Communicating Crisis with Persuasion: Examining Official Twitter Messages on Heat Hazards

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ABSTRACT

Official crisis messages need to be persuasive to promote appropriate public responses. However, little research has examined the content of crisis messages from a persuasion perspective, especially for natural hazards. This study deductively identifies five persuasive message factors (PMFs) applicable to natural hazards, including two under-examined health-related PMFs: *health risk susceptibility* and *health impact*. Using 2016 heat hazards as a case study, this paper content-analyzes heat-related Twitter messages (N=904) posted by eighteen U.S. National Weather Service Weather Forecast Offices according to the five PMFs. We find that the use of descriptions of *hazard intensity* is disproportionately high, with a lack of use of other PMFs. We also describe different types of statements used to signal the two health-related PMFs. We conclude with implications and recommendations relevant to practitioners and researchers in social media crisis communication.

Keywords

Persuasion, crisis communication, susceptibility, social media, heat hazards.

INTRODUCTION

Government agencies often communicate messages to the public during a crisis to help the public appropriately respond and thus decrease adverse impacts. Previous studies have recognized that crisis messaging should be constructed in an up-to-date and informative manner (Mileti and Sorensen, 1990; Reynolds and Seeger, 2005). However, little research attention has been paid to probing the content of crisis messages for its potential contribution to persuasion, especially when those messages are sent through social media. The persuasive perspective of crisis messages refers to a message's ability to persuade members of the public to take appropriate action. The lack of recognition of message content that potentially contributes to message persuasion (i.e., persuasive message factors, PMFs) may result in noncompliance to lifesaving crisis messages by members of the public. To bridge this knowledge gap, we identify five PMFs indicative of effective persuasion for natural hazards. We then investigate the usage of these PMFs in crisis messaging by analyzing the content of Twitter messages ('tweets') posted by National Weather Service (NWS) Weather Forecast Offices (WFOs) about heat hazards.

Some PMFs that play different and potentially critical roles in persuasion are often overgeneralized in previous studies with an emphasis on the informativeness of crisis messages. For example, studies in the natural hazards field often combine descriptions of the physical characteristics of a hazard itself and descriptions of hazard impacts as one content theme regarding hazard information (Mileti and Sorensen, 1990; Sutton et al., 2015a). However, this theme includes

multiple PMFs such as the intensity of a hazard, the uncertainty of a hazard, the subgroups that are vulnerable to hazard impacts, and the potential consequences of being affected. From an informative perspective, the nuances of message content may not be significant enough to be separate content themes. However, from a persuasive perspective, descriptions of hazard intensity, hazard uncertainty, sensitive groups, and potential health impacts can be viewed as four types of message content because they may have varying roles in message persuasion.

PMFs warrant greater attention in crisis messaging because they have been shown to have significant effects on message compliance in other communication fields such as health communication (Maddux and Rogers, 1983; Murray-Johnson and Witte, 2003). A lack of investigation and recognition of PMFs in the context of natural hazards may result in the absence of well-designed PMFs in crisis messages, especially when messages are communicated via short messaging channels such as Twitter. This research deductively identifies five PMFs indicative of persuasion in the context natural hazards, especially two under-recognized PMFs: *health risk susceptibility* and *health impact.* We then, for the first time, investigate to what extent each of the PMFs is included in crisis messages and what typical statements are used to communicate the two under-examined PMFs. To our knowledge, such investigations have not been conducted for crisis messages communicated through any platforms, no matter social media or traditional media. Our investigation of PMFs through social media could have implications to promote crisis messaging communicated via other platforms such as word-of-mouth and television. For some vulnerable subgroups, such as the elderly who may be less reachable via social media messages, our research findings could benefit them by contributing to better crisis messaging communicated via other platforms.

Crisis Messaging over Social Media

In recent years, social media have provided an expanded communication channel where emergency responders can share and gather timely information during crisis events (Hughes and Palen, 2012). Past research has looked at how emergency responders and other sources of official information have used social media to communicate with the public (Chauhan and Hughes, 2017; Denef et al., 2013; Hughes et al., 2014). Studies have focused on the informational content of responder messages (Chauhan and Hughes, 2017; Hughes et al., 2014), the style of communication that responders use (Denef et al., 2013), or the ways that responders seek to foster trust in their messaging (Hughes and Chauhan, 2015). No studies have examined how crisis messages, shared through responder social media, persuade members of the public toward protective action.

Crisis messages on Twitter, Wireless Emergency Alerts, and text messages are brief due to character limits (Sutton et al., 2015b). However, character limitation should not compromise the persuasiveness of messages, but highlight the urgency of providing evidence-based suggestions on which PMFs are critical for effective communication.

Identifying Five PMFs

The five PMFs deductively identified in this paper are 1) *hazard intensity*, 2) *hazard uncertainty*, 3) *health risk susceptibility*, 4) *health impact*, and 5) *response instruction*. Among them, *health risk susceptibility* and *health impact* are also called health-related PMFs. This study identifies the five PMFs based on previous research, following the deductive approaches outlined by Schreier (2014).

Hazard Intensity and Hazard Uncertainty

Hazard intensity refers to the intensity of a hazard itself, e.g., the temperature during heat hazards. *Hazard uncertainty* is the uncertainty of an event occurring, e.g., the possibility of a flood happening. The intensity and the uncertainty of a hazard itself are components commonly involved in crisis messages. Although a growing body of literature tests the effectiveness of alternative ways of communicating hazard uncertainty (Spiegelhalter et al., 2011), it is unclear to what extent *hazard uncertainty* and *hazard intensity* are communicated in crisis messages. Previous studies for natural hazards often combined the two PMFs and other message content such as impacted areas as one single theme (Sutton et al., 2015a; Vos, 2016), and as a result little is known about the degree to which each of the two PMFs was included in crisis messages. This paper separately examines the usage of *hazard intensity* and *hazard uncertainty* because they may influence different psychological aspects of how the public processes crisis messages.

According to the Extended Parallel Process Model (EPPM) and related empirical studies, perceived susceptibility and perceived severity are two critical persuasive concepts for information-processing and decision-making under risks

(Murray-Johnson and Witte, 2003; Witte, 1992). Perceived susceptibility describes an individual's belief regarding the likelihood of experiencing the adverse impact of a threat, and perceived severity refers to the magnitude of harm an individual feels as the result of the threat (Murray-Johnson and Witte, 2003; Witte, 1992). People are likely to simply ignore crisis messages if they do not feel themselves to be at risk or that potential impacts are significant (Mileti and Sorensen, 1990; Murray-Johnson and Witte, 2003). Although future research is needed to empirically test how each persuasive concept (i.e., perceived susceptibility and perceived severity) is influenced by descriptions of *hazard intensity* and *hazard uncertainty*, we hypothesize that communicating the uncertainty of a hazard happening is likely to influence audiences' perceived susceptibility of being impacted since both perceived susceptibility and *hazard uncertainty* are related to probability. On the other hand, *hazard intensity* described in crisis messages may influence an individual's perceived severity of being impacted, and further influence decisions about whether protective action is needed.

Health Risk Susceptibility and Health Impact

The PMF of *health risk susceptibility* refers to message content depicting which subpopulation and/or what behaviors are vulnerable to the health impacts of hazards. The PMF of *health impact* mentions illness or death as health outcomes of hazards. These two PMFs are also called health-related PMFs in this paper.

The message content regarding *health risk susceptibility* and *health impact* have not been well defined and recognized in the field of crisis communication during natural hazards. We identify *health risk susceptibility* in light of communication challenges suggested by previous empirical studies on heat risk perception. Conventional heat-health messages often single-out the elderly as a particular vulnerable subgroup, and several studies on extreme heat hazards have put forward alternative ways to communicate heat-health vulnerability due to undesired outcomes of traditional messaging (Wolf et al. 2010; Sampson et al. 2013). Past studies found that although elderly respondents knew older people are vulnerable to the impacts of heat, many seniors defined older or elderly people as those with ages above their own, not themselves, and thus denied they are personally vulnerable to heat-health impacts (Wolf et al. 2010; Sampson et al. 2013). According to EPPM theory discussed above, if people think adverse consequences cannot happen to themselves, they may well ignore the risks communicated via crisis messages (Murray-Johnson and Witte, 2003). In addition to specific subgroups such as the elderly and the sick, who are vulnerable to heat-health impacts due to compromised thermoregulatory capacity, everyone can be vulnerable to health impacts from heat hazards caused by risky behavior such as outdoor activities in high-heat conditions (Mora et al., 2017). As a result, it is critical for crisis messages to clarify which subpopulation and what behaviors are vulnerable to health impacts. In response, our study identifies *health risk susceptibility* as one message factor to examine.

We identify the *health impact* PMF based on the affect heuristic theoretical framework and prior empirical research in the natural hazards field. The affect heuristic describes the important role affect plays in influencing decisions and motivating behaviors (Slovic et al., 2007). Negative feelings motivate individuals to take actions that are expected to avoid the negative feelings, and positive feelings stimulate actions predicted to repeat such positive feelings (Slovic et al., 2007). Previous empirical research has found that stronger negative affect associated with the consequences of a flood may explain better flooding preparation for people with previous flood experience, compared to those who were not affected (Siegrist and Gutscher, 2008). Accordingly, scholars called for better communication that "help people to envisage the negative emotional consequences of natural disasters" (Siegrist and Gutscher, 2008, p. 771). In response, we identify *health impact* (which includes mentions of illness and death) as one PMF, because these mentions may invoke unpleasant feelings associated with personal or vicarious adverse health experiences. Such feelings may trigger protective actions to avoid the adverse health impacts of hazards as well as the negative feelings.

Response Instruction

The last PMF investigated in this paper is *response instruction* (i.e., providing advice on protective actions). *Response instruction* has the potential to improve perceived efficacy of recommended actions (i.e., resulting in higher confidence both in performing recommended actions and in achieving desired outcomes) which may lead to better adaptive behaviors under risks (Murray-Johnson and Witte, 2003). Unlike the other four PMFs, this PMF has been frequently coded as a separate category in crisis messages (e.g.,Vos, 2016), and this paper also codes *response instruction* as a separate PMF.

Heat-related Tweets and Heat Warning Tweets

Our investigation focuses on heat hazards, the leading cause of weather-related fatalities in the U.S. over the past few decades (NWS, 2017). We propose two research questions in this study. 1) To what degree are the five PMFs (i.e., *hazard intensity*, *hazard uncertainty*, *health risk susceptibility*, *health impact*, and *response instruction*) included in heat-related tweets and heat warning tweets posted by U.S. NWS WFOs? 2) How do heat-related tweets describe the two health-related PMFs (i.e., *health risk susceptibility* and *health impact*)? For the first research question, we quantify the usage of the five PMFs among two types of messages: heat-related tweets and heat warning tweets. For the second research question, since this is the first effort to investigate detailed statements of the under-examined health-related PMFs, this paper focuses on heat-related tweets in general, and does not separately investigate heat warning tweets.

Heat-related tweets refer to specific current and/or upcoming heat events. We further separate heat-related tweets into two categories, heat warning tweets and non-warning heat-related tweets. To be considered a heat warning tweet, a heat-related tweet must mention at least one of the three NWS's heat-related watch, warning, and advisory (WWA) products: 1) an Excessive Heat Watch, 2) an Excessive Heat Warning, or 3) a Heat Advisory product. If heat-related tweets do not mention any active heat WWAs, these heat-related tweets are non-warning heat-related tweets. For example, the tweet "LOT continues Excessive Heat Warning for Kendall, Will [IL] till 7:00 PM CDT https://t.co/fCPmYyYojR" (the URL linked to a map showing the affected areas of this excessive heat warning) is a heat-related tweet and also a heat warning tweet. However, the following tweets are heat-related tweets but not heat warning tweets, since they alert the public about current and/or upcoming heat events but do not mention any current or upcoming in-effect heat WWAs: "225pm: Now officially a high of 118 in Phoenix. Ties for the 5th hottest temperature ever recorded in Phoenix." and "High of 94 degrees at #Shelton today! Hottest day since June 5. #wawx".

In this paper, we quantify the usage of PMFs for both types of messages: heat-related tweets and heat warning tweets. All heat-related tweets and the subset of heat warning tweets are important types of heat risk messages and need to be persuasive to protect public health from heat hazards. Heat warning tweets alert the public about extreme heat events. The official heat WWAs mentioned in heat warning tweets indicate potentially dangerous conditions for much of the population (NWS, n.d.b). Heat-related tweets contribute to protecting the public from adverse impacts of all heat events, both extreme heat events and non-extreme heat events. Extreme heat events are dangerous. For non-extreme heat events when heat conditions were not hot enough or their duration was not long enough to issue heat WWAs, negative heat-health impacts are still possible for heat-sensitive populations such as children and the elderly, and those working or being active outside. Prior studies on heat-health impacts have found that in addition to the intensity of temperature and humidity, social vulnerability factors such as age and adaptive behaviors are key determinants of heat-health impacts (Bouchama et al., 2007; Kovats and Hajat, 2008). Measuring usage of these PMFs in heat-related tweets will help describe an aggregate level of factor usage for all tweets alerting the public about heat-health risks. By quantifying factor usage for both heat-related tweets and heat warning tweets, we improve our understanding of factor usage and inform message design for both heat risk messages in general and warning messages about extreme heat events.

METHOD

We selected eighteen NWS WFOs across the U.S. from among the total 123 WFOs using purposive sampling. These sampled offices (see Figure 1) reflect critical variations among the field offices regarding the local climate of forecast areas and regional variation across the four NWS regions in the continental U.S.

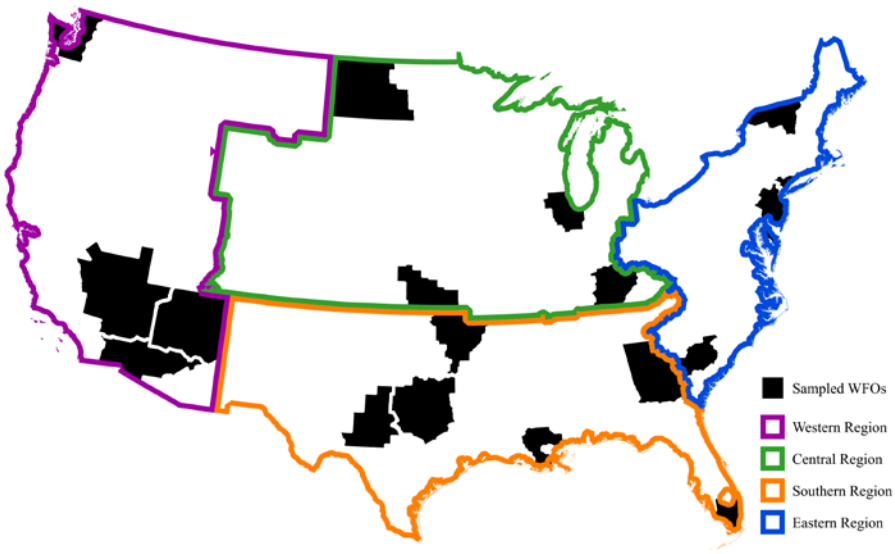

Figure 1. Map showing the distribution of the sampled NWS WFOs, and the NWS regional offices' operational boundaries. White lines separate adjacent WFOs. No WFOs are across NWS regional boundaries.

Second, for each of these sampled offices, the most recent 3200 tweets were collected from their official Twitter accounts using the Twitter Search application programming interface. To narrow the scope to tweets most likely to be heat-related, we extracted tweets containing the English words "heat" or "hot" in the message text. We also restricted the data collection window to the meteorological summer of 2016 (June 1- August 31, 2016, UTC), when most heat events happen. Only original public tweets were included in the final *Heat Data Set* by removing public retweets and reply tweets. The final *Heat Data Set* contained 1,139 tweets for the next step in the analysis, human coding.

Each tweet in the *Heat Data Set* was first coded as heat-related tweets, "other on-topic" tweets, or off-topic tweets. No further coding took place for "other on-topic" tweets and off-topic tweets. This topic variable aims to identify heat-related tweets that are suitable and comparable to code for the five PMFs. For example, we found intensity and uncertainty of a specific heat event often were not applicable for general education tweets independent from specific heat events. Heat-related tweets indicated that specific current and/or upcoming heat events either are occurring or will occur in the forecast areas. "Other on-topic" tweets were on the topic of heat but not dependent on specific current or upcoming heat events. These tweets included general education messages independent from specific heat events, tweets stating a break in recent heat events, and tweets in which it was difficult to tell without local knowledge whether the weather condition reported in the tweets was cool or hot (e.g., tweets reporting forecast heat indices less than 100 °F or temperature less than 95 °F and containing no other information signaling that the forecast condition is hot). Off-topic tweets were not on the topic of heat, for example, tweets posting photos of storms or hail and containing no heat information. The first author was the first coder and an undergraduate researcher worked as the second coder. Two coders split coding tasks. A 20% subset of tweets was randomly selected and both coders coded the subset independently to check the reliability of the coding process. For intercoder reliability, the Cohen's Kappa for this topic variable was 0.83. Among the heat-related tweets, we further coded heat warning tweets which mentioned at least one of heat WWAs that are or will be in effect (Cohen's Kappa = 0.97).

Next, we developed a coding scheme for PMFs with a directed approach of content analysis (Hsieh and Shannon, 2005). We deductively identified five PMFs as initial coding categories: 1) *hazard intensity*, 2) *hazard uncertainty*, 3) *health risk susceptibility*, 4) *health impact*, and 5) *response instruction*. Based on a sample of tweets, we clarified operational definitions for each category. The operational definitions were tailored in response to heat hazards and captured key message content corresponding to each PMF. The coding scheme (see Table 1) was finalized after pilot coding and discussion. All information in each tweet that is visible to Twitter users was included in the coding, including the displayed text (which has a character limit of 140) and textual information in attached images. We coded all heat-related tweets, including heat warning tweets, for different PMFs. If a single tweet contained more than one PMF, multiple codes responding to each PMF mentioned by the tweet were applied to this single tweet. The intercoder

reliability coefficients, Cohen's Kappa, were above 0.93 across these five factor variables.

PMF	Definition	Tweet Example
Hazard Intensity	Refers to tweets that mention Heat Index (HI) and/or the temperature of current and/or upcoming heat events	"The #heatwave continues w/ heat indices of 105-111 expected today!"
Hazard Uncertainty	Refers to tweets that contain the degree of forecast uncertainty with the temperature or HI for the upcoming weather.	"6-10 DAY OUTLOOK TEMPERATURE PROBABILITY. (With color ramps showing) Probability of Below (Normal) and Probability of Above (Normal)."
Health Risk Susceptibility	Refers to tweets that contain information signaling who, which behaviors and/or which places (e.g., outdoor, on the beach) are vulnerable to heat-health impacts.	"Who's At High Risk? Much of the population, especially those who are heat sensitive and anyone without effective cooling and hydration."
Health Impact	Refers to tweets that contain at least one word indicating heat-related illnesses and/or deaths.	"Take frequent breaks, stay hydrated and wear light-weight clothing to avoid heat-related illnesses."
Response Instruction	Refers to tweets that contain generic and/or specific heat safety tips.	"Stay cool! – Use air conditioning if possible; fans alone DO NOT provide enough cooling when it is very hot outside."

Table 1. Coding Scheme and Examples for PMFs

RESULTS

In total, 904 tweets were identified as heat-related tweets. Among them, 224 (25%) were heat warning tweets. All eighteen sampled accounts posted at least thirteen heat-related tweets, with an average of 50 (SD = 30). Fifteen accounts posted heat warning tweets, with the exception of the official Twitter accounts for the NWS WFOs of Atlanta/Peachtree City (Georgia), Bismarck (North Dakota), and Burlington (Vermont). We found in some cases, heat-related tweets did not mention co-occurring heat WWAs. For example, the Atlanta WFO did issue a heat advisory and the Bismarck WFO issued an excessive heat warning and a heat advisory during the same time period the tweets were collected (Iowa Environmental Mesonet, 2017), but the corresponding heat-related tweets in both accounts did not contain any mention of these heat WWAs. We suspect that a lack of coordinated social media practices may have contributed to these two accounts missed co-occurring heat WWAs.

Descriptions of Health-related PMFs

We investigated two health-related PMFs including *health risk susceptibility* and *health impact*. Given that previous studies have rarely examined these two health-related PMFs in the field of natural hazard communication, here we provide detailed descriptions on how heat-related tweets communicated these two factors.

For *health risk susceptibility*, four types of statements, separately or jointly, appeared in heat-related tweets to explicitly or implicitly signal susceptibility to heat-health risk. First, some messages indicated that a certain subpopulation such as children and/or the elderly is more vulnerable to health impacts from the heat event. These were "subpopulation" statements. Second, some messages signaled higher heat-health risks associated with certain behaviors and/or certain places such as traveling, working outside, or going to the beach. These were "behavior/place" statements. Third, some messages emphasized that heat can potentially harm everyone without appropriate adaptation (see the susceptibility example in Table 1). These were "anyone" statements. Last, some messages indicated that it is worth paying attention to heat-health risks everywhere, not just in specific places. These were coded as "everywhere" statements. In "behavior/place" statements and "everywhere" statements, the place does not refer to the administrative areas such as a county or a city, but generic situations such as outdoors, indoors, the workplace, the home, etc. The

health risk susceptibility PMF either used one type of these statements or simultaneously used several types of statements to illustrate the concept of susceptibility.

For the other health-related PMF, *health impact*, some messages conveyed the health consequences of sickness or death with generic statements such as "Avoid risk of heat related illness" and "deadly heat". Some messages specifically stated health impact with a long list of symptoms of heat exhaustion and heat stroke, and/or heat-related fatality statistics in recent years.

As an illustrative example, the heat-health message in Figure 2 combines "subpopulation" statements, "behavior/place" statements, and "everywhere" statements for *health risk susceptibility*, and generic statements for *health impact*. This image appears on the NWS heat safety website (http://www.nws.noaa.gov/os/heat/), and was also attached to some of the heat-related tweets in our data set. In the message contained in the image, "subpopulation" statements include "Check up on the elderly, sick and those without AC" and "Never leave kids or pets unattended – LOOK before you LOCK" which implicitly indicate that certain subpopulations are vulnerable to heat-health risks. Moreover, "behavior/place" statements were used in this message by listing four places exposed to heat-health risks, i.e., "Job Sites", "Indoors", "Vehicles", and "Outdoors". Last, the statement "Practice HEAT SAFETY Wherever You Are" is one example of an "everywhere" statement that implies all places have potential for heat-health risks.

Although the statements in Figure 2 implicitly pointed out the associated risks, the four types of statements (i.e., "subpopulation" statements, "behavior/place" statements, "anyone" statements and "everywhere" statements) can also be explicit. The example of susceptibility found in Table 1 states "Who's At High Risk? Much of the population, especially those who are heat sensitive and anyone without effective cooling and hydration." In this example, the heat-health risks are explicitly linked to heat sensitive populations and anyone with poor adaptation ability by asking, "Who's At High Risk?" Figure 2 also includes a generic statement of *health impact*: "Heat related deaths are preventable."

Figure 2. A heat-health message posted on the NWS heat safety website and used by some heat-related tweets. This message illustrates how heat-related tweets describe *health risk susceptibility* and *health impact*. Source: http://www.nws.noaa.gov/os/heat/

Descriptive Statistics of PMFs

Results indicate (Figure 3) that *hazard intensity* was by far the most frequently used PMF in heat-related tweets (84%) and heat warning tweets (71%) as well. More than half of all heat-related tweets (n=484, 54%) only contained the *hazard intensity* PMF, without mention of any of the other four PMFs. *Response instruction* was the next most used PMF (heat-related tweets: 37%, heat warning tweets: 46%). A relatively small percentage of tweets contained the PMF of *health risk susceptibility* (heat-related tweets: 20%, heat warning tweets: 29%), and even less for the PMF of

health impact (heat-related tweets: 11%, heat warning tweets: 17%). *Hazard uncertainty* was rarely mentioned in both heat-related tweets and heat warning tweets, possibly because the forecast of heat is generally perceived as accurate (EPA, 2006). Three PMFs—*health risk susceptibility*, *health impact*, and *response instruction*—were more frequently included in heat warning tweets than overall heat-related tweets, but the differences were small. The use of each PMF had the same position rank in both heat-related tweets and heat warning tweets.

For both heat-related tweets and heat warning tweets, tweets using only one of the five PMFs accounted for the largest proportion (heat-related tweets: 56%, heat warning tweets: 30%). Surprisingly, many heat warning tweets contained none of the PMFs investigated in the paper (n= 53). For example, "LOT continues Excessive Heat Warning till Jul 22, 7:00 PM CDT https://t.co/fCPmYyYojR" (the URL linked to a map showing the affected areas of this excessive heat warning). For both types, more than half of the tweets used zero or one PMF (heat-related tweets: 54%, heat warning tweets: 64%). The proportion of tweets containing at least one of the two health-related PMFs were less than two fifths, 24% for all heat-related tweets and 38% for heat warning tweets.

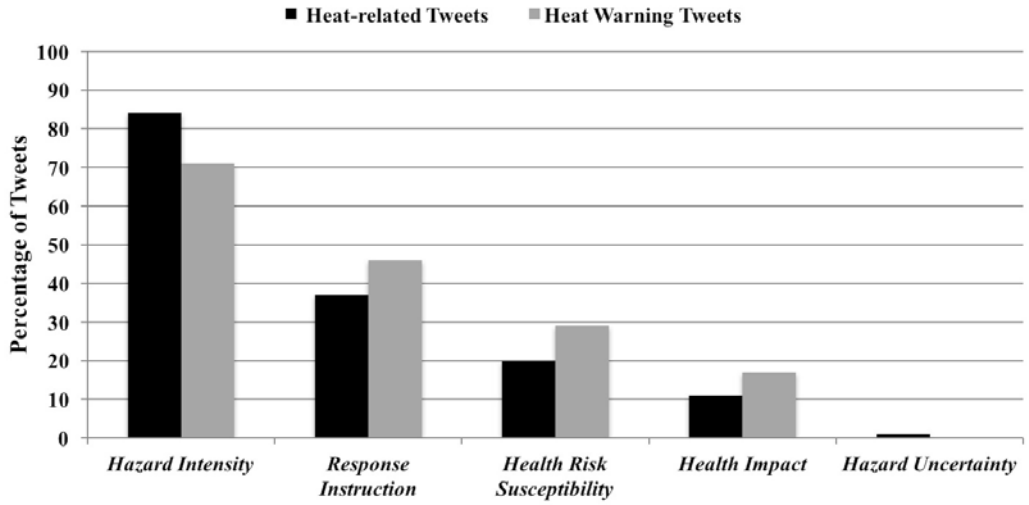

Figure 3. The Percentage of Each Type of Tweet Containing a Certain PMF

The Number of PMFs	Number of Heat-related Tweets (n=904)	Number of Heat Warning Tweets (n=224)
0	75(8%)	53(24%)
1	506 (56%)	67(30%)
2	132(15%)	26(12%)
3	157(17%)	66(29%)
4	33(4%)	12(5%)
5	1(0%)	0(0%)

Table 2. The Number of Each Type of Tweet that Contain Varying Numbers of Different PMFs.

DISCUSSION

During the meteorological summer of 2016, 904 tweets posted by 18 sampled NWS WFOs were heat-related tweets that alerted the public about current or upcoming hot weather. Three quarters of these heat-related tweets were not heat warning tweets, which means only one quarter of heat-related tweets mentioned active heat WWAs. This suggests

that although heat warning tweets are a critical subset of social media messages that communicate about heat risks to the public, heat warning tweets—which alert the public about specific extreme heat events—do not capture all heat-related tweets which alert the public to both extreme heat events and non-extreme heat events. During non-extreme heat events, heat-related tweets were also post-worthy since they address preventing possible extreme health impacts by alerting the heat sensitive population such as the sick and those engaged in potentially risky behaviors such as being physically active outside. To date, little research attention has been paid to crisis messages related to avoiding serious impacts of non-extreme hazards. Compared with crisis messages posted during extreme events, crisis messages surrounding non-extreme events may require different susceptibility statements and behavioral instructions to be effective, which warrants more research attention in the future. During extreme heat events when WFOs did issue heat WWAs, we found some corresponding heat-related tweets missed mentioning co-occurring heat WWAs. An important implication of this finding is that the communication process in social media must be well planned (Veil et al., 2011). In this case, official messages have the responsibility to share information about active heat WWAs to assist the public to make informed decisions.

Our research provides insights into how official crisis messages posted on Twitter communicate two health-related PMFs in the context of natural hazards: *health risk susceptibility* and *health impact*. Most previous studies on crisis messaging for natural hazards, to our knowledge, have not specifically examined the use of health-related PMFs. One exception is a social media study specifically investigating public health messages during the flooding in Boulder, Colorado in 2013 (Sutton et al., 2015b). The health-related content investigated in that paper was limited to health-related instructions such as drinking water safety and hand washing/hygiene, without an investigation of other health-related PMFs (Sutton et al., 2015b). Drawing on prior theoretical and empirical studies, this paper identified two health-related PMFs: *health risk susceptibility* and *health impact*. We find that Twitter messages about hot weather jointly or separately used four types of statements for pointing out *health risk susceptibility*: "subpopulation" statements, "behavior/place" statements, "anyone" statements and "everywhere" statements. The four types of statements respectively state that certain subpopulations, certain behaviors/places, anyone, or everywhere is vulnerable to heat-health impacts. For both heat-related tweets and heat warning tweets, the two health-related PMFs were much less used than PMFs of *hazard intensity* and *response instruction*.

This paper identifies five PMFs that have the potential to persuade the public to appropriately respond to natural hazards. We find the use of descriptions of *hazard intensity* is disproportionately high among heat-related tweets, with a lack of use of other PMFs. 54% of heat-related tweets exclusively used the *heat intensity* PMF by mentioning the Heat Index and/or temperature (n=484). For both heat-related tweets and heat warning tweets, more than half contained zero or only one of the five investigated PMFs. To enhance the persuasiveness of crisis messages about heat hazards and other types of hazards, future research should empirically test whether the five PMFs persuade or not, which specific statements depicting health-related PMFs are more persuasive, and whether different people respond to the same PMFs differently. This study provides a foundation for future message-testing studies by identifying these five PMFs and by specifying the different types of statements used to communicate health-related PMFs.

CONCLUSION

In this paper, we examine the content of crisis messages from a persuasive perspective. We deductively identify five PMFs that have the potential to persuade the public in the context of natural hazards. Using heat hazards as a case study, we contribute to understanding persuasive content in crisis messaging by quantifying to what degree each PMF is contained in official heat risk tweets. We quantify the use of PMFs not only among tweets mentioning active official heat alert products (e.g., an Excessive Heat Warning), but also among all tweets alerting about specific heat events that may or may not be extremely hot. We also provide insights into the different types of statements used to convey the two under-examined health-related PMFs: *health risk susceptibility* and *health impact*. Future experimental research is needed to empirically test how persuasive the five PMFs are in terms of promoting appropriate public thoughts and behaviors in the context of natural hazards.

ACKNOWLEDGMENTS

We thank Jared Stewart for assistance in coding. Funding was provided in part by the National Science Foundation,

award OIA-1208732 “iUTAH-innovative Urban Transitions and Aridregion Hydro-sustainability,” and SES-1459872 “Collaborative Research: Multi-Scale Modeling of Public Perceptions of Heat Wave Risk.”

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