power=.80, alpha=.05) for one-way ANOVA) using G*Power software assumed a small-to-medium effect (*f*=.175) and determined a minimum sample size of *N*=360. Participant characteristics are presented in Table 1.

Table 1. Experiment participant characteristics (*N*=489)

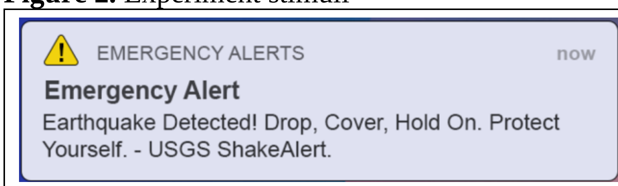
Characteristic	*n*	%
Sex		
Male	193	40
Female	291	59
Other/Decline	5	1
Hispanic, Latino		
Yes	70	14
No	419	86
Race/ethnicity		
African American	28	6
American Indian/Alaskan Native	17	4
Middle Eastern	0	0
Pacific Islander	6	1
East Asian	22	5
South Asian	11	2
Southeast Asian	11	2
White	345	71
Other	7	1
Age		

18-29 years	105	22
30-49 years	149	31
50-69 years	136	28
70+ years	99	20
State of residence		
California	352	72
Oregon	63	13
Washington	74	15

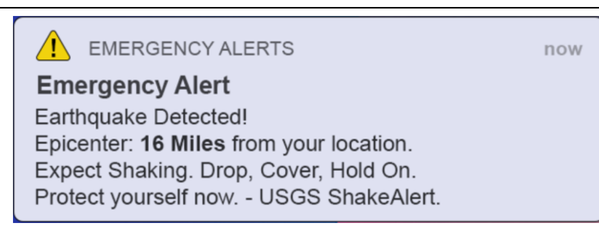
Stimuli

We compared a “standard” ShakeAlert EEW message to three “enhanced” messages that specified hazard location (i.e., earthquake epicenter) via different formats (Figure 2). The standard ShakeAlert EEW message served as the control (Message 1), and the three enhanced messages specified the hazard location via text (Message 2), a map (Message 3), and both text and map (Message 4). In Message 1, hazard location was merely implied. In Message 2, the receiver’s proximity to the epicenter (i.e., number of miles) was added to the standard message in bold *text* to specify hazard location. In Message 3, we added a *map* to the standard message to specify hazard location. The map included the location of the message receiver with a pin labeled “YOU,” representing an egocentric perspective of the environment (Lindell 2020), as well as an icon representing the earthquake epicenter. The message was both allocentric and dynamic in that it communicated the path of the earthquake from the epicenter in concentric shaded rings. In Message 4, we added the enhanced elements of Messages 2 and 3 to the standard message, communicating hazard location via both *text and a map*.

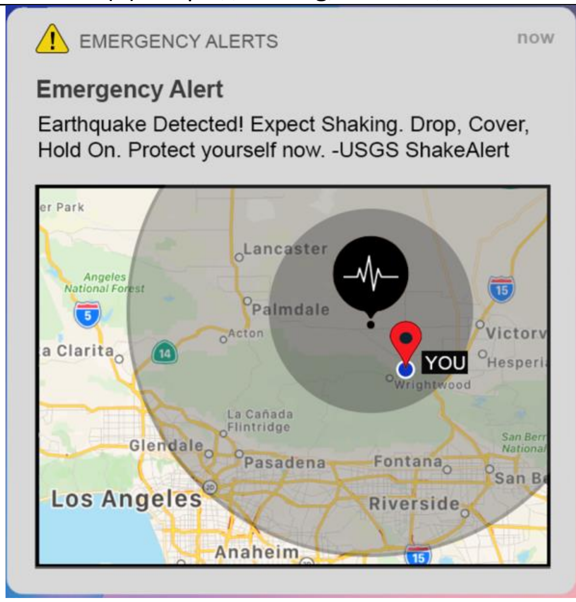
Figure 2. Experiment stimuli



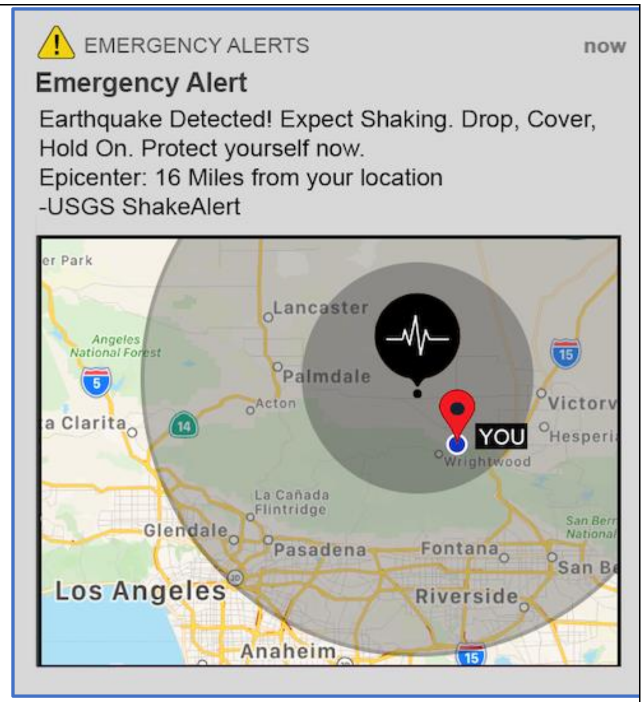
Message 1.
Standard message (location implied)



Message 2.
Location specified via text



Message 3.
Location specified via map



Message 4.
Location specified via text and map

Measures

The research team developed the experiment questionnaire based on our theoretical framework. The independent variable was message condition, which varied by format; the dependent variables were key outcomes of the warning response model: understanding, belief, personalizing, milling, and deciding. We developed most constructs based on key literature (Gutteling 1993; Lindell and Perry 2012; Mileti and Sorensen 1990; Sutton et al. 2018; Wood et al. 2018). Wording of questionnaire items for key constructs is included in Figure 3. We constructed mean scales with items measured on a 1-5 Likert-type scale ranging from "strongly disagree" to "strongly agree." Milling (response delay) was computed as an index; those who reported they would immediately take protective action scored a 1 (less delay), those who reported they would check on others or wait to feel shaking before taking action scored a 2, those who reported they would wait for both scored a 3, and those who reported they would ignore the message and not take action scored a 4 (more delay). The research team pretested the questionnaire internally, sought feedback from colleagues in the USGS SSWG, and pilot-tested the revised questionnaire prior to use. The experiment took roughly 15 minutes to complete (*M*=15.5, *SD*=11.4).

Figure 3. Experiment outcome measures

Understanding. *After viewing this warning message, I understand…*
1. What is happening.
2. The risks.
3. What to do to protect myself.
4. What location is affected.
5. Who the message is from.
6. When I am supposed to take action to protect myself.
7. How long I am supposed to continue taking action to protect myself.

Belief. *After viewing this warning message, I believe that…*
1. The earthquake is heading my way.
2. The message is trustworthy.
3. I know when I will be in danger.
4. I should take action to protect myself.
5. Taking protective action will make me safer.

Personalizing. *After viewing this warning message, I think that…*
1. I might become injured.
2. People I know might become injured.
3. People I do not know might become injured.
4. I might die.
5. People I know might die.
6. People I do not know might die.

Deciding. *After viewing this warning message, I believe that…*
1. It will be easy to decide what to do.
2. I will be able to decide what to do quickly.
3. I can decide what to do with confidence.

Milling. *If you received this message, how do you think you would respond?*
1. Immediately protect myself from the earthquake.
2. Check in with others before protecting myself from the earthquake.
3. Wait to feel shaking before protecting myself from the earthquake.
4. Do nothing to protect myself from the earthquake.

Procedure

We recruited the volunteer sample via a Qualtrics participant panel; respondents elected to participate by clicking a hyperlink included in the invitation email. After participants read about the study and provided informed consent, they were randomized to condition. The online questionnaire presented one of the four EEW messages (i.e., random assignment), and then asked questions measuring outcomes. Next, the questionnaire presented all four messages tested in the experiment side-by-side, and asked participants to rank order them based on their perception of how well the messages would motivate protective action and to explain their choice (open-ended). Finally, the questionnaire asked about their background. As a participation incentive, Qualtrics provided respondents points with a small cash-value (approximately $4) for use toward gifts, travel, and other products.

Analysis

We computed composite scores for each outcome. We calculated Cronbach's alpha to assess internal consistency for each of the four mean outcome scales—understanding (0.84), belief (0.86), personalizing (0.92), and deciding (0.92). The team determined that internal consistency was appropriate (Kline 2013). The milling construct was collected as an index, so internal consistency was not applicable for this outcome. We performed one-way ANOVA using SPSS software; all statistical assumptions for ANOVA were met. To test for differences between individual treatments, LSD (Least Significant Difference) post-hoc comparisons were performed. For the side-by-side message rankings, we calculated frequencies and mean rankings, and performed a Chi-Square Goodness-of-Fit test to test for differences in proportions. We performed an inductive thematic analysis on open-ended explanations. We interpreted statistical significance using conventional thresholds ($p < .001$, $p < .01$, $p < .05$) and note "borderline significance" where $p < .10$ (Tshikuka et al. 2016). We interpreted effect size magnitude (partial eta-squared) as 0.01 = "small", 0.06 = "medium", and 0.14 = "large" (Cohen 1988). In a public warning context, even small effect sizes can have large impacts when spread over populations and may translate to marked reductions in injury, mortality, and cost (Wood et al. 2018).

Study I Results

Univariate statistics for warning response outcomes (understanding, belief, personalizing, deciding, and milling) are presented in Table 2.

Table 2. Experiment univariate statistics: Message outcomes

		Understanding	Belief	Personalizing	Deciding	Milling
Condition	*n*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
1. Standard (control)	121	3.79 (.85)	4.09 (.85)	3.70 (.97)	3.66 (1.13)	1.41 (.54)
2. Standard, Text	113	4.04 (.79)	4.14 (.82)	3.80 (.89)	4.04 (1.00)	1.43 (.71)
3. Standard, Map	142	3.81 (.82)	4.07 (.81)	3.58 (.97)	3.85 (1.01)	1.48 (.64)
4. Standard, Text, Map	113	3.96 (.75)	4.06 (.82)	3.48 (.91)	3.79 (1.01)	1.42 (.64)
Total	489	3.89 (.81)	4.09 (.82)	3.64 (.94)	3.83 (1.04)	1.44 (.63)

Note: Higher scores indicate better outcomes than lower scores for understanding, belief, personalizing, and deciding; lower scores indicate better outcomes than higher scores for milling.

We compared the three enhanced messages using different formats for communicating hazard location (i.e., earthquake epicenter) to a standard ShakeAlert message, in which hazard location was merely implied. One-way ANOVA results indicated significant differences by condition in understanding (F(3, 485)=2.669, p=.047) and deciding (F(3, 485)=2.778 p=.041), with results approaching significance for personalizing (F(3, 485)=2.467, p=.061). There were no significant differences in belief or milling. (See Table 3.)

Table 3. Experiment ANOVA results: Effect of hazard location format on outcomes

Outcome	Type III Sum of Squares	Mean Square	*F* *(DF=3)*	Sig.	Partial Eta Squared
Understanding	5.170	1.723	2.669	**.047***	.016
Belief	0.460	0.153	0.226	.878	.001
Personalizing	6.545	2.182	2.467	**.061**†	.015
Deciding	8.955	2.985	2.778	**.041***	.017
Milling	0.369	0.123	0.307	.820	.002

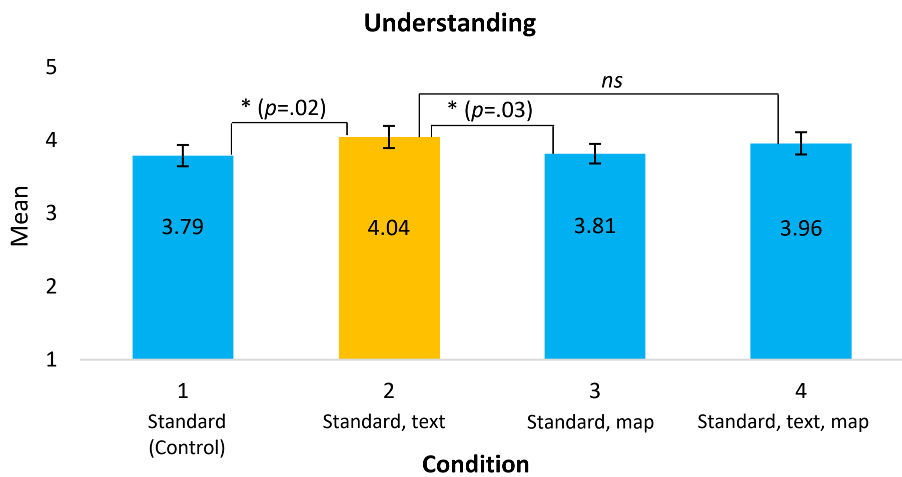
* p < .05; † .05 > p < .10, approaching significance

Understanding

Respondents who received Message 2 (the standard message plus hazard location communication via text) showed significantly greater levels of message understanding (M=4.04, SE=.076) compared to those who received Message 1 (the standard message with hazard location implied) (M=3.79, SE=.073;

p=.02) and Message 3 (the standard message plus hazard location communication via map) (*M*=3.82, *SE*=.067; *p*=.03). The overall effect size for this outcome (Partial η2=.016) is considered "small" (Cohen 1988).

Figure 4. Mean Understanding by experimental condition



Deciding

Respondents who received Message 2 (the standard message plus hazard location communication via text) showed significantly greater levels of deciding (*M*=4.04, *SE*=.098) compared to those who received Message 1 (the standard message with hazard location implied) (*M*=3.66, *SE*=.094; *p*=.005) and Message 4 (the standard message plus hazard location communication via text and map) (*M*=3.79, *SE*=.098; *p*=.07, approaching significance). The overall effect size for this outcome (Partial η2=.017) is considered "small" (Cohen 1988).

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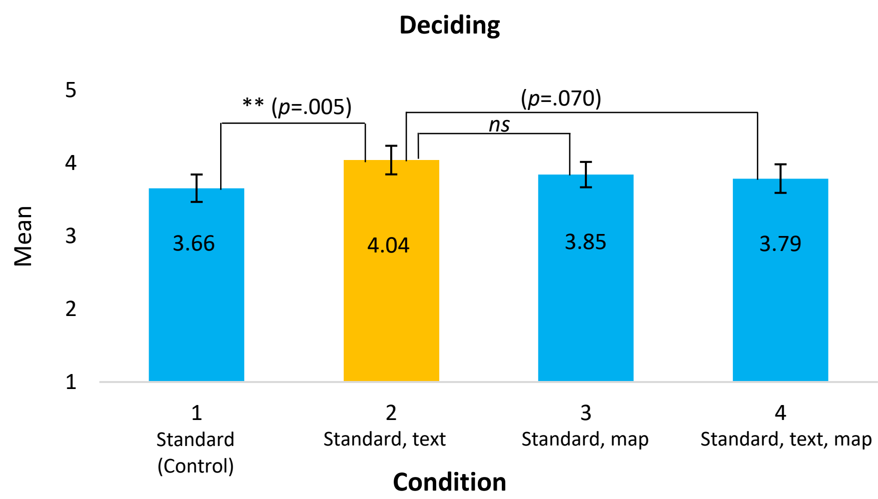
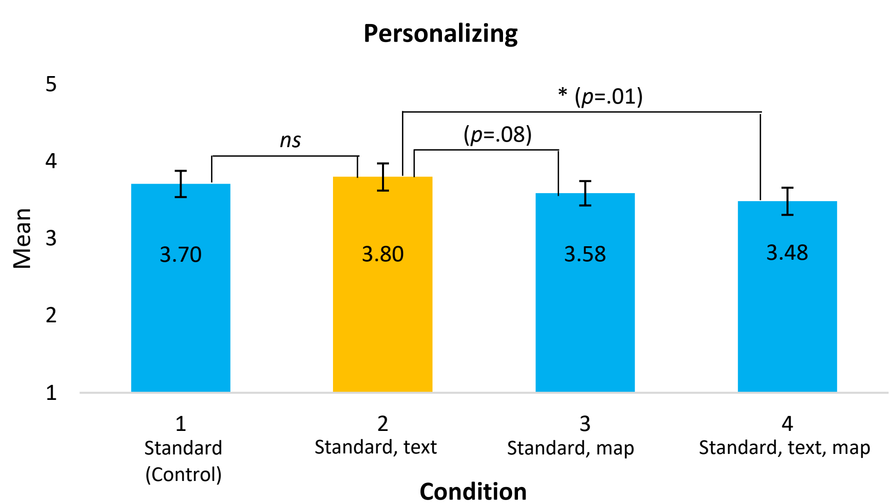
Figure 5. Mean Deciding by experimental condition



Personalizing

Respondents who received Message 2 (the standard message plus hazard location communication via text) showed significantly greater levels of personalizing (M=3.80, SE=.088) compared to those who received Message 4 (the standard message plus hazard location communication via text and map) (M=3.48, SE=.088; p=.01) and Message 3 (the standard message plus hazard location communication via map) (M=3.58, SE=.079; p=.08, approaching significance). The overall effect size for this outcome (Partial η2=.015) is considered "small" (Cohen 1988).

Figure 6. Mean Personalizing by experimental condition



Message ranking

The Chi-Square Goodness-of-Fit test indicated the most preferred message (highest ranked) was not equally distributed in the sample, X^2 (3, N = 489) = 278.40, p < .001. Message 4, the standard message plus hazard location communication via text and map, had the best mean ranking, and Message 1, the standard message with hazard location implied, had the worst (see Table 4).

Table 4. Frequency messages considered most able to motivate protective action (N=489)

Condition	*n*	%	Mean rank[1]
1. Standard (control)	55	11	3.22
2. Standard, Text	108	22	2.46
3. Standard, Map	47	10	2.54
4. Standard, Text, Map	279	57	1.78

[1] Participants ranked the messages from 1 to 4, with 1 (first place) indicating the best ranking (i.e., most effective) and 4 (last place) indicating the worst ranking (i.e., least effective).

Opposing preferences included a desire for messages providing more detailed information on one hand and the simplicity of short and concise messages on the other. Those who preferred Message 4 (the standard message plus hazard location communication via text and map) explained they liked the more detailed information provided by including the combination of a map as well as textual content about their proximity to the epicenter. Those who preferred Message 2, which included the standard message plus hazard location communication via text, stated they preferred this message to Message 4 because they found map distracting. In contrast, those who preferred Messages 1 (the standard message with hazard location implied) and 3 (the standard message plus hazard location communication via map) said that these messages were simple and concise in comparison with those that included the additional hazard location information in text format.

STUDY II - FOCUS GROUPS

In Study II, we conducted focus groups to investigate preferences across three warning messages. Each message included mapped location, but they varied in style. Study I and Study II were not sequential in nature; therefore, the focus groups did not endeavor to uncover additional thoughts about the experiment stimuli. Rather, we were interested in perceptions of varying style and design features, including the use of animation, colors, and personalizing markers.

Method

To explore participants' preferences among different methods of presenting specific hazard location using a map format, as well as their reasoning, we conducted virtual focus groups via Zoom videoconferencing with members of the public in November 2021. Focus groups are commonly used in disaster research to identify perceptions in response to a defined topic through interaction and discussion (see Peek and Fothergill 2009; Rivera 2021). The use of video-conferencing software allowed participants to join the group from multiple locations and allowed both video and audio recording of discussion. Notably, questions focusing on how to best communicate hazard location using a map was one subset of questions included in a larger study of earthquake early warning messages.

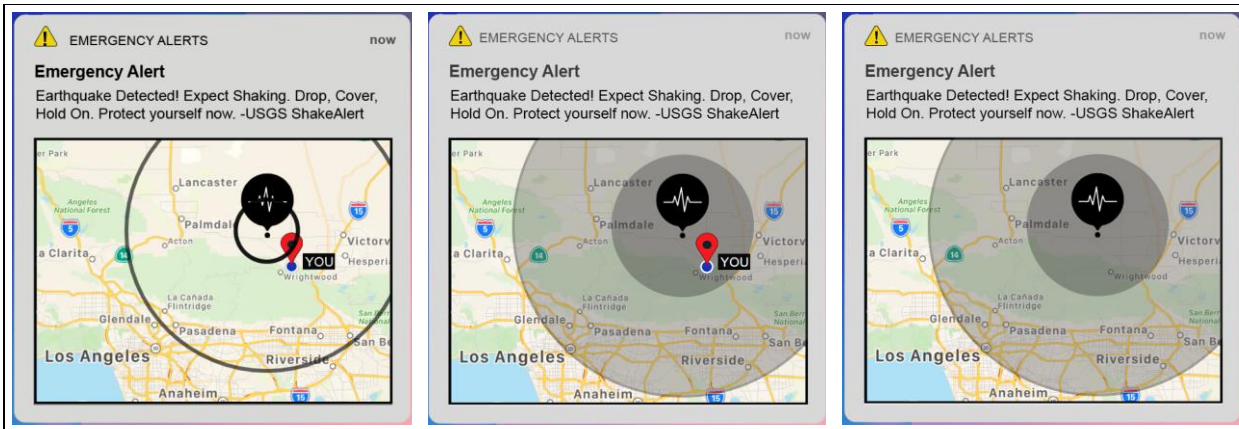
Sample

Participants were recruited via a Facebook advertisement posted to individuals in California, Oregon, and Washington—states that have active earthquake early warning delivered through various apps—as part of a larger study that investigated message specificity. Disaster researchers have used social media recruitment strategies to narrowly target populations that have experienced local events, allowing for self-selection of participants willing to talk about their experiences (see DeYoung et al. 2019; Mongold et al. 2021). In this case, we were interested in recruiting participants with all levels of prior earthquake experience in order to obtain perspectives from those with potentially high familiarity as well as limited or no familiarity with earthquakes. Eligible participants were 18 years of age or older and able to read and speak English. They were offered a $50 Amazon gift card for completing the interview. The two focus groups focusing on location specificity were conducted with 21 participants from Washington (n=13) and Oregon (n=8). (A total of 56 focus group participants were recruited for the complete study, with 16 representing the state of California. We report here only the findings from the groups discussing location specificity.) Of the 21 participants, about 43% identified as men (*n*=9) and 62% as women (*n*=13). Participant ages ranged from 18 years to over 65, with an average age of 50. Of participants who identified their race, 23% (*n*=5) identified as black or African American, 4% (*n*=1) identified as Asian, and 52% (*n*=11) identified as white (of this last group, one identified as Latino).

Stimuli

We compared three versions of a map that specified hazard location via different styles. All three messages use an atlas map, with location of the epicenter indicated by a point marked by a round black icon with the image of jagged lines in white, representing an earthquake seismogram. In Message 5 the hazard impact location is dynamic, shown by an animated series of rings that appear to be pulsing outward from the epicenter. In Message 6 the hazard impact location is static, depicted by a series of transparent grey-filled circles over the area of expected shaking where the darker color is closest to the epicenter and the lighter color is further away. Messages 5 and 6 indicate the location of the individual receiving the message, represented by a blue dot with a red location marker reading "YOU" in white font on a black background in all-capital letters. Message 7 replicates the style of Message 6 but does not include the location of the individual receiving the message.

Figure 7. Focus group stimuli



Message 5. Dynamic map with location maker

Message 6. Static map with location marker

Message 7. Static map without location marker

Procedure

Focus groups were conducted by a lead moderator while notes were taken by a focus group assistant. The entirety of each focus group lasted approximately one hour and was audio-recorded for transcription and analysis; time spent in discussion about the presentation of location specificity was approximately fifteen minutes in each group.

Focus group participants joined the Zoom call and began by reviewing the objectives of the focus group interviews with the moderator and then provided verbal informed consent, which allowed for audio recording. The moderator used the shared screen feature allowing group participants to view each message one-at-a-time and to provide their feedback about design features that "stood out" to them, provided helpful information, or left them with unanswered questions. After participants viewed and discussed each individual message, all three messages were viewed side-by-side, and participants were asked to rank them by preference while describing their reasons for the ranking. Throughout each focus group, participants muted and unmuted their microphones to talk and were asked to keep their video cameras turned on (some were unable to do so due to internet connection issues). The moderator called on individual participants to ensure that each participant shared their impressions and preferences for each message.

Analysis

Following the focus groups, transcriptions were checked for accuracy and notes from group assistants were reviewed to help identify emergent themes (Creswell and Poth 2016). Transcripts were then coded thematically. Thematic coding focused on comments about the style in which hazard location was presented (e.g., the use of shapes, color, icons, and animation) and how the presentation of information was perceived (positively or negatively) or thought to motivate action.

Study II Results

Focus group results along with exemplative quotes from participant discussion about communicating hazard location via different map styles follow.

Animated map

Message 5 presents the specific hazard location using animation to depict the area of impact. Participants explained that although the message animation attracted their attention, it was not clear whether the animation represented the movement of the earthquake, a cyclical or repeating movement, or some other dynamic activity. Participants also raised concerns about the data requirements needed to deliver an animated message with particular worry about the resulting "drag" on their mobile devices.

Static map

Messages 6 and 7 used grey circles to represent the hazard and areas of impact. The use of color again attracted viewer attention; however, the fact that no legend was provided within the message resulted in participants questioning how they should interpret the shades of grey. For example, one participant asked, "What do the circles mean? Is the light grey [representing] aftershocks?" Another participant interpreted the shading somewhat more accurately and replied by suggesting, "the colors seem to indicate levels of severity." In truth, the shading was intended to represent distance from the earthquake epicenter and the possible diminishment of shaking intensity as distance increased.

Use of icon to indicate hazard type

Across all three maps, participants asked about the meaning of the white jagged lines on the icon in the center of the map. This symbol was intended to represent an earthquake hazard (i.e., seismogram) and was "pinned" on the map to mark the earthquake epicenter. Because the symbol was unfamiliar to participants, it required interpretation on the part of message viewers and left them with questions and uncertainty.

Including personalized location information

In general, focus group participants preferred an allocentric map, that is, they preferred the focus to be placed on the hazard and not on their location. Some participants raised concerns about the need for location information to be turned on while another said, "I usually know where I am; I don't need the phone to tell me." A third participant, however, stated that the location pin in relation to the unfamiliar hazard icon prevented quick interpretation of the alert saying, "I have no idea what this means quickly. This could be showing me how close I am to McDonald's."

Preferences

Most participants preferred Message 7 (the static map without personalized information) to Messages 5 and 6. Nonetheless, many participants agreed they would have trouble interpreting Message 7. They reported it would take them time to decipher the meaning and the message would "only make sense if there's been training or prior exposure" to understand the icon, colors, and what they signified in relation to the text content. Considering these challenges, one person remarked, "I would prefer just the message [written in text]."

CONCLUSION

Hypothesis 1, "*The "standard" ShakeAlert EEW message, which does not specify hazard location, will be associated with worse message outcomes than messages that include specific hazard location*," was largely supported. Among all four messages, mean message understanding and deciding were lowest for the standard ShakeAlert message (Message 1), and were significantly lower than the message specifying hazard location via text format (Message 2); likewise, mean personalizing was lower for Message 1 than for Message 2, but this difference was not significant.

Hypothesis 2, "*Communicating hazard location in a text format will be associated with better message outcomes than communicating in a map format*," was largely supported, with the text format resulting in significantly better message outcomes for understanding, deciding, and personalizing. However, when we consider the ranking and open-ended comments for side-by-side comparisons all four conditions, we found that participants preferred the standard message with the added location text and map (Message 4) more than half the time (57%). The open-ended comments suggested that the additional information contained in the map would be useful for the message receiver because there was more content. This difference between the format that was preferred (combination text and map) and the format that led to better message outcomes (text alone) is noteworthy. While preference is important, how people actually respond in an emergency is likely the more important outcome.

Hypothesis 3, "*Communicating hazard location via a combination of text and a map will be associated with worse message outcomes than communicating via either format alone,*" was somewhat supported. Message 4, which communicated hazard location information in both text and map formats, resulted in a lower mean deciding and personalizing scores than Message 2, which communicated hazard location via text.

With regard to Research Question 1, *"Is the inclusion of specific hazard location information positively associated with better message perception outcomes?"* we found that including specific hazard location about the earthquake epicenter led to better message outcomes than did omitting location information, as is the case in the standard ShakeAlert message. For Research Question 2, *"What is the best format for presenting hazard location in earthquake early warnings messages—text, a map, or both?"* we found, at least in the case of earthquakes, where impact is expected within seconds, a text format for communicating specific hazard location information was more effective than a map format.

The focus groups provided useful insight about preferences among members of the public about how to communicate hazard location using maps. Here, participants preferred a map that was similar to the map used in the experiment, but that omitted their personal location information because of privacy concerns. Participants expressed confusion about the hazard icon due to its unfamiliarity. ANSI (American National Standards Institute) standards (National Electrical Manufacturers Association 2002) suggest that at least 80% of message receivers must understand the meaning of the icon for it to be used effectively (Wogalter et al. 2006). In this case, the icon, which was designed to represent the sudden jolt of earth movement as portrayed in a seismogram, may not have been a clear physical likeness (Wogalter et al. 2006). Participants also found the use of greyscale unclear. While color has been found to influence warning effectiveness in terms of behavioral compliance (Kalsher 2006), especially the use of red, which has a greater hazard association for most westernized people (Braun et al. 1994), grey was interpreted not as a threat to safety, but as potential amounts of shaking intensity or areas of impact. And finally, while animation can be visually appealing and capture the attention of message receivers (Wogalter 2006), when presented as part of the earthquake early warning, it was found to be distracting rather than engaging and informative.

Maps, if crafted well, have the potential to be instructive and/or to help message receivers to personalize information. In the case of extremely short-fuse hazards, like earthquakes, it may be that additional effort and time is required to interpret the visual information. Messages that state the location of the threat relative to the message receiver, using textual content, may reduce the cognitive load issues that are also likely to be heightened under conditions or imminent threat. The inclusion of a map, especially one that does not use a well-known icon to represent the hazard or provide a legend or other interpretive mechanism for the color-scheme, will require interpretation and may delay protective action. The development of a standard approach to communicating essential warning content using maps and graphics accompanied by education efforts to familiarize the public with the user “dashboard” may help overcome low map literacy skills and other challenges members of the public encounter when receiving imminent threat alerts and warnings.

What is important to note when we triangulate these findings is that while there appears to be a preference for a map, its inclusion does not improve outcomes but rather raises questions among message receivers. In other words, what people think they want in a message may not be what works best. If alerting authorities choose to heed public opinion and intuition over evidence-based guidelines, it may result in alerts that satisfy a desire for additional information while sacrificing message effectiveness. In a time-limited context, messages designed to increase location specificity must also be exceptionally clear in their presentation of that content.

Research has pointed to ‘problems that can arise in interpreting maps when the user is under time pressure, such as during emergency situations (Liu et al. 2017); however, maps can also support public protective action decision making by improving risk perception. Arguably, earthquake early warnings may be the shortest-fuse natural hazard event for which a warning currently exists; the need to comprehend, personalize, and decide to take action is urgent and to be effective, these tasks must be accomplished within *moments* of message receipt. It is reasonable to conclude that the use of a map to communicate location absent parallel text content reduces the message recipient's ability to reach conclusions quickly because of the time needed to interpret and make sense of the map.

Prior research on message structure and design (Sutton et al. 2021) found that although design features draw attention (e.g., color, font, icons), the textual content included in the message was the most salient for decision making. Providing more information does not necessarily improve message outcomes; the presentation of more specific information must be in the right format for it to be easily understood.

Implications for Theory

Our findings have implications for warning response theory and for communicating specificity. Increasing specificity about hazard location, in this case, the earthquake epicenter, leads to improvements in some key message outcomes. However, the format in which location specificity is communicated affects outcomes as well. Specificity has been described as a part of message style (Mileti and Sorensen 1990) and has been previously focused on text-based message content. In this study we observed that by manipulating the *format* of the content (i.e., text or map) and the *structure* of the message (where the specific information is included), location specificity can be provided in multiple ways. The outcomes from the experiment provide clear evidence that the inclusion of written text improves the communication of location information while the inclusion of a map with graphic content does not. Additional evidence from the focus groups demonstrated the challenges associated with interpreting visual risk information presented in a map, which can be highly problematic for very short-fuse warnings that require quick message understanding and decision-making. Specificity increases complexity, however, and making information more specific does not translate to making information more simple. Finding ways to simplify the communication of more specific, and therefore more complex, information is an important end, as is developing a better understanding of the ideal amount of specificity needed to help users respond appropriately to mobile alerts.

Implications for Practice

This research has implications for application developers working on mobile warning technology. If it is possible to include a map, it is important to also include text content interpreting the map. For apps that are location-based, that is, tracking users, when users have given consent for location information to be turned on when the app is in use, they may have an expectation of receiving ego-centric information. This does not apply to WEA, which does not require consent and is turned on as a default, requiring users to “opt out.”

For mobile alerting technology such as EEW, ShakeAlert, and WEA, it is not clear that including a map is desirable, even if technologically possible. Our results showing that the presentation of hazard location in text format was associated with better message outcomes than presentation in a cartographic format may be related to technology acceptance issues. If users have not elected to download a warning app on their device, they may be uncomfortable when presented with alerts that include location-aware information. Furthermore, text is more accessible for audiences with visual impairments (the inclusion of a map would require the implementation of alt text for interpretation) and the combined display of text plus map and legend may become difficult to view due to screen size limitations on a mobile device.

Our research could have implications for the future of IPAWS and WEA. Although there is enthusiasm for technological advances in WEA, including the use of maps for location-based content, we do not yet know if our findings related to earthquakes apply to longer-fuse hazards. Until additional studies are conducted and establish that the inclusion of a map improves measured outcomes, policy makers should err on the side of caution when adding maps by ensuring they are structured with information that allows the message receiver to interpret the icons, colors, and other aspects included in the message. Should maps be included in future EEW messaging, it will become imperative to offer training on how to interpret them accurately and efficiently when time is limited.

Limitations

One potential limitation is that we did not ask what "16 miles away" (from the epicenter) means to message receivers. We also did not ask whether they interpreted the distance as key to knowing the *timing* of when the shaking might arrive, the *area* of greatest impact, or the *likelihood* that they will experience shaking due to their location relative to the epicenter. Furthermore, some might question the value of including both a map and text in a message when a receiver must act within seconds of its arrival. Another limitation is that there are a great many other ways to increase hazard location specificity, which we did not study. We tested only three ways in the experiment and received additional detail on the presentation of specific hazard location using maps from a small set of focus group respondents. There may be other, potentially more effective strategies for presenting location that were not included here. Furthermore, all our participants viewed a message on a screen that replicated the look of a mobile screen but not necessarily the size. Should maps be included on a physical mobile device, they may be even smaller than those displayed to our study participants. Although we attempted to adhere to best practice in terms of visual access (Lindell, 2020), the maps presented did not fully conform to best practices for cartography. Specifically, no scale or compass rose were included, and no legend was provided. The maps did include color, symbol, and font differences, to create visual salience, but the color meaning was not defined in a legend. While ShakeAlert powered EEW messages can be delivered in Spanish, this study was limited to English-speakers and did not include other language groups. For the experiment, we recruited a volunteer sample, and although we used quotas to achieve approximate balance for gender and age categories, and minimal representation across smaller race/ethnicity categories, we did not employ strict quotas to achieve perfect demographic representation; in an experimental research design, this is not essential, however (Babbie 2016; Guest and Namey 2015). We also did not measure reading comprehension or map literacy to assess educational disparity among participants. Finally, given the small effect sizes, the experiment may not have had sufficient power, which could have attenuated the results.

Future Research

Lindell and colleagues (Lindell et al. 2016) conducted research on tornado warning polygons and found that people tend to judge the polygon centroid as the location of highest risk. Future research should consider how this finding in a tornado context might apply to earthquake map perceptions. Future research also should test our findings in other hazard contexts. EEW stands apart as a singular alert type that is automated, arrives within seconds of threat detection, and requires immediate action. Earthquakes are infrequent and have no comparison with other seasonal hazards, such as tornado or hurricane. Furthermore, their geographical footprints and the speed at which people must make decisions and take action differ from those of more familiar threats. Therefore, while this research offers insight into the inclusion of a map in warning messages, we do not know if these findings will be consistent across other hazards that are slower moving or more geographically bound, such as flooding, tsunami, or tropical cyclone/hurricane and storm surge. The potential value of including maps or graphics in warning messages as a means of transcending language barriers is also worthy of further study; future research should consider including non-English speaking populations, investigate the use of icons to represent the threat and protective actions, and add measures to assess reading comprehension and map literacy. Finally, future research should examine the effectiveness of education campaigns designed to help diverse audiences interpret and respond to warning messages that communicate content via images and maps.

DATA AVAILABILITY STATEMENT

Anonymized data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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DISCLAIMERS

Not applicable.

NOTATION LIST

Not applicable.

SUPPLEMENTAL MATERIALS

Not applicable.

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