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Designing Effective Tsunami Messages: Examining the Role of Short Messages and Fear in Warning Response

Jeannette Sutton
University of Kentucky, jeannette.sutton@uky.edu

Sarah C. Vos
University of Kentucky, sarah.vos@uky.edu

Michele M. Wood
California State University - Fullerton

Monique Turner
George Washington University

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JEANNETTE SUTTON AND SARAH C. VOS
University of Kentucky, Lexington, Kentucky

MICHELE M. WOOD
California State University, Fullerton, Fullerton, California

MONIQUE TURNER
George Washington University, Washington, D.C.

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ABSTRACT

Although tsunamis have the potential to be extremely destructive, relatively little research on tsunami messaging has taken place. Discovering whether tsunami warning messages can be written in a way that leads to increased protective response is crucial, particularly given the increased use of mobile message services and the role they play in notifying the public of imminent threats such as tsunami and other hazards. The purpose of this study was to examine the possibility of designing warning messages for tsunamis that improve upon message style and content used by public alerting agencies to date and to gain insight that can be applied to other hazards. This study tested the impact of tsunami messages that varied in length and content on six message outcomes—understanding, believing, personalizing, deciding, milling, and fear. Relative to the short message, revised messages resulted in significantly more understanding and deciding, known precursors to taking protective action under threat. The revised message also resulted in significantly more fear, which is believed to influence behavioral intentions. Findings suggest that shorter messages may not deliver enough content to inform message receivers about the threat they face and the protective actions they should perform. Longer messages delivered with more specific information about the location of impact, threat-associated risks, and recommended protective actions were associated with better message outcomes, including quicker intended response. Recommendations for future tsunami warnings are provided.

1. Introduction

In the last five decades, a number of significant tsunamis have occurred worldwide, capturing the interest of international agencies tasked with motivating preparedness for tsunamis and warning the public at risk. Tsunamis usually occur after significant underwater earthquakes or landslides and consist of a series of powerful ocean waves. In December 2004, a magnitude-9.0 earthquake in the Indian Ocean created a tsunami that resulted in more than 225 000 deaths. In March 2011, an earthquake and tsunami off the coast of Japan resulted in more than 15 000 deaths and one of the worst nuclear disasters to date. Although the United States has not experienced a significant tsunami recently, both Hawaii (1960 Hilo Tsunami) and Alaska (1964 Good Friday Earthquake) have experienced destructive tsunamis within the last 100 years resulting in preventable loss of life had adequate warning systems been in place (National Research Council 2011b). Furthermore, the potential exists for destructive tsunamis along much of the Pacific West Coast (Geist et al. 2004) where sizable coastal populations are placed at risk (Wood 2007; Wood and Soulard 2008).

Previous research has established that warning messages have the potential to reduce life loss during severe events like tsunamis by encouraging individuals to take protective action (Mileti and Sorensen 1990; Lindell and Prater 2010). However, little research provides guidance for the design and content of effective tsunami warning messages. Although much research has been conducted

Corresponding author: Jeannette Sutton, jeannette.sutton@uky.edu

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on warnings in general (Mileti and Sorensen 1990), only a handful of studies have focused on tsunami warning messages, including their content, style, and structure (Gregg et al. 2012a; Sutton and Woods 2016). In addition, the changing media environment—in particular the advent of short message systems—has changed the ways in which warning messages can be sent. Much of the prior research on warnings assumes that officials will use the Emergency Alerting System (EAS), which has a relatively long message capacity (1380 characters; Drabek 1999). However, warning messages are increasingly sent on social media platforms, such as Twitter, which restricts messages to 140 characters, and the Wireless Emergency Alert (WEA) service, which sends 90-character, geographically targeted messages directly to individual mobile phones (National Research Council 2011a). For tsunamis, especially those triggered by major, near-field sources, which offer little time to take protective action, short messaging systems that deliver content to geotargeted areas may be a primary strategy for warning populations at risk (National Oceanic and Atmospheric Administration 2016). Such platforms allow messages to reach people quickly and can potentially increase the amount of time people have available to take protective action. Unfortunately, only one study that we know of has examined the effectiveness of these shorter messages compared to longer messages (Wood et al. 2015), and it did not focus on tsunamis.

In this paper, we build upon existing research by testing tsunami messages for a distant-source tsunami with members of the public. In doing so, we expand Mileti's (1999) warning response model to include message length, as a feature of message style, and fear, as an affective response to message content. Based on our findings, we identify messaging strategies to improve the effectiveness of future tsunami warnings.

2. Literature review

a. *Research on tsunami warning messages*

There has been considerable research on understanding tsunami risk perception (Anderson 1969; Johnston et al. 2005), preparedness (Lindell and Prater 2010), and response to recent events (Wilson et al. 2011, 2013). However, in 2011, the National Research Council of the National Academy of Sciences (NAS) conducted a review on tsunami warning and preparedness and identified a lack of research on evidence-based messages (National Research Council 2011b); specifically focusing on message design features including message content that has demonstrated likelihood for increasing protective action taking among those at risk. While preevent education about natural cues, personal preparedness, and response, such as plans for evacuation and reunification, is vitally important for decreasing loss of life during a local source tsunami event (Johnston et al. 2005; Esteban et al. 2013), preparedness efforts must be supplemented by warning messages that can persuade individuals to act quickly for both local-source and distant-source tsunami events. The NAS report also noted the need for research on messages delivered via next-generation technologies such as mobile devices or social media applications that can extend the reach of messages across networks.

Since then Gregg et al. (2012) and C. Gregg et al. (2012, unpublished report) undertook two studies on behalf of the NOAA tsunami program. The first included focus groups with community stakeholders including leaders in business, government, civic organizations, and emergency response agencies, including emergency managers (Gregg et al. 2012). In this study, participants rated the characteristics of the content and style of tsunami bulletins, discussed the strengths and weaknesses of existing message products, and identified sources and channels by which they had previously received tsunami information. The second study was an evaluative review of 37 NOAA tsunami products, including warning messages, conducted by a team of social scientists. Based on the variables identified in the warning response model (Mileti and Sorensen 1990), the investigators developed a "tsunami message metric" consisting of 21 factors that described message content, style, order, formatting, and receiver characteristics (C. Gregg et al. 2012, unpublished report). Together, these two studies resulted in recommended changes to 1) message formatting and organization of existing material (Gregg et al. 2012) and 2) content order and style to improve readability (C. Gregg et al. 2012, unpublished report). Suggested changes included moving the "most important information" up front in the message (Gregg et al. 2012, p. ii) and using clearer language for recommended actions and expected impacts of a tsunami (C. Gregg et al. 2012, unpublished report).

More recently, Sutton and Woods (2016) conducted focus group research with members of the public to identify gaps in sense making about tsunami warning messages. Focus group participants, none of whom had any direct experience with tsunami, reviewed an NWS tsunami message that had previously been distributed to populations at risk along the coast of Northern California during the 2011 Tohoku tsunami (a distant source tsunami) and discussed their cognitive and emotional responses to message content and style characteristics. Findings from the focus groups were consistent with those reported by Gregg et al. (2012) and C. Gregg et al. (2012, unpublished report). Focus group participants consistently expressed confusion about the hazard threat, hazard impact, and recommended protective actions owing to the lack of details about the potential severity of tsunamis and their personal susceptibility. Furthermore, they indicated that the lack of specificity in describing the location of impact significantly affected their ability to make a decision about taking action. That is, they were unable to determine whether they were personally susceptible to the threat. In addition, several participants reported feeling extremely anxious owing to their inability to determine whether they or their loved ones were personally at risk.

b. *Warning messages*

The goal of a warning message is to overcome people's belief in their own safety (i.e., the optimism bias) and then guide them to take protective actions (Burningham et al. 2008). Prior research on warnings for imminent threats and disaster has shown that effective messages result in a series of cognitive shifts as individuals make sense of changing situations and that influence their intent to take protective action (Lindell and Perry 2012; Mileti and Sorensen 1990). These shifts begin as individuals 1) understand what the warning means for them, 2) believe the risk, and 3) personalize the risk. These shifts occur in the context of 4) milling, that is, searching for and confirming information, resulting in a 5) decision to take protective action. Mileti (1999) argued that public warning systems that take these mental and social processes into account are more likely to help at-risk publics.

Understanding is the process of comprehending the meaning of the message (Drost et al. 2016). Believing the message is to trust that what is being communicated is accurate (Mileti and Peek 2000). Personalization is the process of individuals' recognizing that they are susceptible to the threat (Wood et al. 2017; Nigg 1987). Personalization plays a crucial role in warning response as it has been linked to an increased likelihood of taking protective action (Casteel 2016; Mileti and Peek 2000; Perry 1979; Perry et al. 1981). Throughout the warning period, message receivers have an increased likelihood of engaging in milling. Milling consists of informal interactions with others to search for additional information (Drabek 1986; Lindell and Perry 2004, 2012). Finally, message receivers decide what action to take in response to the warning message (Wood et al. 2017).

The warning response model does not, however, consider how fear affects these cognitive shifts and what role this emotion may play in the decision to take protective action. Fear is a negative emotion that is accompanied by high levels of arousal (Witte 1992). It is often operationalized as feeling anxious (at lower levels). Warnings have the potential to evoke anxiety, especially if individuals are confused by the message (Sutton and Woods 2016). For example, in one study, focus group participants indicated that the lack of specificity in the location of impact significantly affected their ability to make a decision about taking action. As a result, participants could not determine if they were personally susceptible to the threat. This inability to determine the personal impact of the threat resulted in verbal expressions of anxiety and fear. The emotional response was not due to the content that was present in the message, but rather, what was absent. Those expressing fear said they would need to seek additional information to confirm the impact (Sutton and Woods 2016). While research on fear appeals, guided by Witte's (1994) extended parallel processing model (EPPM), suggests that fear may be a motivating emotion (Witte 1992; Peters et al. 2013), especially when individuals believe that they know how to take protective action (i.e., perceived efficacy), the relationship between fear and warning messages has yet to be studied.

The research record on warning messages demonstrates that the intrinsic features of warning messages influence the nonaffective cognitive shifts described above (e.g., Bean et al. 2016; Mileti and O'Brien 1992). This body of research suggests that warning messages that contain five key content features (i.e., hazard, guidance, location, time, and source) are more effective. As these features are described in detail elsewhere (Mileti and Sorensen 1990), we provide brief definitions here.

Effective messages must contain information about the hazard including a description of physical characteristics of the threat, as well as its potential impact and effects (Covello 1998; Drabek 1999; Mileti and Peek 2000). Warning messages should also provide guidance, which includes information about the actions people need to take to increase their safety (Lindell and Perry, 1992; Mileti and Sorensen 1990). Public warning messages must also identify the location of the threat, including the geographical and physical boundaries (Greene et al. 1981; Nigg 1987) and the populations at risk. Messages should contain information about time, that is, when individuals need to initiate protective actions and the amount of time they have available in which to do so (Drabek and Boggs 1968; Perry et al. 1981; Mileti and Sorensen 1990). And finally, messages must also indicate the source or sources initiating and sending the warning (Casteel 2016; Mayhorn and McLaughlin 2014).

In addition to these content variables, the style of the warning affects message interpretation (Mileti and Peek 2000). According to the warning response model, the style of warnings should be specific, in that the warning should provide precise information and details (Drabek and Boggs 1968; Mayhorn and McLaughlin 2014; Mileti and Sorensen

1990). Warnings should be consistent within and across messages (Mileti and Peek 2000; Mileti and Sorensen 1990). Messages should employ clear language that is simple and straightforward (Drabek and Stephenson 1971; Quarantelli 1984). Information also should be conveyed with certainty, even when the actual impact may be uncertain and conditions are changing (Mileti and Peek 2000). Finally, messages should be accurate in that the information is timely and complete (Mileti and Sorensen 1990).

c. *New warning technologies and message length*

One feature of warning messages that has become particularly relevant because of evolving technologies is the length (National Research Council 2011a). Although WEA- and Twitter-based warning messages have the potential to reach people quickly, the character constraints of these systems (90 and 140, respectively) force officials to write short messages. Logistically, these messages may not contain enough characters to allow emergency managers to include the five types of content identified by the warning response model (Mileti 1999).

Existing research on short messages has found that relative to longer 1380-character messages, shorter messages resulted in poorer message outcomes (Bean et al. 2014, 2016). A recent study (Wood et al. 2017) found that the amount of information contained in a message was positively associated with message understanding and deciding and negatively associated with response delay.

One possible solution is to use the distributed practice strategy (Seabrook et al. 2005; Underwood 1961). This strategy suggests that sequenced presentation of information yields better understanding than massed presentation, or cramming. In the context of Twitter or WEA messages, this strategy would require that longer messages be broken up into a series of digestible, sequenced messages. Breaking up messages may make them easier to understand. Wogalter and Mayhorn (2005) argued that safety-related information could be learned, or understood, more efficiently when presented in shortened presentations distributed across time. Taken together, this research suggests that sequenced messages should be as effective as nonsequenced messages and more effective than short messages.

In this study, we advance research on warning messages in general, and on tsunami warning messages in particular, by examining the ways in which message content and length affect 1) key outcomes of the warning response model and 2) the affective outcome, fear, an understudied emotional reaction to warning messages.

3. Method

An online experiment comparing outcomes for four different public tsunami warning messages was conducted using a posttest only, between-subjects design. Participants gave informed consent and then were presented with one of four randomly assigned warning messages about a distant-source tsunami event off the California coast. All four messages informed the participants about the tsunami and encouraged them to take protective action. After viewing the randomly assigned message, participants were asked to imagine how they would feel if they had received the message on their phone and were then asked a series of questions. The study protocol was approved by the Institutional Review Board at a large university.

a. *Participants*

A volunteer sample ($N = 401$) was drawn from an online survey audience panel of individuals recruited for experiment participation in exchange for ‘‘points’’ in a no-cash, point system of rewards, including sweepstakes and merchandise. The panel included a diverse group of individuals who have Internet access and have joined the audience panel to take surveys. Eligible panel members were invited by e-mail to participate, and invitations were sent to provide general balance in terms of gender. To be eligible to participate in this study, individuals had to be 1) 18 years of age or older, 2) U.S. residents, and 3) English speakers.

Given that the tested messages were about a hypothetical tsunami occurring in California, most participants (96%) were drawn from within the state, largely from coastal regions. Warning messages may be received by nonresident visitors to a given area; thus additional participants were drawn from out of state (4%) to reflect visitors to coastal areas who may be unfamiliar with the tsunami hazard. In general, demographic characteristics were similar to those of California residents (U.S. Census Bureau 2017), although Hispanic residents were underrepresented. Demographic characteristics of the sample are provided (Table 1). Just over half the participants were women (54%); the median age was 38 years. The majority (54%; $n = 215$) self-identified as white, 21% ($n = 84$) as Hispanic/Latino, 15% ($n = 62$) as Asian/Native Hawaiian/Pacific Islander, 7% ($n = 27$) as black or African American, and 3% ($n = 13$) as some other group.

b. *Materials*

Four messages were tested: 1) an actual federal agency message (‘‘standard’’), 2) a revised specificity- and clarity-enhanced message (‘‘revised’’), 3) a short, length-constrained message (‘‘constrained’’), and 4) the specificity- and clarity-enhanced revised message delivered as a sequenced set of shorter messages (‘‘sequenced’’). The standard message was an actual distant-source tsunami warning message that was issued by the National Weather

TABLE 1. Sample Characteristics.

	Condition[a]									
	Total (*N* = 401)		Standard (*n* = 113)		Revised (*n* = 111)		Constrained (*n* = 93)		Sequenced (*n* = 84)	
Characteristic	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Sex										
Male	183	46	52	46	41	37	51	55	39	46
Female	218	54	61	54	70	63	42	45	45	54
Race/ethnicity										
African American/black	27	7	10	9	6	5	3	3	8	10
Asian	62	15	13	12	23	21	17	18	9	11
Hispanic/Latino	84	21	25	22	23	21	20	22	16	19
White	215	54	60	53	58	52	48	52	49	58
Other	13	3	5	4	1	1	5	5	2	2
Age[b]										
Younger (18–54 years)	339	84	98	87	100	90	73	78	68	81
Older (55+ years)	62	16	15	13	11	10	20	22	16	19
Income										
$0–$74,999	240	60	70	62	70	63	52	56	48	57
$75,000 and more	161	40	43	38	41	37	41	44	36	43
Live in California										
Yes	386	96	111	98	107	96	86	92	82	98
No	15	4	2	2	4	4	7	8	2	2
Comfort using cell phone										
No	34	8	11	10	8	7	11	12	4	5
Yes	367	92	102	90	103	93	82	88	80	95
Disaster experience										
Low	156	39	42	37	42	38	34	37	38	45
High	245	61	71	63	69	62	59	63	46	55
Prior mobile alert										
Yes	252	63	70	62	73	66	52	56	57	68
No	149	37	43	38	38	34	41	44	27	32

[a] $^{2}_{(N\text{-}1\ \mathrm{DF})}$ was nonsignificant for each participant characteristic, indicating that there were no baseline differences between treatment groups.
[b] Median age was 38 years.

Service in Eureka, California, on 11 March 2011, in response to the Tohoku Tsunami event that occurred off the coast of Japan and provided the basis for discussion in prior focus group research (Sutton and Woods 2016). This message served as the control. The revised message was a revision of the standard NWS message based on the findings from four focus groups held in October 2014 (Sutton and Woods 2016). The revised message included changes to specify characteristics about the hazard threat and potential impact, clearly identify the location of impact using city names, and specify the recommended protective actions. The message content was also reorganized to improve message clarity and specificity, per the warning response model (Mileti and Sorensen 1990). The constrained message was a 140-character warning message that included all five content features in a condensed form. The sequenced message was the revised warning message presented as a sequence of eleven 140-character messages. All messages were written in capital letters to mimic NWS style and were reviewed by an outside expert. See the appendix for message text.

c. *Procedure and data analysis*

After informed consent procedures, participants were presented with the following scenario:

> Imagine that you are on vacation on the coast in Humboldt, California. It's 10:20 in the morning. You are home alone, and you just received the following message on your mobile/cellular phone. (If you do not have a mobile/cell phone, imagine that you do.) This is what you see when you view the message.

Participants were then presented with an image of a cell phone containing a randomly assigned message (standard, revised, constrained, or sequenced). After reading

TABLE 2. Scale descriptive statistics ($N = 401$).

Scale	Mean	Std dev	Skew	Kurtosis	No. of items	Cronbach's α
Understanding	4.70	1.13	−0.89	0.59	7	0.94
Belief	4.81	1.25	−1.28	1.43	3	0.92
Personalization	4.34	1.29	−0.63	−0.06	7	0.94
Milling	4.55	1.37	−0.97	0.37	1	—
Deciding	4.76	1.33	−1.06	0.62	1	—
Minutes to take action	155.11	113.76	1.38	0.96	2	—
Fear	4.78	1.67	−0.54	−0.33	3	0.95

the message, participants completed a questionnaire that measured six primary outcomes (understanding, belief, personalization, deciding, milling, and fear). Standard questionnaire items used in prior research (Gutteling 1993; Lindell and Perry 2012) were employed when they existed and there was evidence that the items had performed well. Existing items were adapted to the context of the project.

OUTCOME SCALES

Exploratory and confirmatory factor analysis was conducted to create composite mean outcome scores for four of the six outcomes (understanding, belief, personalization, and fear). Two measures (deciding and milling) were measured as single items. Principal component analysis and oblimin rotation was used to assess whether items reliably represented a single construct. Six scales were extracted. Coefficient alpha values ranged from 0.92 to 0.95. Descriptive statistics for the outcome scales are presented in Table 2.

d. *Measures*

1) UNDERSTANDING

The understanding scale measured how well individuals thought they understood the message. The scale included seven items: "After reading this message, I understand: 1) what happened, 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, and 7) how long I am supposed to continue taking action to protect myself." Each of the items was rated on a 6-point scale, where 1 = *Do not understand at all* and 6 = *Understand fully*.

2) BELIEF

The belief scale included three items. The specific wording was: "After reading this message, do you believe that: 1) A tsunami is headed your way? 2) You should immediately move to high ground? and 3) Moving to high ground will make you safer?" Each of the items was rated on a 6-point scale, where 1 = *Do not believe* and 6 = *Believe*.

3) PERSONALIZATION

The personalization scale included seven items. The specific wording was: "If I received this message on my cell phone, I would 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, and 7) the message was meant for me." Each of the items was rated on a 6-point scale, where 1 = *Extremely unlikely* and 6 = *Extremely likely*.

4) MILLING

Participants were asked one question that tapped into their willingness to engage in quick, efficient, protective behaviors: "How likely would you be to take action to protect yourself before confirming the information somewhere else?" This item was rated on a 6-point scale, where 1 = *Very unlikely* and 6 = *Very likely*. Higher scores indicated less milling and quicker protective action.

5) TIME TO TAKE PROTECTIVE ACTION

Participants were also asked "How much time did you believe you had before you should begin taking actions?" Each participant indicated their response in hours and minutes, and data were converted to one total score in minutes.

6) DECIDING

Deciding was measured with one item: "The message will help me decide what to do." This item was rated on a 6-point scale, where 1 = *Strongly disagree* and 6 = *Strongly agree.*

7) FEAR

Participants rated four items (afraid, scared, anxious, frightened) using a 7-point rating scale where 1 = *None of this feeling* and 7 = *A great deal of this feeling*. These four items converged to form a mean scale labeled as "Fear."

TABLE 3. Mean message outcomes by group.

Scale	Standard (n = 113) M (SD)	Revised (n = 111) M (SD)	Constrained (n = 93) M (SD)	Sequenced (n = 84) M (SD)
Understanding	4.73a (0.94)	4.95a (1.03)	4.27b (1.32)	4.82a (1.15)
Belief	4.68 (1.16)	5.05 (1.04)	4.61 (1.44)	4.89 (1.34)
Personalization	4.20 (1.14)	4.40 (1.32)	4.26 (1.41)	4.53 (1.30)
Milling	4.47 (1.33)	4.70 (1.24)	4.32 (1.40)	4.71 (1.53)
Minutes to take action	155.79 (109.17)	126.39 (85.88)	174.31 (118.74)	166.17 (142.31)
Deciding	4.66 (1.16)	5.06a (1.24)	4.41b (1.47)	4.86 (1.42)
Fear	4.71 (1.52)	5.13a (1.45)	4.41b (1.86)	4.81 (1.83)

Means with differing superscripts are significantly different at the $p < 0.05$ level.

e. Data analysis

One-way analysis of variance (ANOVA) was used to assess the effect of messages on each outcome. Post hoc analysis was conducted using Scheffe's test (Tabachnick and Fidell 2007), except in cases where the homogeneity of variance assumption was violated. Cell sizes were relatively equal. Although ANOVA is typically robust in the presence of violations, the Games–Howell procedure were employed in those cases, as this test was designed for situations involving unequal variances (Field 2013).

4. Results

One-way ANOVA was used to examine whether self-reported understanding, belief, personalization, milling, deciding, and fear were functions of the type of message viewed. The independent variable represented the four different message types: 1) standard, 2) revised, 3) constrained, and 4) sequenced. The dependent variables were understanding, belief, personalization, milling, deciding, and fear scores. See Table 3 for means and standard deviations for each of the four groups.

a. Understanding

There was a significant effect of message type on understanding (F [3, 397] = 6.851; $p < 0.001$; $\eta_p^2 = 0.05$). This effect can be characterized as small to medium. Games–Howell post hoc results indicated that the constrained message (M = 4.27; SD = 1.32) resulted in less understanding than the standard message (M = 4.73; SD = 0.94; p = 0.003), revised message (M = 4.95; SD = 1.03; $p < 0.001$), and sequenced message (M = 4.82; SD = 1.15; p = 0.001). The revised message did not cause significantly more understanding than the standard or sequenced message; however, examination of the means showed slightly more understanding for the revised and the sequenced messages than the standard message.

b. Belief

There also was a significant effect of message type on belief (F [3, 397] = 2.77; p = 0.04; $\eta_p^2 = 0.02$). However, Games–Howell post hoc tests did not indicate significant differences between messages. The differences between the revised message (M = 5.05; SD = 1.04) and the standard message (M = 4.68; SD = 1.16; p = 0.055) and between the revised message and the constrained message (M = 4.61; SD = 1.44; p = 0.069) approached significance. Examination of the means showed that the revised message resulted in the highest levels of belief, followed by the sequenced message, the original message, and the constrained message.

c. Personalization

There was no effect of message type on personalization (F [3, 397] = 1.25; p = 0.29; $\eta_p^2 = 0.009$), indicating that people who received different types of messages personalized the warnings in a similar manner. Personalization was high (above 4.2) in all conditions.

d. Milling

There was no effect of message type on milling (F [3, 397] = 1.844; p = 0.14; $\eta_p^2 = 0.014$), indicating that the message variations did not influence whether participants would engage in confirming the message before taking protective action. Notably, in all message conditions, individuals indicated high levels of intent to take protective action (4.32 or above) before confirming. Participants in the sequenced condition indicated the highest level of taking protective action before confirming (M = 4.71; SD = 1.53), followed by the revised (M = 4.70; SD = 1.24), standard (M = 4.47; SD = 1.33), and constrained (M = 4.32; SD = 1.40) conditions.

e. Time to take protective action

There was a significant effect of message type on the total number of minutes that participants believed were available in which to take protective action to protect themselves (F [3, 397] = 3.186; p = 0.024; η_p^2 = 0.024). However, Games–Howell post hoc tests did not indicate significant differences between message conditions, although differences between the constrained condition (M = 174.31; SD = 118.74) and the revised condition (M = 126.39; SD = 85.88; p = 0.081), and between the constrained condition and the sequenced condition (M = 166.17; SD = 142.31; p = 0.082) approached significance. In general, participants indicated that they would act relatively quickly (responding within two to three hours).

f. Deciding

There was a significant effect of message type on deciding (F [3, 397] = 4.5; p = 0.004; η_p^2 = 0.033), indicating participants did vary significantly in their perceived ability to make a decision as a result of the message conditions. Games–Howell post hoc tests indicated that participants receiving the revised message reported significantly more ability to decide whether to take protective action (M = 5.06; SD = 1.24) than participants receiving the constrained message (M = 4.41; SD = 1.47; p = 0.005) and participants receiving the original message (M = 4.66; SD = 1.16), although this latter difference only approached significance (p = 0.066).

g. Fear

There was a significant effect of message type on fear (F [3, 397] = 3.303; p = 0.02; η_p^2 = 0.024). Games–Howell post hoc tests indicated that the revised message caused significantly more fear (M = 5.13; SD = 1.45) compared to the constrained message (M = 4.41; SD = 1.86; p = 0.014). However, fear did not vary significantly among other message conditions.

5. Discussion

Effective tsunami warnings are essential to limit the loss of life that may occur when these events happen. The results from this study suggest that existing tsunami warning messages can be improved by including more specific information about the geographical location and population under threat, clearly explaining the potential impact of tsunami, and providing specific guidance about protective actions that should be taken by populations at risk. Although the effect sizes are small, when applied across the large populations that may need to be reached in the event of a catastrophic tsunami, these changes have the potential to increase protective action measures taken by the public and save lives. While this research was conducted on a distant-source tsunami threat, prior research (Bean et al. 2016; Lindell and Perry 2012; Mileti and Sorensen 1990) suggests that our findings likely apply to other hazards in general as well as those with short response times that require quick decision-making with little time to seek additional information.

Furthermore, the results provide insight into using short messages to communicate warnings. These results suggest that while a single, short message may have some effect, this type of message is not as successful as messages that include more information. In this study, participants who only saw a single, short message reported significantly less understanding, fear, and ability to decide, compared to participants who received the revised message.

This result, however, should not be interpreted to mean that warnings should not be sent via short messages such as Twitter or WEA. Rather, it may be more effective to send short messages in a distributed fashion on these message systems. Our results showed that the sequenced 140-character set of messages was as effective as the revised, longer-length message. Thus, even when technology limits the length of messages, our findings demonstrate that public officials can send messages to mobile devices in a way that circumvents these constraints by sending a series of related messages that include more information than a single shorter message and are more effective. To our knowledge, this research is the first to have demonstrated the potential value of sequenced warning messages.

Our finding that longer messages that included more information had better outcomes is consistent with research by Wood et al. (2017), who examined the effect of amount of information on outcomes for an improvised nuclear device warning. Our study extends that research by examining a different hazard type and by including fear, an affective precursor to protective action. Moreover, our research compares three different approaches to writing longer messages: 1) actual messages that are sent by federal agencies, 2) actual messages that are revised to enhance specificity and clarity, and 3) actual messages that are revised to enhance specificity and clarity and that are delivered as a sequenced set of shorter messages.

Importantly, across all four message conditions, we found no differential effects for intended milling, that is, the desire to confirm the message before taking protective action. In other words, message content and length did not differentially affect people's intent to seek confirmation response to a tsunami warning message. These data indicated that, overall, participants perceived strong intent to act, regardless of which of the four randomly assigned messages they had read.

A key implication of this research is that it remains imperative that emergency communicators continue to develop mastery in writing messages that are not only clear and succinct but that also convey the threat as well as the necessary steps to mitigating the threat. This may involve consideration of sending longer messages, sending sequenced messages, including messages with links to further information, and developing message templates in advance that can be used as an event unfolds.

6. Limitations and future research

There are some limitations to this study, which should be addressed in future research. First, this study assessed emotions, cognitive shifts, and behavioral intention in response to an imagined scenario using a controlled experimental design. The use of an experimental design, which includes randomization to message condition, helps reduce the likelihood that there will be baseline differences between groups on participant characteristics such as prior hazard knowledge (Babbie 2016). We collected information about prior disaster experience and found no differences between groups (see Table 1). Owing to concerns about response burden, however, we did not assess prior knowledge of the hazard; therefore, we cannot be certain that there were no preexisting group differences in tsunami knowledge. Although experimental designs maximize internal validity by controlling for baseline differences between groups (Babbie 2016) and have been used successfully to investigate warning messages (Frisby et al. 2014; Liu et al. 2017), future research should investigate the effects of tsunami warning messages during real-world events to strengthen the external validity of our findings. Furthermore, this scenario depicted a distant-source event, which would allow for additional time for both the development of a long form message that can be sent in a single shot or in sequence. A local source event would not allow the development of a long message, nor time for information seeking before decision-making. Therefore, future research is needed to investigate responses to near-field tsunami messages. Likewise, future research should examine the effect of prior hazard knowledge on warning outcomes.

Second, our focus has been on a single, largely unfamiliar hazard. Globally, few individuals have experience with this threat except vicariously through media accounts of large-scale, high-impact events. In addition, recommended protective actions for tsunami threat are not terribly complicated; the goal for those at risk is to get to higher ground as quickly as possible. In contrast, people at risk from other hazards may have different recommended protective actions depending upon their location and protective structure. Therefore, future experiments on warning message response for other hazards, such as hurricane, flood, and tornado, or less familiar hazards, such as technological threats, should examine the effects of using shorter messages and sequenced messages.

Third, in this study, we considered two types of message length—a long message and a constrained message, delivered as a single shot or a series of 11 messages. We did not investigate the possibility of a middle-range message that is longer than 140 characters and shorter than a full 1380 characters. Future research should investigate the possibility of an optimal message length that can increase intent to take protective action. Additional testing should also be conducted on sequenced messages delivered over constrained messaging channels. This study demonstrates that using sequenced messages may be an effective strategy for delivering warning messages. In this study, we numbered each message in sequence (1/11, 2/11, etc.); however, future research should investigate how participants might respond if messages are sent out of order or if messages are not complete, as these outcomes are distinct possibilities when messages are sequenced. Likewise, research should examine whether the number of messages included in a sequenced set should be limited.

Fourth, this research investigated the effect of messages on emotions, specifically looking at fear. Our findings indicated the presence of fear; however, because of concerns about respondent fatigue, we did not assess how messages influenced perceived efficacy. Risk communication scholarship suggests that fear, when accompanied by high perceived efficacy, increases behavioral intentions (Witte 1992); future research should examine whether warning messages can increase protective action responses by increasing perceived efficacy.

7. Conclusions

When warning members of the public about imminent threats, risk communicators intend for people to take action immediately in response to the warning messages they receive. Therefore, individuals must believe that the threat is real, that they are at risk, and that they have the information necessary to make a decision about how to respond. Indeed, the goal of much hazard warning research has been to increase the persuasiveness of messages in order to reduce the time spent searching for more information before engaging in protective action. The hope has been that a specific combination of message content and message style will lead to greater compliance among those at risk, reducing the loss of life under severe conditions. Most importantly compliance needs to be quick—action must happen fast.

Of great importance is the need for risk communicators to deliver messages that are highly specific and clear about the hazard threat, its impact, and the protective actions that should be taken, regardless of message length. Messages must be understandable and useful for people with varying levels of education and ability. Furthermore, as risk communicators continue to use channels that transmit shorter messages in order to relay warnings in real time, greater attention should be given to strategies to make these short messages more effective. In this study, a single, content-constrained warning message, such as a 140-character message sent as a single message, was the least successful strategy for delivering a warning that would be understood or believed. The results of this study suggest that a series of short messages may serve as a viable alternative for delivering additional information that can help people to make decisions about how to protect themselves. In light of this finding, public communicators utilizing short messaging channels should consider sending a series of messages rather than a single message under conditions of imminent threat. Additional research is critical to help clarify when and how sequenced messages can be most effective in reducing death and injury.

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APPENDIX

Message 1: Original Tsunami Message

WWUS86 KEKA 111820
SPSEKA
SPECIAL WEATHER STATEMENT
NATIONAL WEATHER SERVICE EUREKA CA
1020 a.m. PST FRI MAR 11 2011
CAZ001–002–120030-
REDWOOD COAST-MENDOCINO COAST-
1020 a.m. PST FRI MAR 11 2011

...A TSUNAMI WARNING REMAINS IN EFFECT FOR DEL NORTE...HUMBOLDT AND MENDOCINO COUNTIES COASTAL AREAS...

EARTHQUAKE DATA. PRELIMINARY MAGNITUDE 8.9. LOCATION 38.2 NORTH 142.5 EAST. NEAR EAST COAST OF HONSHU JAPAN. TIME 21:46 PST MAR 10, 2015. A TSUNAMI WAS GENERATED AND HAS CAUSED DAMAGED ALONG THE DEL NORTE COUNTY, AND DAMAGE ALONG THE HUMBOLDT AND MENDOCINO COASTS IS STILL EXPECTED. PERSONS AT THE COAST SHOULD BE ALERT TO INSTRUCTIONS FROM LOCAL EMERGENCY OFFICIALS.

DAMAGING WAVES HAVE BEEN OBSERVED ACROSS HAWAIIAN ISLANDS. DAMAGING WAVES HAVE ARRIVED AT CRESCENT CITY HARBOR WHERE ALL DOCKS HAVE BEEN DESTROYED. WAVES HAVE BROKEN OVER THE SPIT AT STONE LAGOON. A 3-FOOT WAVE HAS BEEN REPORTED IN HUMBOLDT BAY. A 2–4 FOOT FLOOD WAVE WAS REPORTED MOVING UP THE MAD RIVER AT 08:45 a.m. PST. DAMAGING WAVES WILL CONTINUE FOR THE NEXT SEVERAL HOURS.

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY GAUGE LOCATION TIME AMPLITUDE

CRESCENT CITY, CA 08:44 a.m. 8.1 FT, NORTH SPIT HUMBOLDT 8:30 a.m. 3.1 FT, ARENA COVE 09:17 a.m. 5.3 FT.

REMEMBER...DO NOT BE FOOLED...TSUNAMI WAVES CAN SEEM TO STOP FOR LONG PERIODS AND THEN BEGIN AGAIN. WAIT FOR THE OFFICIAL ALL CLEAR TO RETURN TO THREATENED AREAS.

IN DEL NORTE COUNTY...PEOPLE ARE ORDERED TO EVACUATE TO ABOVE 9TH STREET. SHELTER LOCATIONS INCLUDE SMITH RIVER ELEMENTARY...DEL NORTE HIGH SCHOOL AND YUROK TRIBAL OFFICE IN KLAMATH.

IN HUMBOLDT AND MENDOCINO COUNTIES... PEOPLE ARE ADVISED TO STAY OFF BEACHES...NOT TRAVEL BY WATERCRAFT AND EVACUATE LOW LYING COASTAL AREAS IMMEDIATELY UNTIL ADVISED THAT IT IS SAFE TO RETURN.

PEOPLE SHOULD STAY CLEAR OF LOW LYING AREAS ALONG COASTAL RIVERS AS TSUNAMI WAVES CAN TRAVEL UP FROM THE MOUTH OF COASTAL RIVERS.

BULLETINS WILL BE ISSUED HOURLY OR SOONER IF CONDITIONS WARRANT TO KEEP YOU INFORMED OF THE PROGRESS OF THIS EVENT. IF AVAILABLE...REFER TO THE INTERNET SITE HTTP://TSUNAMI.GOV FOR MORE INFORMATION.

DUE TO RAPIDLY CHANGING CONDITIONS ASSOCIATED WITH TSUNAMI WAVE ACTIVITY...LISTENERS ARE URGED TO TUNE TO LOCAL EMERGENCY ALERT SYSTEM

MEDIA FOR THE LATEST INFORMATION ISSUED BY LOCAL DISASTER PREPAREDNESS AUTHORITIES. THEY WILL PROVIDE DETAILS ON THE EVACUATION OF LOW-LYING AREAS…IF NECESSARY…AND WHEN IT IS SAFE TO RETURN AFTER THE TSUNAMI HAS PASSED.

Message 2: EPPM-Enhanced Tsunami Message

NATIONAL WEATHER SERVICE EUREKA CA.

AN EARTHQUAKE WITH A PRELIMINARY MAGNITUDE OF 8.9 OCCURRED NEAR THE EAST COAST OF HONSHU, JAPAN AT 11:46 p.m. PST MAR 10, 2015. IT HAS GENERATED A TSUNAMI. INITIAL WAVES WERE DETECTED AT 08:30 a.m. PDT MAR 11, 2015. DOCKS HAVE BEEN DESTROYED AT CRESCENT CITY HARBOR. DAMAGING WAVES HAVE BEEN SIGHTED IN HUMBOLDT BAY AND MOVING UP THE MAD RIVER. OTHER WAVES WILL STRIKE OVER MANY HOURS. TSUNAMI WAVES CAN BE DEADLY AND CAUSE INJURY AND WIDESPREAD DAMAGE.

THE TSUNAMI WARNING REMAINS IN EFFECT FOR DEL NORTE, HUMBOLDT, AND MENDOCINO COUNTY COASTAL AREAS. THIS INCLUDES THE TOWNS OF CRESCENT CITY, KLAMATH, EUREKA, ARCATA, TRINIDAD, FORT BRAGG, GUALALA, AND WESTPORT.

IF YOU ARE ON OR NEAR A BEACH, IN A LOW LYING COASTAL AREA, OR NEAR A COASTAL RIVER ANYWHERE IN THE DEL NORTE, HUMBOLDT, AND MENDOCINO COUNTY COASTAL AREAS, YOU WILL BE SAFEST IF YOU IMMEDIATELY GET TO HIGH GROUND OF AT LEAST 50 FEET OR MORE. IF YOU CANNOT REACH HIGH GROUND, EVACUATE TO AN UPPER FLOOR OF A HIGH RISE BUILDING, IF ONE IS AVAILABLE. DO NOT TRAVEL BY WATERCRAFT. TSUNAMI WAVES MAY BE FILLED WITH DEBRIS, WHICH CAN INJURE OR KILL PEOPLE AND WEAKEN OR DESTROY STRUCTURES.

IF YOU SEE THE OCEAN WATER PULL BACK AND EXPOSE THE SEA FLOOR, RUN TO HIGH GROUND AS FAST AS YOU CAN BECAUSE A TSUNAMI WILL STRIKE IN A FEW MOMENTS. IF YOU ARE NOT IN A TSUNAMI IMPACT AREA, STAY AWAY. ONCE YOU ARE IN A SAFE LOCATION, STAY THERE UNTIL ADVISED BY OFFICIALS THAT IT IS SAFE TO LEAVE. KEEP LISTENING TO YOUR LOCAL MEDIA AND EMERGENCY OFFICIALS FOR MORE INFORMATION AND ADDITIONAL UPDATES. IF AVAILABLE, REFER TO TSUNAMI.GOV FOR MORE INFORMATION.

THIS MESSAGE WILL BE UPDATED IN 30 MINUTES OR SOONER.

Message 3: Constrained, 140-Character Tsunami Message

Emergency Alert.

@NWS EUREKA.

EVACUATE COASTAL AREAS IN MENDOCINO, HUMBOLDT, DEL NORTE COUNTIES. TSUNAMI WARNING. DESTRUCTIVE WAVES SIGHTED. WARNING EXPIRES 9:00 p.m. PDT.

Message 4. EPPM-Enhanced, Sequenced Tsunami Message

Emergency Alert

NWS EUREKA, CA. TSUNAMI WARNING. A MAGNITUDE 8.9 EARTHQUAKE OCCURRED NEAR JAPAN AT 11:46 p.m. PST JULY 24, 2015. (MESSAGE 1 OF 11)

Emergency Alert

INITIAL WAVES WERE DETECTED AT 0830 a.m. PDT JUL 25, 2015. DOCKS HAVE BEEN DESTROYED AT CRESCENT CITY HARBOR. (MESSAGE 2 OF 11)

Emergency Alert

DAMAGING WAVES HAVE BEEN SIGHTED IN HUMBOLDT BAY AND MOVING UP THE MAD RIVER. OTHER WAVES WILL STRIKE OVER MANY HOURS AND MAY BE DEADLY. (MESSAGE 3 OF 11)

Emergency Alert

THE TSUNAMI WARNING IS IN EFFECT FOR DEL NORTE, HUMBOLDT and MENDOCINO COUNTY COASTAL AREAS INCLUDING CRESCENT CITY, KLAMATH, EUREKA and ARCATA (MESSAGE 4 OF 11)

Emergency Alert

IF YOU ARE ON OR NEAR A BEACH IN A LOW LYING COASTAL OR RIVER TSUNAMI IMPACT AREA, GO NOW TO HIGH GROUND AT LEAST 50 FEET ABOVE SEA LEVEL (MESSAGE 5 OF 11)

Emergency Alert

IF YOU ARE IN AN IMPACT AREA AND CANNOT REACH HIGH GROUND, GO TO AN UPPER FLOOR OF A TALL BUILDING. STAY OFF BEACHES. DO NOT USE WATERCRAFT. (MESSAGE 6 OF 11)

Emergency Alert

TSUNAMI WAVES MAY BE FILLED WITH DEBRIS, WHICH CAN INJURE OR KILL PEOPLE

AND WEAKEN OR DESTROY STRUCTURES. (MESSAGE 7 OF 11)

Emergency Alert

IF YOU SEE THE OCEAN WATER PULL BACK AND EXPOSE THE SEA FLOOR, RUN TO HIGH GROUND AS FAST AS YOU CAN BECAUSE A TSUNAMI IS ABOUT TO STRIKE (MESSAGE 8 OF 11)

Emergency Alert

IF YOU ARE NOT IN A TSUNAMI IMPACT AREA, STAY AWAY. ONCE YOU ARE IN A SAFE LOCATION, STAY THERE UNTIL OFFICIALS ADVISE IT IS SAFE TO LEAVE. (MESSAGE 9 OF 11)

Emergency Alert

LISTEN TO YOUR LOCAL MEDIA AND EMERGENCY OFFICIALS FOR ADDITIONAL TSUNAMI UPDATES. IF AVAILABLE, REFER TO TSUNAMI.GOV FOR MORE INFORMATION (MESSAGE 10 OF 11)

Emergency Alert

TSUNAMI WARNING MESSAGES WILL BE UPDATED EVERY 30 MINUTES OR SOONER. (MESSAGE 11 OF 11)

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