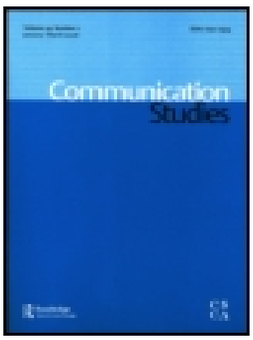

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Unraveling Public Health Crises Across Stages: Understanding Twitter Emotions and Message Types During the California Measles Outbreak

Charles W. Meadows III, Cui Zhang Meadows, Lu Tang, & Wenlin Liu

Social media can be used to assess public opinions and emotions during different stages of a crisis. Guided by the Crisis and Emergency Risk Communication (CERC) model, this study examined a systematic sample of 2,881 tweets from a corpus of over one million tweets posted during the initial, maintenance, and resolution stages of the 2015 California measles outbreak. It found that the public showed the greatest interest (as measured by the number of tweets and retweets) in the initial stage of the crisis, but their interest drastically declined afterward. The expression of humor/sarcasm was significantly more frequent in the initial stage than in the maintenance or resolutions stage, while the expression of reassurance increased significantly from the initial, maintenance, and resolution stage. The emotion of alarm/concern was most frequently expressed during the initial stage. For message types, the public were more likely to tweet about their personal opinions and less likely to tweet about resources during the initial stage. These findings allow public health professionals to better design messages in response to the public's concerns and emotions during public health crises.

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Social media platforms, such as Twitter, are widely used for health communication. Health departments use social media to develop timely and locally situated messages in response to public health crises. However, non-expert users generate most of the health content on social media. Examining social media content during a public health crisis, such as an infectious disease outbreak, allows public health professionals and researchers to assess the attitudes, emotions, and needs of the affected populations through unobtrusive observations (Tang, Bie, Park, & Zhi, 2018).

Presented in this article is a content analysis of tweets posted during the California measles outbreak in 2015. Guided by the Crisis and Emergency Risk Communication (CERC) model, this study shows how the number of tweets posted, emotions expressed, and messages types used change during the initial, maintenance, and resolution stages of a crisis. Because the best strategies for health crisis management and risk communication using social media are still "unstructured and untested" (Lin, Spence, Sellnow, & Lachlan, 2016, p. 601), the findings of this study provide baseline data for public health professionals to better address the public's emotional concerns and meet the public's information needs in future outbreaks of infectious diseases.

The CERC Model

Reynolds and Seeger (2005) proposed the CERC model as a comprehensive guide for public health professionals to effectively communicate with the public during public health crises, such as infectious disease outbreaks, natural disasters, and bioterrorism attacks. According to the CERC model, public health crises are likely to develop in predictable patterns in the following stages: pre-crisis, initial, maintenance, resolution, and evaluation (Reynolds & Seeger, 2005). Each stage is typically defined by a significant event (e.g., the first case of measles reported or the official announcement of the end of the measles outbreak) (Centers for Disease Control and Prevention [CDC], 2014). Conceptualizing a public health crisis in stages can help public health professionals develop effective strategies to communicate with the public, as the public's attitudes and sentiments change over time (CDC, 2014).

The *pre-crisis stage* is the period before a crisis occurs, which may last for years. Public health practitioners should disseminate information to help the public prepare for potential risks at this stage (Reynolds & Seeger, 2005). The *initial stage* is characterized by the outbreak of a threat (Spence, Lachlan, Lin, & Del Greco, 2015). During this stage the public are directly affected by an event or outbreak (Reynolds & Seeger, 2005). They start to make sense of the event and create a basic understanding of the situation based on information from multiple sources, such as word-of-mouth, news media, and health care professionals (CDC, 2014). The public may experience a high level of uncertainty, and the information they receive may be false or inaccurate (CDC, 2014). The third stage, *maintenance stage*, begins when "most or all of the direct harm is contained, and

the intensity of the crisis begins to subside" (CDC, 2014, p. 6). During this stage the public are involved in the process of information dissemination (Lachlan, Spence, Lin, Najarian, & Del Greco, 2016). The fourth stage is the *resolution stage*, during which the crisis continues to wind down, and more details about the crisis may emerge. A return to normality may be expected, and recovery may start. The last stage is the *evaluation stage*, when the immediate threat subsides and the public starts to reflect on the causes of the crisis, responsible parties, and response efforts (Spence et al., 2015). According to the CERC model, effective communication "must begin long before an event erupts and continue after the immediate threat has subsided" (Reynolds & Seeger, 2005, p. 53).

Several other crisis and risk communication stage models also offer insights into the stages through which a risk event develops and resolves (e.g., Coombs, 2014; Fink, 1986). One of the most popular models is Fink's (1986) four-stage model, which divides a crisis into four stages: prodromal (clues or hints of a potential crisis), crisis breakout or acute (consisting of a trigger event and initial damage), chronic (efforts to deal with the damage), and termination (clear signals marking the end of the crisis event). Lachlan, Spence, Lin, Najarian, and Del Greco (2014b) and Spence and colleagues (2015) adopted this model in examining the Twitter content during the prodromal and acute stages of natural disasters. Regardless of the number of stages and the specific terms used, Fink's model and the CERC model both recognize that crises have developmental features and both identify three basic stages, pre-crisis, mid-crisis, and after-crisis stages (Spence et al., 2015). In addition, both models stress the importance of understanding the communication actions that occur in each stage. This study adopts the CERC model for two reasons. First, the CERC model has been built on the previous risk communication models blending both risk and crisis communication elements, thus making it a comprehensive one, whereas other crisis stage models primarily focus on organizational crisis communication (Reynolds & Seeger, 2005). Furthermore, the CERC model has been recognized and adopted by the CDC as a tool to educate and prepare public health professionals for communication opportunities during emergency situations. Adopting this model will allow the findings of this study to be easily understood by practitioners in the health communication area.

The body of literature using the CERC model has focused on offering the best practices to public health departments and professionals by detailing communication strategies and tactics suited for different stages of a crisis (Reynolds & Seeger, 2005). However, an equally important yet less-used approach is to use the CERC model to guide the chronological examination of the public's sense-making and reactions during different stages of public health crises. The CERC model suggests that public health practitioners match their messages to audience characteristics, such as preferred communication channels, informational needs, and emotions (CDC, 2014). Because Twitter has become an increasingly prominent online platform for health-related information seeking and self-expression, the content emerging from this platform provides a window into public opinions and sentiments through different stages of a crisis (Tang et al., 2018). As such, a basic question revolves around the number of tweets generated across stages of the crisis. The number of tweets can

indicate the amount of public interest in a crisis. Although previous studies, such as Lachlan et al. (2014b), found that Twitter use fluctuated across the crisis life cycle, most of our knowledge about Twitter use across crisis stages is related to ecological disasters, such as hurricanes and winter storms, which are forecasted. A disease outbreak, which cannot be predicted, may present a different picture. Reynolds and Seeger (2005) suggested that each risk event had its very own characteristics. Thus, it is worthwhile to examine the fluctuation of public interests as measured by number of tweets during different stages of an infectious disease outbreak. In addition, previous research (e.g., Lachlan et al., 2014b; Spence et al., 2015) primarily examined the pre-crisis (or prodromal) and the initial (or acute) stage of extreme weather events. More research is needed to examine later stages, such as the maintenance and resolution stages, to provide a complete picture of the temporal changes in the number of tweets posted during the entire crisis. Thus, we propose the first research question (RQ_1).

> RQ_1: *How do the numbers of original tweets and retweets vary during the initial, maintenance, and resolution stages of the California measles outbreak?*

Emotional Tones in Crisis Communication

The public's emotional responses to crises often affect their behaviors (Dillard & Peck, 2000). In the context of risk and crisis communication, emotional responses can affect an individual's health risk perceptions, intentions, and behaviors (Dunlop, Wakefield, & Kashima, 2008). Researchers also consider emotions in trying to persuade individuals to take pro-health behaviors and avoid risky ones. For example, Dillard and Peck (2000) found that specific emotions, regardless of valence, such as happiness, sadness, surprise, and guilt, enhance persuasion effects, whereas anger and contentment impede persuasion. Furthermore, a health message eliciting emotional responses was more likely to be shared in an individual's social networks. Specifically, the more intense the emotion, the more likely the message will be shared to a large circle of individuals (Dunlop et al., 2008). Hence, a number of crisis communication models, such as the CERC model, have recognized the importance of understanding public emotions (Reynolds & Seeger, 2005).

Social media offer an ideal platform for the public to share affective reactions and offer emotional support (Lachlan, Spence, & Lin, 2014a; Liu & Kim, 2011). Recently, researchers started to examine emotional expression on social media during public crises (e.g., Liu & Kim, 2011). For example, Macias, Hilyard, and Freimuth (2009) found that one-third of bloggers expressed discernible emotions when blogging about Hurricane Katrina, including concern, disgust, anger, fear, and hope. Brummette and Sisco (2015) found that during the 2007 Virginia Tech shooting, anger was the most frequently expressed emotion on Twitter, followed by fright, sadness, and anxiety. Humor is another important emotion expressed during a crisis. Austin, Fisher Liu, and Jin (2012) found through in-depth interviews that some participants read, watched, and shared social media messages during a crisis because of the humor contained in the messages. When facing a stressful situation, such as a measles outbreak, discrete emotions can be highly associated with cognitive

appraisals, such as certainty and control (Jin, 2010). Hence, public health practitioners need to accurately understand the public's affective processes during a crisis to respond effectively.

According to Reynolds and Seeger (2005), during the course of a public health crisis, emotional expressions from the public are highly expected; however, little is known about the types of emotions experienced and expressed by the public during different stages of the crisis. Spence et al. (2015) studied how tweets' emotional tones vary before and after the landfall of Hurricane Sandy and found that tweets with humorous or sarcastic tones decreased as the pre-crisis stage progressed into an acute stage. Emotional content on social media is indicative of the state of mind of the public, and practitioners can develop intervention strategies by evaluating their mindsets. Hence, we propose the next research question:

> RQ_2: *How do emotional tones in measles-related tweets vary during the initial, maintenance, and resolution stages of the California measles outbreak?*

Message Types in Crisis Communication

Outbreaks of infectious disease pose a unique challenge to public health practitioners, who must constantly adapt their messages during different crisis stages. Several crisis communication models (Fink, 1986; Reynolds & Seeger, 2005) suggest that during each stage of a crisis, the public engages in information-seeking processes to make sense of the nature of the crisis. Because social media allow individuals to directly engage in generating content, transmitting, curating, filtering, and amplifying knowledge, it is critical for health professionals to monitor and respond to public messages on social media.

The public extensively use social media, such as Twitter, during a crisis to share information, reduce uncertainty, and cope with threats (Lachlan et al., 2016). During different stages of a crisis, the public may rely on Twitter to share news updates, resources, and personal experiences and opinions. For instance, at the initial stage of a crisis, the public may focus on sense-making and rely heavily on news updates. As the event unfolds and in the aftermath of a crisis, social media platforms are often used for cleanup efforts, disaster rebuilding, and fundraising initiatives (Stewart & Wilson, 2016).

Spence et al. (2015) stressed the importance of examining public responses on Twitter during various stages of a natural disaster. They found that the amount of useful information on Twitter decreased, as the storm approached landfall. More work is needed to identify a more comprehensive list of information types, such as whether the message is about sharing news updates, resources, personal experience, or emotional expression, so that implications regarding the pattern of information available can be drawn for those who attempts to manage emergency health risk events. An understanding of the types of messages generated by the public on social media across the various stages of a crisis can allow public health practitioners to tailor messages to fill gaps in public knowledge or offer corrections of misinformation to the right public at the

right time (Chew & Eysenbach, 2010). Therefore, the following research question is proposed.

> RQ_3: *How do the types of messages vary during the initial, maintenance, and resolution stages of the California measles outbreak?*

Methods

Sampling

Tweets that included the term "measles" posted between December 1, 2014, and April 30, 2015, were purchased and downloaded from DiscoverText.com. DiscoverText.com is a social media analytics software allowing customers to retrieve complete Twitter content retrospectively, by using certain parameters such as keywords or hashtags. A total of 1,154,156 tweets were collected during this time frame. A systematic sampling method (every 384th data point was selected with the first data point randomly chosen) was used to select 3,000 tweets from this population for manual coding. The sample of 3,000 tweets was determined on the basis of formulas for standard error and confidence intervals (Neuendorf, 2002) and similar previous studies (Lachlan et al., 2014a, 2014b; Spence et al., 2015). Because this study focused on the initial, maintenance, and resolution stages, tweets before January 5 were excluded because the first measles case occurred on January 5, 2015. Tweets after April 17, 2015, were also excluded because on that day the California officials declared the measles outbreak was over. As a result, 2,881 tweets were included in the coding and analysis.

Crisis Stages

Crisis stages were determined on the basis of the CERC model and specific events in the California Measles outbreak. The CERC model acknowledges that each risk event is unique and develops in its own way (Reynolds & Seeger, 2005). The California measles outbreak mostly follows the stages described in the CERC model, including the initial, maintenance, and resolution stages.

Initial Stage

The first case associated with the Disney Theme Parks was reported in California on January 5, 2015, which marked the beginning of the outbreak. Two days later, the California Department of Public Health warned the public through a press release (Zipprich et al., 2015). After February 8, 2015, CDC data showed that the intensity of new measles cases began to subside (Zipprich et al., 2015). Thus, January 5 to February 8 was considered the initial stage (35 days).

Maintenance Stage

The last case during this outbreak was reported on March 6, 2015. Thus, February 9 to March 6 was considered the maintenance stage (26 days).

Resolution Stage

On April 17, 2015, California officials declared the measles outbreak was over. Because the resolution stage signaled a clear end of the event (Fink, 1986), and no new cases were reported during this period, March 7 to April 17 was designated as the resolution stage (42 days).

Unit of Analysis and Coding Scheme

The unit of analysis was each individual tweet. Each tweet was coded in the following three variables: (a) tweet versus retweet, (b) emotional tone, and (c) message type. All categories within each variable were mutually exclusive.

Tweet Versus Retweet

A "tweet" referred to the original tweet created by a user, whereas a "retweet" was the one forwarded or shared by the user and included "RT" as part of its text.

Emotional Tone

Emotional tone was coded into one of the following five categories: (a) alarm/concern, (b) reassurance, (c) anger, (d) humor/sarcasm, and (e) neutral or none (adapted from Chew & Eysenbach, 2010). A tweet was coded as showing alarm/concern if it expressed a measles-related fear, anxiety, worry, or sadness for oneself or others. For example, the phrase "measles kill" was coded as alarm/concern. In contrast, a tweet was coded as reassurances if it downplayed the risks of measles to convey relief. An example of a tweet expressing reassurance is "The public should not be worried about measles." Tweets such as "I'm very upset at Disney" were coded as expressing anger. Tweets were coded as expressing humor/sarcasm when they provided jokes or discussed the risk of measles in a funny or sarcastic way. For example, the statement "Wonkblog: A new threat appears along the U.S.–Mexico border: Americans with measles" was coded as humor/sarcasm. The final category, neutral, was coded when a tweet did not express any obvious emotions. Because tweets were short, each tweet was coded for one dominant emotional tone only.

Message Type

Each tweet was coded into one of the following message types: news updates, resources, personal experiences, personal opinions, questions, and others (adapted from Chew & Eysenbach, 2010). News updates consisted of tweets featuring news or a press release about measles. These tweets were often direct updates, such as "Measles outbreak at Disneyland linked to non-vaccinations." Tweets were coded as resources if they contained medical information. For example, "The CDC recommends learning the symptoms of measles, find out more at this link." The distinction between resources and news updates was based on whether a tweet referenced current events or general background, history, or medical knowledge about measles. Personal experience was coded when a tweet

mentioned a direct (one's own experience) or indirect experience (a friend's or family's experience) (e.g., "I was at Disney World when the outbreak happened."). Personal opinions referred to tweets where people expressed their thoughts, attitudes, or opinions about measles or measles vaccination. For example, "Parents! If your kids are not vaccinated, do not send them to school!" is an example of personal opinion. The question category included all genuine inquiries about the measles outbreak. A tweet such as "I'm in my late 60s. Can I still contract the measles?" would be coded as a question. Rhetorical questions and other "nonquestions" were not coded in this category. If a tweet did not belong to any of the previous message types or only included a link, it was coded into "other" category. Each tweet was coded for one primary message type.

Intercoder Reliability

Two of the authors, who were knowledgeable of the research topic, coded the tweets manually. After several rounds of training and practice coding, they both coded a systematically selected sample (n = 320, 11%), which did not overlap with the 2,881 tweets in the sample, and reached acceptable intercoder reliability (Cohen's kappa = .57 for emotion and = .59 for message type). Although there is no discipline-specific consensus about the minimum reliability coefficients acceptable, several scholars suggested that Cohen's kappa values between .40 and .75 indicated fair to good agreement beyond chance (Krippendorff, 1980; Neuendorf, 2008). We accepted these kappa values after taking several threats to reliability into account. The first threat came from the length of the coding unit. Twitter only allowed 140 characters or less at the time of data collection. Short tweets created challenges for coders' judgment. In addition, each variable in this study included many categories (5–6), which also affected intercoder reliability. Afterward, the two coders divided the 2,881 tweets in the sample and coded independently.

Results

RQ_1 asked how the numbers of original tweets and retweets changed during different stages of the California measles outbreak. Our sample showed an almost equal division of tweets (50.7%, n = 1,460) and retweets (49.3%, n = 1,420) and a drastic decrease of number of tweets from the initial stage to the later stages. The initial stage witnessed the largest number of tweets, and more retweets (n = 1,004, 52.8%) were posted than original tweets (n = 897, 47.2%). During the maintenance stage, more original tweets (n = 423, 58.7%) were posted than retweets (n = 298, 41.3%). In the resolution stage, the numbers of both original tweets (n = 140, 54.3%) and retweets (n = 118, 45.7%) decreased from the earlier two stages.

RQ_2 asked how the tweets' emotional tones changed over the course of the California measles outbreak. Across all stages, more than half of the tweets did not express any emotion (n = 1717, 59.6%). Humor/sarcasm (n = 394, 13.7%) and alarm/concern (n = 386, 13.4%) were the two most commonly expressed emotions, followed by anger (n = 252, 8.7%) and reassurance (n = 107, 3.7%).

A chi-square test revealed significant differences in emotional tones across stages, $\chi^2(10, N = 2{,}881) = 188.19$, $p < .001$, Cramer's V = .18. Pairwise tests were conducted to further explore the differences of four emotional tones among the three stages with an adjusted alpha level of .017. The following three pairs of comparisons were performed: the initial stage versus the maintenance stage, the maintenance stage versus the resolution stage, and the initial stage versus the resolution stage. We found the percentage of tweets expressing humor/sarcasm, reassurance, and alarm/concern changed significantly across stages. Specifically, significantly more tweets expressed humor/sarcasm during the initial stage (n = 323, 17.0%) than in the maintenance stage (n = 51, 7.1%) or the resolution stage (n = 20, 7.8%). In contrast, the percentage of tweets expressing reassurance in the initial stage (n = 36, 1.9%) was significantly lower than the maintenance stage (n = 35, 4.8%) and the resolution stages (n = 36, 14.0%). In addition, significantly more tweets expressed alarm/concern in the initial stage (n = 283, 14.9%) than in the maintenance stage (n = 78, 10.8%). Table 1 shows the results of pairwise tests.

RQ_3 examined how Twitter message types changed across different stages of the California measles outbreak. Overall, nearly half of the tweets were news updates (n = 1,195, 41.5%), and more than one-third shared personal opinions (n = 986, 34.2%). These message types were followed by resources (n = 551, 19.1%), personal experiences (n = 74, 2.6%), and questions (n = 48, 1.7%).

A chi-square test showed significant differences for message type across stages of the outbreak, $\chi^2(10, N = 2{,}881) = 105.53$, $p < .001$, Cramer's V = .14. Pairwise tests (with an adjusted alpha level of .017) showed that the percentage of tweets about resources, personal experience, and personal opinion/interests changed significantly across stages. The percentage of resource tweets was significantly lower in the initial stage (n = 318, 16.7%), compared to the maintenance stage (n = 163, 22.6%) or the resolution stage (n = 96, 28.3%). In contrast, the initial stage saw a significantly higher percentage of personal opinion tweets (n = 748, 39.3%) than the maintenance (n = 178, 24.7%) or the resolution stages (n = 78, 23.0%). Finally, Twitter users were more likely to tweet about personal experience in the maintenance stage (n = 37, 5.1%) than the initial stage (n = 33, 1.7%). Table 2 shows the results of pairwise tests.

Discussion

Guided by the CERC Model, the current study examines Twitter content about measles across multiple stages of a measles outbreak in the number of tweets, emotional tones, and message types.

Tweeting Across Stages of an Outbreak

Our results paint an interesting picture regarding the public's interest in the measles outbreak as measured by the number of tweets. The public's interest in the outbreak peaked in the initial stage and declined radically in the maintenance and the

Table 1 Pairwise Comparisons of Emotional Categories During Three Crisis Stages

	Initial vs. Maintenance				Maintenance vs. Resolution				Initial vs. Resolution			
	p	Adjusted *p**	χ^2 (df = 1)	Cramer's V	*P*	Adjusted *p**	χ^2 (df = 1)	Cramer's V	*p*	Adjusted *p**	χ^2 (df = 1)	Cramer's V
Alarm/ Concern	.007	.007	7.35	.05	.62	1.24	.25	.02	.025	.05	5.02	.05
Reassurance	.00	.00	17.34	.08	.00	.00	23.45	.16	.00	.00	102.49	.22
Anger	.002	.004	9.35	.06	.36	1.08	.86	.03	.28	.28	1.19	.02
Humor/ Sarcasm	.00	.00	42.18	.13	.71	.71	.13	.01	.00	.00	14.51	.08

* Holm's sequential Bonferroni correction was used to adjust for multiple testing.

Table 2 Pairwise Comparisons of Message Type Categories During Three Crisis Stage

	Initial vs. Maintenance				Maintenance vs. Resolution				Initial vs. Resolution			
	p	Adjusted *p**	χ^2 (df = 1)	Cramer's V	*P*	Adjusted *p**	χ^2 (df = 1)	Cramer's V	*p*	Adjusted *p**	χ^2 (df = 1)	Cramer's V
News	.014	.028	6.04	.05	.48	.96	.50	.02	.016	.048	5.79	.05
Resources	.001	.003	11.95	.07	.14	.42	2.18	.05	.00	.00	16.68	.09
Personal experiences	.00	.00	23.13	.09	.014	.07	6.06	.08	.83	.83	.05	.01
Personal opinions	.00	.00	49.47	.14	.65	.65	.20	.01	.00	.00	25.12	.11
Questions	.05	.05	3.99	.04	.03	.12	4.79	.07	.16	.32	2.02	.03

* Holm's sequential Bonferroni correction was used to adjust for multiple testing.

resolution stages. This trend shows that the public's response to the risk changes from "alarming" to "apathetic" in the stages identified in Sandman's (2012) "Risk = Hazard + Outrage" model. Sandman's (2012) "Risk = Hazard + Outrage" suggests that when the public are "excessively alarmed" (p. 1), risk communication should focus on reassuring the anxious public, whereas when the public's response is apathetic, communication messages should focus on the severity and danger of the risk. The variation of tweet volumes has valuable practical implications. In this particular measles outbreak, when the public show the greatest interest during the initial stage, experts should closely monitor public opinions and think about how to calm the public if there is a high level of outrage; when the outrage is low during later stages, experts should consider how to appropriately alert the public with useful resources and help the public prepare for possible future outbreaks.

Emotional Change Across Stages

Our findings suggest the emotions expressed in tweets change across stages of the outbreak. Similar to the conclusions of previous studies (e.g., Dunlop et al., 2008; Jin, 2010; Macias et al., 2009), this study finds that emotional tones are indeed quite visible, and a wide range of emotions is present. Two emotional tones deserve particular attention from public health professionals: reassurance and humor/sarcasm. The public are more likely to express reassurance as the outbreak progresses from the maintenance stage (4.8%) to the resolution stage (14.0%). This indicates that the public may still feel uncertain during the maintenance stage, as predicted in the CERC model. Although the CERC model suggests that public health agencies should offer reassurance in the maintenance stage, risk communication experts do not recommend messages to be overly reassuring, because such information is likely to be inaccurate and undermines an authority's credibility (Seeger, 2006). What public health communication experts should do at this stage is to accept the uncertainty inherent to the situation and further adjust their messages as more information becomes available during later stages. Our finding also indicates that during the resolution stage, the public feel more at ease and optimistic. However, it does not mean the health communication should stop at this time, because the potential threat can still be present and the public need to be vigilant. In addition, any issues regarding cause, blame, rebuilding, and new understanding of risk should be considered and communicated.

Although humor/sarcasm is the most frequently expressed emotion at the initial stage of the crisis, the expression of humor/sarcasm decreased significantly afterward. This finding is consistent with existing studies (Chew & Eysenbach, 2010; Spence et al., 2015). Two possible explanations exist. First, humor can increase attention to a message (Weinberger & Gulas, 1992). Therefore, during the initial stage of a measles outbreak, people may be more likely to pay attention to funny messages and are more likely to share them via social media. Second, it is also possible that initially the public attempt to cope with the psychological discomfort caused by the crisis through the use of humor. However, humor can trivialize the

perceived importance or severity of potential consequences (Moyer-Gusé, Mahood, & Brookes, 2011) and can steer people away from pro-health behaviors (Fraustino & Ma, 2015). As a result, during the initial stage, public health professionals should warn the public that the risk is no laughing matter by incorporating messages about the severity and magnitude of the risk.

Message Types Across Stages

Our findings also suggest that different types of messages are shared by the public, depending on crisis stages. Initially, personal opinion is the dominant message type. During later stages the percentage of tweets sharing resources increases steadily. Previous research suggests that information from authoritative sources or health officials was considered most helpful and was likely to be shared by the public on social media (Lin et al., 2016). Our finding shows that initially, such credible resources may not be available among the public, consistent with the CERC model (CDC, 2014), and, consequently, the public may experience a high level of uncertainty during the initial stage of a crisis.

During the initial stage of an outbreak, experts and public health officials are often unsure if the outbreak is inevitable or how soon it will be over. There is a constant tension between releasing accurate information and providing information in a timely manner (Lin et al., 2016). The lack of reliable information is particularly prominent during the initial stage of an outbreak, which is an apparent challenge to effective crisis and risk communication. As the outbreak progresses, more resources from multiple sources become available to the public. Therefore, at the later stages a greater percentage of tweets about resources is posted.

Conversely, the public are more likely to tweet about their personal opinions during the initial stage, consistent with the findings of earlier studies (Lachlan et al., 2014b; Spence et al., 2015). During this stage the public may be outraged and shocked by the eruption of a sudden public health crisis and feel a great level of uncertainty (Reynolds & Seeger, 2005; Sandman, 2012). Their needs to express themselves and seek emotional venting are high. This phenomenon on social media demonstrates that the public "have an immediate and sometimes exaggerated role in the conversation" during a crisis event (Lin et al., 2016, p. 602). Public health agencies should allocate considerable efforts and resources to explain the risk and to provide accurate information to assist the public in their sense-making. More importantly, it is imperative to provide the public with tangible behavioral recommendations (Spence et al., 2015). Efforts should be made to reduce unnecessary anxiety among the public without being overly assuring.

Our finding also shows that as the outbreak progresses, the percentage of tweets on resources increases, especially during the resolution stage. During this stage the authorities should take ownership of the information creation and dissemination (Lachlan et al., 2014b). Key information, such as protective recommendations, should be available during this stage to meet the information needs of the public. Useful information should be continuously disseminated through later stages to capitalize on the remaining public interest. In addition, ongoing communication

about lessons learned and "new understandings of risk and amended procedures and policies for risk avoidance" is also needed (Reynolds & Seeger, 2005, p. 51).

Opportunities for Further Developing the CERC Model

The CERC model is an integrated crisis and risk communication model outlining specific communication activities that should be used at various stages of a public health crisis (Reynolds & Seeger, 2005). On the basis of the findings of the current study, we propose two areas where the model can be further developed: (a) identifying and mapping discrete emotions in each stage and (b) analyzing message types during different stages.

First, our findings reveal the need for the model to include a more in-depth discussion of emotions. The current CERC model does mention that public health practitioners should consider emotions when developing communication messages. For example, the model states that the public mainly feel uncertain during the initial and maintenance stages, and health practitioners should engage in the reduction of emotional turmoil during the initial stage. However, the current model does not discuss other specific emotions experienced by the public or provide suggestions on how to handle the wide range of emotions expressed by the public during each stage. Our findings indicate that the public undergo distinct changes in emotions, depending on the crisis stage. This offers an opportunity to further develop the CERC model regarding the public's emotional reactions to a health crisis. On the basis of previous research about disaster communication on social media (e.g., Lachlan et al., 2014b; Spence et al., 2015) and our own findings, we suggest that it is possible to map out the dominant emotions in each stage of the crisis. For example, the initial stage can be dominated by humor/sarcasm or other unwanted emotions, such as fear, uncertainty, and anxiety, and the resolution stage can be marked by assurance and other calming emotions. Understanding these emotions can help public health practitioners develop effective messages of crisis and risk communication. Future studies should extend the list of emotions examined and continue to identify discrete emotions in different stages of crisis development. Furthermore, machine learning approaches, such as the neural network model, could be used to analyze the emotions Twitter users express during different stages of an ongoing outbreak to provide public health professionals with the most up-to-date data (e.g., Du et al., 2018).

Second, the CERC model can be more specific about the type of messages that are dominating the public discourse at each stage of the crisis development, and social media could be a source of timely information. For instance, this study finds that during the initial stage, personal opinions tend to dominate the social media discussion, and useful information might be buried. Thus, during the initial stage it is essential for practitioners to establish formal communication channels, develop authoritative information, and build credibility based on the information available. Mapping the types of messages posted by the affected public in different stages allows practitioners to better understand the information needs of the public in a specific stage of crisis development, so that they can be prepared in the design and dissemination of messages.

Limitations

One major limitation of the study is its relatively low intercoder reliability. Although the coefficients were acceptable, they were not considered excellent. As discussed in the method section, practical difficulties exist in the coding of extremely short messages. However, future studies should strive to increase reliability coefficients so that more powerful conclusions can be drawn from data analysis. In addition, this study only focuses on three stages of the crisis (initial, maintenance, and resolution) and does not examine the pre-crisis stage and evaluation stage. Further research is needed to provide a more comprehensive description of the temporal changes of crisis communication on Twitter. Another limitation of the study is that our discussion of the CERC model is based on Twitter data alone. Twitter users have a very specific demographic profile. A 2016 Pew internet study notes that only 21% of all U.S. adults use Twitter, and of those individuals, 36% are between the ages of 18 and 29 (Greenwood, Perrin, & Duggan, 2016). In that sense, those who tweeted about the California measles outbreak were not representative of the entire population. In addition, our analysis does not consider the geographic locations of Twitter users. Therefore, it is hard to judge whether geographic proximity may play a role in the emotions expressed or the ways in which the tweets are composed.

Conclusion

This study examines the number of tweets, emotional tones, and message types on Twitter during the initial, maintenance, and resolution stages of a measles outbreak. The findings of this study reinforce the current view of social media in health communication literature: even though they pose many challenges, social media have considerable potential as a digital health surveillance tool. As an outbreak unfolds, the percentage of tweets expressing different emotions and adopting different message types fluctuate. If Twitter can be considered a reliable information source to assess public opinions and emotions, public health authorities and communication experts need to develop stage-specific communication strategies to respond to the public based on the timely analysis of Twitter data.

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